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Spatial Panel Modeling of Beijing-Tianjin-Hebei Urban Economic Synergy Mechanisms

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SUMMARY: *This research paper utilizes the economic data of the Beijing-Tianjin-Hebei region from 2001 to 2020 for in - depth study. It first performs spatial correlation tests to examine the regional economic interrelationships. Following this, a measurement framework is constructed. This framework includes 19 metrics associated with economic coordination, social amalgamation, and the resource - environment. The purpose of this framework is to evaluate the degree of regional economic cooperation. Additionally, a spatial panel framework is set up, with industrial cooperation as the primary explanatory factor. The empirical results show that there is a notable spatial connection between the quality of economic growth and the synergy between industry and the environment. In contrast, the synergy of industrial capacity shows distinct variations across different time periods.Taking into account the regional economic and industrial characteristics, this study proposes innovation - driven strategies. These strategies aim to enhance regional cooperation, optimize the allocation of factors, and promote stable and coordinated economic development.*

KEYWORDS: *spatial correlation test; economic development level measurement; spatial panel model; Beijing-Tianjin-Hebei economic synergy mechanism*

1 Introduction

The collaborative economic development of the Beijing-Tianjin-Hebei urban region is a major initiative by the state to promote the modernization of regional governance and achieve high - quality development [1, 2]. This undertaking is not simply the combination of regional economies. Rather, it requires the establishment of a more sophisticated integrated operating mechanism among the cities of Beijing, Tianjin, and Hebei. This mechanism is realized by rationalizing the industrial division of labor, improving the allocation of resources, and strengthening the infrastructure and public service systems[3-5]. Through economic synergy, the three places can complement each other's shortcomings, overcome problems and share opportunities, and enhance the overall competitiveness and risk resistance in the global competition pattern [6, 7]. The urban economic synergy among Beijing, Tianjin, and Hebei, a distinctive regional economic development paradigm in China, has drawn wide - ranging attention from the academic community. Sun and his associates pointed out that the level of coordinated development in the Beijing - Tianjin - Hebei area has been increasing steadily over the past years. The favorable advancement of subsystems and spatial coordination within this area has been verified via the coupled coordination model and spatial analysis. They emphasized that the deepening of reforms and the optimization of the system state, guided by

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the national-level strategy, have established a crucial foundation [8]. Zhang and Yang investigated the effect of the coordinated development strategy of the Beijing-Tianjin-Hebei region on regional economic convergence by utilizing panel data from 1999 to 2018. Their results revealed that the strategy is having an increasingly favorable effect on Beijing. It strengthens the stimulating influence of human capital on regional economic growth. Nevertheless, it also slows down the overall growth of the Beijing-Tianjin-Hebei and Tianjin-Hebei areas, and the economy within the regions exhibits fluctuations and dispersion [9].

Furthermore, Liao and his associates chose the Beijing-Tianjin-Hebei region as the focus of their study. They measured the overall score and the coupling coordination degree between economic development and the ecological environment from 2000 to 2018. The results of their research showed that the coupling degree of these two elements completed a full cycle, first increasing and then decreasing. At the same time, the degree of coordination was at a moderately low level but generally showed an upward tendency. This finding provides valuable empirical evidence for the region to achieve a balance between economic expansion and ecological conservation during the process of coordinated development[10]. Tian and colleagues employed government - related factors as independent variables. They developed a multiple mediation model that incorporated market, technological innovation, and location factors. Employing the PLS - SEM method, they investigated the impact of these elements on the cooperative development of the urban economies in Beijing, Tianjin, and Hebei. The assessment indicated that technological advancement had the most notable mediating effect. Consequently, they suggested setting up a sharing system for green technology research and development, optimizing the demographic makeup of high - pollution industries, and constructing a tiered financial protection and an accessible environment[11]. Deng and his associates emphasized that the collaborative innovation among Beijing, Tianjin, and Hebei can effectively promote the high - quality economic growth of the city and its neighboring regions. Moreover, it can elevate the development status of the entire urban cluster. Through the spatial Durbin model, the research verified that collaborative innovation exerts positive internal and spatial spill - over effects, even though there are disparities in the development levels[12]. Sun and Wang pointed out that the bay area economy has the characteristics of openness, high efficiency, strong agglomeration and radiation, and is an important platform for leading innovation and driving global development. Sun and Wang pointed out that the Bay Area economy is characterized by openness, high efficiency, strong agglomeration and radiation, and is an important growth pole for leading innovation and driving global development, and on the basis of summarizing the global experience of the Bay Area, they pointed out the purpose and significance of the concept of “Beijing Bay” for the collaborative development of Beijing-Tianjin-Hebei, and analyzed the path to enhance the vitality of its urban agglomeration [13].

Spatial panel modeling, a technique that combines panel data analysis and spatial data analysis, is a vital tool for investigating the mechanism of urban economic synergy in the Beijing-Tianjin-Hebei region. A spatial panel model is a framework proposed for the analysis of spatial panel data [14]. Unlike the ordinary regression model and the spatial regression model, it can improve the efficiency of parameter estimation. Spatial modeling plays a significant part in finding scientific justifications. By means of spatial panel modeling, it becomes possible to more effectively integrate the spatial and temporal distribution traits of the research subject and uncover its influencing elements and patterns [15, 16]. In analyzing the mechanism of Beijing-Tianjin-Hebei urban economic synergy, spatial panel modeling, a technique that combines panel data analysis and spatial data analysis, can not only capture the changes in the time series [17, 18]. In addition, it can also consider geospatial interactions to reveal the linkages between the Beijing-Tianjin-Hebei city economies, which can effectively quantify such spatial dependence and help us understand the Beijing-Tianjin-Hebei city economy synergy mechanism [19, 20].

When exploring the application of the spatial panel model in analyzing urban economic development, Wang and his research team used principal component analysis to create indicators for information and communication technology (ICT) and socioeconomic development. Subsequently, they applied the spatial panel data model to analyze data from Chinese provinces. Their results showed that there is a significant spatial relationship in the socioeconomic development of these provinces. Moreover, although ICT promotes local development, its spatial spillover effect has an adverse influence on neighboring areas[21]. Ge et al. used a spatial panel model to explore the relationship between NOx emissions and economic development and urbanization, pointing out the spatial dependence of interprovincial emissions and finding that income and urbanization levels are related to emissions in an inverted N-shaped environmental Kuznets curve, emphasizing the importance of formulating a targeted nitrogen reduction policy based on this, and providing new insights into coordinated development and pollution management [22]. Resende et al. used a spatial panel model to analyze multi-scale regional economic growth in Brazil and found that the model coefficients and spatial spillovers vary with scale, confirming the club convergence hypothesis and providing empirical evidence for cross-scale economic analysis [23]. Zhang and his associates crafted a new regional economic disparity model that integrates spatial weights. By conducting empirical research, they showed that the spatial spillover effects of human capital and foreign direct investment (FDI) play a significant role in the development of regional disparities. The crucial variables have a positive association with the growth of per - capita gross domestic product (GDP). Additionally, the findings passed the robustness test, providing a basis for the adjustment of regional economic disparities [24]. Lim and Kim utilized a spatial panel model to investigate regional income convergence in the United States. They found that the coefficient of initial per - capita income differs depending on the model. This indicates that the growth of a particular region is affected not only by local disturbances but also by the indirect and induced impacts of neighboring and higher - order adjacent regions. Such findings offer valuable perspectives for initiating a virtuous cycle of sustainable growth via spatial interactions and policy coordination [25].

However, the use of spatial panel modeling is not without challenges. Data availability is one issue that cannot be ignored. Spatial panel modeling requires that the collected panel data contain both sufficient time series and cover a wide range of spatial information [26]. This can be a practical obstacle in some cases, especially for economic data that are not fully publicized or are relatively hidden.

This research explores the global and local spatial autocorrelation of economic growth in the Beijing-Tianjin-Hebei area. Utilizing the economic statistics from 2001 to 2020, the objective is to clarify the spatial layout of regional economic development. Relevant indicators are carefully selected, and a measurement model is developed to assess the orderliness and characteristics of synergistic development within the regional economic system.Subsequently, this paper chooses appropriate research variables to establish a spatial panel model centered around industrial synergy. Drawing on the results of the regression analysis, a summary is made of the mechanism behind the formation of coordinated urban economic development within the region.

2 Spatial correlation analysis of economic development in Beijing-Tianjin-Hebei region

2.1 Status of economic development in the Beijing-Tianjin-Hebei region

The conventional Beijing - Tianjin - Hebei metropolitan area covers 10 regions, including Beijing, Tianjin, and eight prefecture - level cities in Hebei. Given the significant gap in economic development within this area under the national coordinated development strategy, this paper expands the research scope by incorporating Xingtai, Hengshui, and Handan. In the end, the research subjects of this paper are a total of 13 regions, namely Beijing, Tianjin, Langfang, Zhangjiakou, Qinhuangdao, Handan, Xingtai, Baoding, Tangshan, Chengde, Cangzhou, Shijiazhuang, and Hengshui.

Ever since the adoption of the reform and opening - up policy, China's economy has undergone a notable and swift expansion. The economic groupings in the Beijing - Tianjin - Hebei region, the Pearl River Delta, and the Yangtze River Delta have acted as potent drivers for this development. Nevertheless, the Beijing - Tianjin - Hebei region suffers from a substantial disparity in internal development. Cities like Beijing, Tianjin, Tangshan, and Qinhuangdao have enjoyed robust economic growth. In contrast, cities in central and western Hebei have had a sluggish development pace, which has further widened the regional economic gap. Severe regional polarization, an irrational industrial structure, and an over - concentration of human resources and fixed - asset investment have resulted in an extreme degree of economic agglomeration. Consequently, the coordinated growth of the region has been impeded. To boost the economic collaboration within the region, this research paper makes use of the regional economic statistics spanning from 2001 to 2020. It delves into the regional economic disparities from four aspects: economic output, human resources, investment magnitude, and technological capabilities.

2.2 Spatial correlation test

2.2.1 Full spatial autocorrelation test

(1) Moran's I index

The Moran's I index is defined by equations (1) - (2):

$$I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}\left(Y_i - \bar{Y}\right)\left(Y_j - \bar{Y}\right)}{S^2 \sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}} \tag{1}$$

$$S^2 = \frac{1}{n}\sum_{i=1}^{n}\left(Y_i - \bar{Y}\right)^2, \bar{Y} = \frac{1}{n}\sum_{i=1}^{n} Y_i \tag{2}$$

In Eqs. (1)-(2), Y_i denotes the observed value (e.g., economic efficiency level) of the i nd region, n is the total number of regions, and $C_{ij} = \left(Y_i - \bar{Y}\right)\cdot\left(Y_j - \bar{Y}\right)$ denotes the attribute similarity of region i and region j. Having determined the location adjacency W_{ij} and attribute similarity C_{ij}, The index of global Moran's I can be computed as shown in equation (3):

$$W_{ij} = \begin{cases} 1 & \text{Region } i \text{ is adjacent to region } j \\ 0 & \text{Region } i \text{ is not adjacent to region } j \end{cases} \quad (3)$$

(2) Test of Moran's I index statistics

The Moran's I index gauges the extent of resemblance in the attribute values of spatially contiguous or neighboring regional units. This index ranges from -1 to +1. When the index value falls between 0 and 1, it suggests that the examined regions possess comparable levels of economic efficiency and exhibit an agglomeration effect geographically. Moreover, the nearer the index is to 1, the more pronounced the spatial autocorrelation of these regions becomes.Conversely, when the index value lies between 0 and -1, it implies that the economic efficiency levels of the tested regions are alike and display an agglomeration effect in geographical terms. The nearer the index approaches -1, the more pronounced the negative spatial autocorrelation of the area becomes. When the index reaches 0 and the test yields significant results, it suggests that the economic statuses of the regions under examination are randomly and independently distributed geographically.

The scatterplot of Moran's I for economic efficiency depicts the spatial interrelationship of economic efficiency between local regions and their neighboring areas. This entity is segmented into four quadrants, each related to a distinct form of spatial clustering. The first quadrant depicts a strong positive correlation, which means that both the area under consideration and its adjacent areas demonstrate elevated levels of economic productivity. The third quadrant reveals a weak positive correlation, where both the given area and its nearby regions have low economic productivity. These two patterns belong to the class of positive spatial autocorrelation.On the contrary, the second quadrant displays a negative correlation. In this case, the local area has low economic productivity, while the neighboring areas have high productivity. The fourth quadrant represents a high - low correlation, with the local region having high economic efficiency and its neighboring regions having low efficiency. These two types are classified as negative spatial autocorrelation. The corresponding calculation formulas are presented in Equation (4) and Equation (5).

$$\omega_0 = \sum_{i=1}^{n}\sum_{j=1}^{n}\omega_{ij} \quad (4)$$

$$\omega_1 = \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n}\left(\omega_{ij} + \omega_{ji}\right)^2 \quad (5)$$

Equation (4) denotes the sum of the elements in the spatial weight matrix. If the spatial weight matrix related to in Equation (5) is symmetric, then Equations (6) - (7) are derived.

$$\omega_1 = 2\sum_{i=1}^{n}\sum_{j=1}^{n}\omega_{ij} = 2\omega_0 \quad (6)$$

$$\omega_2 = \sum_{i=1}^{n}\left(\omega_i + \omega_j\right)^2 \quad (7)$$

Within Equations (6) through (7), represents the aggregate of the entries in row of the spatial weighting matrix. Conversely, signifies the total of the entries in column of the spatial weighting matrix. In the instance where the spatial weighting matrix exhibits symmetry, there are $\omega_2 = 4\sum_{i=1}^{n}\omega_i^2$. $K = \frac{m_4}{m_2^2}$ are the sample kurtosis coefficients, and $m_4 = \frac{\sum_{i=1}^{n}\left(Y_i - \bar{Y}\right)}{n}$ and $m_2 = \frac{\sum_{i=1}^{n}\left(Y_i - \bar{Y}\right)}{n}$ are the second sample moments and fourth sample moments, respectively.

Normalizing the Moran's I index I yields the normalized Z value as in equation (8):

$$Z = \frac{I - E\left(I\right)}{\sqrt{D\left(I\right)}} \tag{8}$$

The value of test statistic Z can be calculated according to equation (8), and according to the magnitude of the value of test calculation statistic Z, the significance of the null hypothesis (H_0: the economic efficiencies of all regional units are independent of each other and there is no spatial autocorrelation) can be judged. If the absolute value of the test statistic Z, If, at a significance level of 0.05 (or 0.1), a value that adheres to a normal distribution exceeds the critical value of 1.65 (or 1.96), This implies that, regarding their spatial arrangement, there exists a significant spatial interdependence among the economic efficiencies of different regions.

2.2.2 Local spatial autocorrelation test

In spatial statistics, the detection and examination of local spatial correlation patterns are a crucial part of exploratory spatial data analysis. Global spatial correlation tests often struggle to pinpoint the spatial correlation patterns present in distinct geographical areas. Moreover, when global spatial effects tests fail to demonstrate the existence of global spatial correlation, it becomes even more essential to employ local indicators to identify potentially significant local spatial correlation patterns.To put it simply, global spatial autocorrelation merely offers a general description of the spatial autocorrelation pattern of economic efficiency. However, it has the tendency to smooth out regional disparities and does not precisely reflect the spatial dependence of individual regions. As a result, the use of local spatial correlation indicators is necessary.

A local measure of spatial correlation pertains to any statistical metric that meets the subsequent two criteria. To begin with, for each regional spatial observational unit, the Local Indicator of Spatial Association (LISA) can present an indication of the degree of notable spatial clustering around the similarity value of this particular observation. Secondly, the aggregate of the LISAs for the observations of all spatial regional units must be in proportion to the corresponding global measure of spatial autocorrelation. Popular local spatial correlation measures are the local Moran's I index and the local index.

The local Moran's I index of an observation unit, which is a specific instance of the local spatial correlation index LISA, can be expressed as equation (9).

$$I_i = Z_i \sum_{j=1}^{n} W_{ij} Z_j \tag{9}$$

In Equation (9), the values and represent the discrepancies of the observations from the mean. To simplify the interpretation of the spatial weight matrix when using the row - normalized format, it is conventionally assumed that. As a result, is the outcome of multiplying by the weighted average of the observations from the neighboring observation cells of the given observation cell.

The local Moran statistic can also be defined as equation (10):

$$I_i = \frac{Z_i}{m_2}\sum_{j=1}^{n}\omega_{ij}\cdot Z_j \tag{10}$$

In Eq. (10), Z_i and Z_j are the same as in Eq. (9), m_2 is the second sample moment, and m_2 is a constant for all observation cells.

The subsequent local Moran statistic employs the definition presented in Equation (11) to conduct an analysis of the estimation for the local Moran's I index. Assuming a random distribution, the expectation and variance of are given by Equations (11) and (12) respectively:

$$E\left(I_i\right) = \frac{-\omega_i}{n-1} \tag{11}$$

$$D\left(I_i\right) = \frac{\omega_{i(2)}(n-b_2)}{n-1} + \frac{2\omega_{i(hh)}(2b_2-n)}{(n-1)(n-2)} - E^2\left(I_i\right) \tag{12}$$

In Eq. (12), $\omega_i = \sum_{j=1}^{n}\omega_{ij}$, $\omega_{i(2)} = \sum_{j,j\neq i}^{n}\omega_{ij}^2$, $\omega_{i(hh)} = \sum_{k,k\neq i}^{n}\sum_{h,h\neq i}^{n}\omega_{ik}\omega_{ih}$, $b_2 = \frac{m_4}{m_2^2}$, m_4 , m_2 are the fourth sample moments and second sample moments of the sample, respectively. The normalized form as I_i is as in Eq. (13):

$$Z(I_i) = \frac{I_i - E(I_i)}{\sqrt{D(I_i)}} \tag{13}$$

Subsequently, Equation (13) can serve as a test statistic for the local Moran spatial autocorrelation assessment.

2.3 Beijing-Tianjin-Hebei regional economic spatial test results

2.3.1 Economic global spatial correlation analysis

The per - capita GDP figures of all counties within the Beijing - Tianjin - Hebei region spanning from 2001 to 2020 were inserted into the global Moran's I formula. A commonly - employed rook neighborhood approach was utilized to build the spatial weight matrix. The comprehensive results of the global spatial correlation are presented in Table 1.During the period from 2001 to 2020, the global Moran's I values for this region are all positive and have passed the significance test with a P - value of 0.000. Moreover, these values show an overall upward trend. This suggests that counties in the Beijing - Tianjin - Hebei area with comparable economic development levels exhibit distinct spatial clustering. As regional integration progresses, the spatial correlation between neighboring areas continues to intensify, and the linkages in regional economic development become increasingly tight.

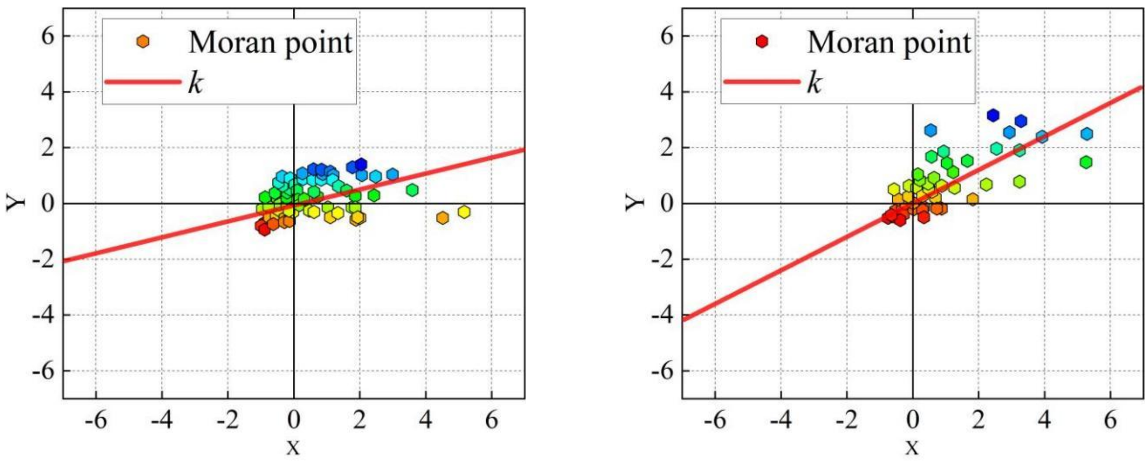
Table 1: Per capita GDP Moran index I value

Year	Moran's I	P	Year	Moran's I	P
2001	0.4101	0.000	2011	0.5457	0.000
2002	0.4221	0.000	2012	0.6122	0.000
2003	0.4336	0.000	2013	0.5261	0.000
2004	0.4259	0.000	2014	0.6020	0.000
2005	0.3994	0.000	2015	0.6313	0.000
2006	0.4841	0.000	2016	0.6452	0.000
2007	0.4981	0.000	2017	0.6183	0.000
2008	0.4609	0.000	2018	0.5562	0.000
2009	0.4882	0.000	2019	0.6136	0.000
2010	0.4976	0.000	2020	0.6261	0.000

2.3.2 Analysis of localized spatial autocorrelation of the economy

(1) Moran scatter plot analysis

The outcomes of utilizing the local spatial correlation analysis tool to create the Moran scatter plot for the overall regional economic development of the Beijing-Tianjin-Hebei region in 2001 and 2020 are shown in Figure 1(a)-(b). In this scatter plot, the dots located in the first quadrant represent High-High category counties. These are the counties that possess a high degree of their own economic development and are also surrounded by adjacent counties with a high level of economic development.The dots in the second quadrant indicate Low-High category counties. These counties have a comparatively low level of their own economic development, while their neighboring counties experience a high level of economic development.The dots in the third quadrant represent Low-Low category counties, which are distinguished by both the county itself and its neighboring counties having a low level of economic development. It seems there are some repeated and incorrect statements in the original text. Once the correction is made, we can readily comprehend the significance of each quadrant in the Moran scatter plot in relation to the economic development traits of various types of counties within the Beijing - Tianjin - Hebei region. The data points within the third quadrant signify Low - Low counties. These are counties where both their own economic development and that of their neighboring counties are at a low level. Conversely, the dots in the fourth quadrant signify High - Low counties. These counties possess a high degree of self - economic development, while the economic development of their neighboring counties is low. Every quadrant holds dots that stand for the county - level spatial entities in the Beijing - Tianjin - Hebei area. The development relationships between the counties in different quadrants and their surrounding counties fall into distinct types.The slope of the straight line on the graph is the global Moran index I. When comparing the Moran scatter plots of 2001 and 2020, it is evident that the slope in 2020 is notably steeper than that in 2001. This suggests that from 2001 to 2020, the correlation of economic development among the counties in the Beijing - Tianjin - Hebei region has increased significantly.



(a) 2001 (b) 2020

Figure 1: Moran scattered points for regional competitive development

(2) LISA agglomeration map analysis

A significance assessment of the local Moran index is carried out to obtain the significance measures for the local spatial clustering of the overall county - level economic development within the Beijing - Tianjin - Hebei region during the years 2001 and 2020. These metrics are presented in the form of LISA clustering diagrams respectively. The outcomes of the significance test for 2001 are presented in Figure 2, while those for 2020 are shown in Figure 3.In the diagram, dots of various colors represent different economic development models. Specifically, purple dots denote high - value clustering zones (HH), blue dots signify low - value depression zones (LL), red dots stand for high - low isolation zones (HL), and yellow dots indicate low - high collapse zones (LH).

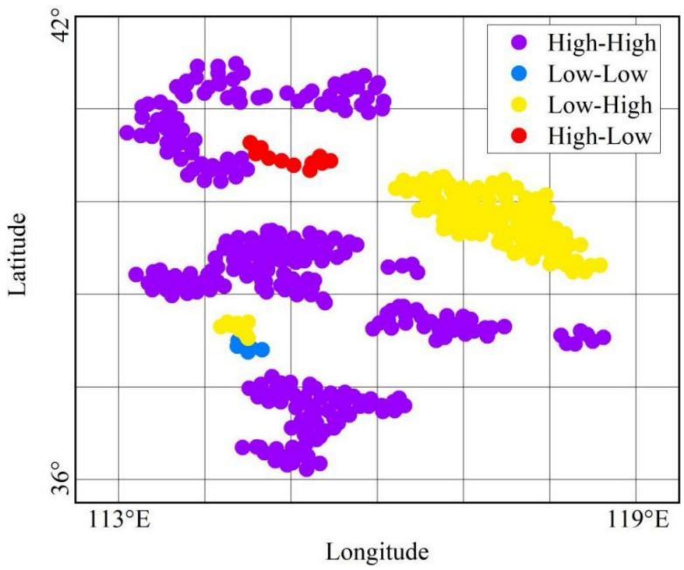


Figure 2: The significance test results of 2001

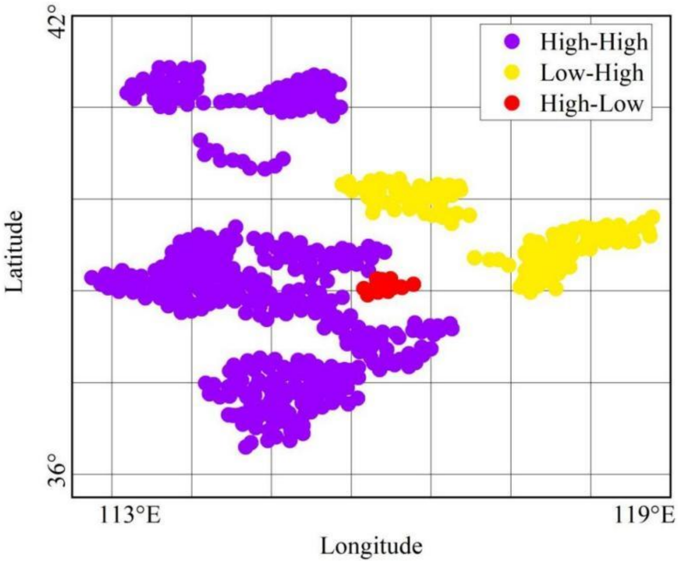


Figure 3: The significance test results of 2020

When combined with geographical location data, it becomes evident that in 2001, the areas with high - value clusters were predominantly centered in Beijing and Tianjin. Meanwhile, among the regions in Hebei Province, only Zhengding County passed the significance test for the local Moran index. The areas with low - value dispersion were primarily located in the western and northern parts of Zhangjiakou, the northern part of Baoding, the southern part of Cangzhou, and the eastern parts of Xingtai and Handan. Additionally, Luancheng County in Hebei Province was a county of the significant LL - HL type.By 2020, across the entire Beijing - Tianjin - Hebei area, there was a considerable rise in the quantity of counties featuring a notable HH - type as well as those with a prominent LL - type. Moreover, the high - value cluster area still encompassed the vast majority of Beijing and Tianjin. There are also Tanggu, Hangu, and Dagang districts in Tianjin and some coastal areas such as Tangshan in Hebei Province, where the level of economic development has risen, and which have also become high-value cluster districts; the number of districts involved in low-value depression districts has increased, including the southern and northern districts of Zhangjiakou, the surrounding districts of Baoding, and some districts to the east of the cities of Hengshui, Xingtai, and Handan; at the same time, only the city of Renqiu in Hebei Province has become a notable HL-type county that It belongs to the economic development pattern of high and low isolated areas, and there is no significant HL collapse area.

3 Level of economic synergy in the Beijing-Tianjin-Hebei region

3.1 Model for measuring the level of regional synergistic development

3.1.1 System of measurement indicators

This paper categorizes three perspectives of economic coordination, social integration, and resource - environment into five aspects: industrial layout, basic facilities, technological innovation, social welfare services, and economic circumstances. Afterward, 19 indicators are selected to assess the degree of order and collaboration of each functional subsystem in the Beijing - Tianjin - Hebei region. By means of this approach, the overall level of synergy in the

Beijing - Tianjin - Hebei region can be ascertained. Table 2 shows the detailed content of the measurement index system for the regional synergy of Beijing - Tianjin - Hebei.

Table 2: Regional collaborative measurement index system

System layer	Element layer	Secondary indicators of order parameters
Economic coordination	Industry development	Value Added of Primary Industry(100 Million Yuan)
		Value Added of Secondary Industry(100 Million Yuan)
		Value Added of Third Industry(100 Million Yuan)
		Per Capita GDP(Yuan per person)
		Total Local Fiscal Revenue(100 Million Yuan)
		Social Consumer Goods Retail Sales Total(100 Million Yuan)
Social integration	Infrastructure construction	Passenger turnover volume(100 Million person-kilometers)
		Cargo turnover volume(100 million tons-kilometers)
		Road Traffic Mileage(ten thousand kilometers)
	sci-tech innovation	Fiscal expenditure on science and technology(100 Million Yuan)
		Number of technical personnel (ten thousand people)
		Number of R&D Projects for Large Industrial Enterprises
		Number of patent applications
	Social services	Number of personnel engaged in education(ten thousand people)
		Public Library Collection Volume(ten thousand books)
		Number of persons employed in information technology services(ten thousand people)
		Number of Medical Personnel(ten thousand people)
Resources and environment	Ecological environment	Completion of investment in industrial pollution control(ten thousand Yuan)
		Harmless treatment rate of household waste(%)

3.1.2 Construction of measurement models

Regional synergistic system $R=\{R_1,R_2\cdots R_i\}$, where R represents the whole regional synergistic system of Beijing-Tianjin-Hebei, and R_1,R_2,R_3 represents the subsystems of Beijing, Tianjin, and Hebei, respectively. $R_i=\{R_{i1},R_{i2}\cdots R_{ij}\}$, i.e., each subsystem is composed of several different ordinal covariates. Each subsystem ordinal parameter value $X_i=\{x_{i1},x_{i2}\cdots x_{ij}\}$, where $\alpha_{ij}\le x_{ij}\le\beta_{ij}$.

The orderliness of each functional subsystem was first measured. Since the unit of each selected ordinal parameter is inconsistent, in order to eliminate the influence of the unit scale between the ordinal parameters, the data are standardized, and the original absolute values are processed into standardized relative values between 0 and 1. According to the index attribute of the ordinal parameter, it can be divided into positive and negative indexes, assuming that $X_{i1},X_{i2},X_{i3}\cdots X_{ik}$ is the positive ordinal parameter index, when the positive ordinal parameter index is bigger, it means that it contributes more to the ordinal parameter order; $X_{ik+1},X_{ik+2},X_{ik+3}\cdots X_{im}$ is the negative ordinal parameter index, the smaller the negative ordinal parameter index is, it means that it contributes more to the ordinal parameter order. α_{ij} and β_{ij} Respectively, they stand for the maximum and minimum values of each subsystem value. The processing of these values is presented in Equations (14) - (15):

$$y_{ij} = \frac{x_{ij} - \alpha_{ij}}{\beta_{ij} - \alpha_{ij}},\ j \in [1, k] \tag{14}$$

$$y_{ij} = \frac{\beta_{ij} - x_{ij}}{\beta_{ij} - \alpha_{ij}},\ j \in [k+1, m] \tag{15}$$

Following the removal of unit scale processing, to prevent the emergence of a value of 0, each ordinal parameter value undergoes non - zero data processing. The process is described by Equations (16) - (17).

$$y_{ij} = \frac{x_{ij} - \alpha_{ij}}{\beta_{ij} - \alpha_{ij}} * 0.99 + 0.01,\ j \in [1, k] \tag{16}$$

$$y_{ij} = \frac{\beta_{ij} - x_{ij}}{\beta_{ij} - \alpha_{ij}} * 0.99 + 0.01,\ j \in [k+1, m] \tag{17}$$

$y_{ij} \in (0,1]$, the greater its index, the greater it indicates that the degree of ordering increases with the index and contributes more to the overall synergy of the system.

The degree of ordering of subsystems is usually through the linear addition of the ordering degree of the order parameter components, subsystem R_i has an ordering degree of Y_i, Y_i the larger, indicating that the R_i subsystems are relatively ordered and have a better degree of synergy. Then there is equation (18):

$$Y_i = \sum_{j=1}^{n} \lambda_j y_{ij}, \lambda_j \geq 0 \text{ Moreover } \sum_{j=1}^{n} \lambda_j = 1 \tag{18}$$

λ_i is the weight of each order parameter, and the methods of selecting the weight include hierarchical analysis method, correlation matrix assignment method and entropy value method. The greater the weight, the more significant the status and function of the ordinal parameter component within the subsystem. In this research paper, the entropy value approach is chosen to measure the weight size of each ordinal parameter. The calculation process of the entropy value approach is as follows: first, calculate the information entropy within the entropy value approach, which is defined by equation (19).

$$E_i = -k \sum_{i=1}^{n} p_{ij} \ln p_{ij}, k = \frac{1}{\ln n}, p_{ij} = Y_{ij} \Big/ \sum_{i=0}^{n} Y_{ij} \tag{19}$$

After calculating the information entropy, the corresponding weights of the ordinal parameters are calculated, The calculation procedure is presented in Equation (20) as follows:

$$\lambda_i = (1 - E_i) \Big/ \left(m - \sum_{m=1}^{m} E_i \right) \tag{20}$$

Ultimately, the comprehensive integrated synergy of the region is gauged. The degree of order of the subsystem at a particular moment \(t_1\) is \(O_1\), and when the system progresses to moment \(t_2\), the degree of order of the subsystem is \(O_2\). Then, the integrated synergy of the entire region is represented by equation (21).

$$E=\theta\sum_{i=1}^{3}\omega_i\left|Y_i^1-Y_i^0\right| \text{ Which } \omega_i\geq 0 \text{ Moreover}$$
$$\sum_{i=1}^{3}\omega_i=1,\theta=\min\left[Y_i^1-Y_i^0\neq 0\right]\Big/\min\left[Y_i^1-Y_i^0\neq 0\right] \tag{21}$$

ω_i are the weights of the subsystems, which in this paper are based on the proportion of GDP that each subsystem represents for the region as a whole.

The degree of regional synergy is reflected by the degree of synergy, which ranges between $\left[-1,1\right]$ and 0. When the degree of synergy is less than 0, it indicates that the whole system is not synergistic and that at least one of the subsystems is in a state of disorder. When the degree of regional synergy is greater than 0, it indicates that the overall development is evolving in the direction of synergy, and the larger the value, the higher the degree of system synergy. The extent of synergy serves as an indicator for the standards of synergistic development. When the synergy extent lies between 0 and 0.3, the area is in a low - level synergistic condition. Conversely, when the synergy extent exceeds 0.8, the area has achieved a high level of synergy. At this stage, the area has evolved into a community with closely intertwined interests. The differences within the region are comparatively small. The industrial framework and the division of labor in the industries are well - organized, and collaborative development has been achieved within the region.

The model takes dynamic effects into account, allowing the overall degree of synergy to be trended over the years. The model comprehensively considers the ordered state of each subsystem, and the whole system is in a synergistic state only when all subsystems are in order; when one subsystem is in disorder, the whole system is in a non-synergistic state.

3.2 Measurement results of the level of economic synergistic development in the Beijing-Tianjin-Hebei region

3.2.1 Analysis of the degree of orderliness of the Beijing-Tianjin-Hebei economic system

Figure 4 illustrates the economic coordination and systematicness of a total of 13 cities in the Beijing - Tianjin - Hebei region over the period from 2001 to 2020. In all the cities of the Beijing - Tianjin - Hebei area, there is a rising trend in economic coordination and systematicness. Among them, (B) Beijing exhibits the highest level, with a range from 0.034 to 0.055, while (T) Tianjin falls in the middle range, with values between 0.018 and 0.043. The cities of Beijing and Tianjin have a more rational industrial structure due to stronger policy support. Although the cities in Hebei have a lower degree of economic coordination and orderliness, they benefit from the Beijing-Tianjin-Hebei synergistic policy, with (H1) Langfang (0.015~0.033), (H2) Zhangjiakou (0.023~0.036), and (H10) Shijiazhuang (0.017~0.043) being relatively high.

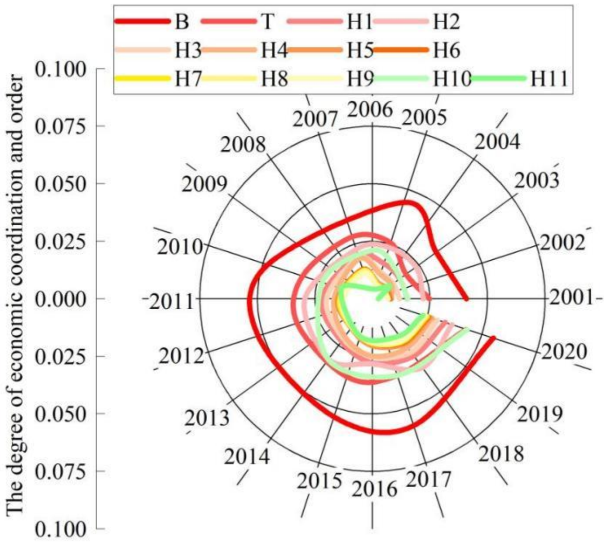


Figure 4: The degree of economic coordination and order among the 13 cities

Figure 5 illustrates the overall social orderliness of a total of 13 cities in the Beijing-Tianjin-Hebei region spanning from 2001 to 2020. The comprehensive social orderliness of these 13 cities shows an overall upward trend. During the first ten - year period, the levels of comprehensive social orderliness across the 13 cities were fairly comparable.After 2011 (B), Beijing started to emerge as the leader. Its index fluctuated between 0.51 and 0.11. Tianjin (T) came next. In contrast, the progress in the 11 cities of Hebei Province was relatively slow.

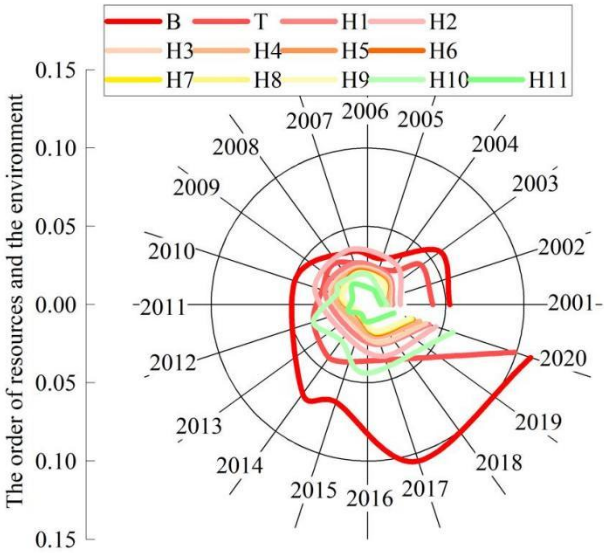


Figure 5: The comprehensive social order of 13 cities

Figure 6 presents the resource - environmental orderliness of the 13 cities within the Beijing - Tianjin - Hebei region during the period from 2001 to 2020. Unlike the performance of the economic coordination orderliness and the comprehensive social orderliness, although the performance of (B) Beijing and (T) Tianjin is still better, the difference of the resource-environmental orderliness of the region as a whole is relatively small. By 2020, the resource-environmental orderliness of the 13 cities is concentrated in the range of (0.050,0.100), and the internal difference is <0.03.

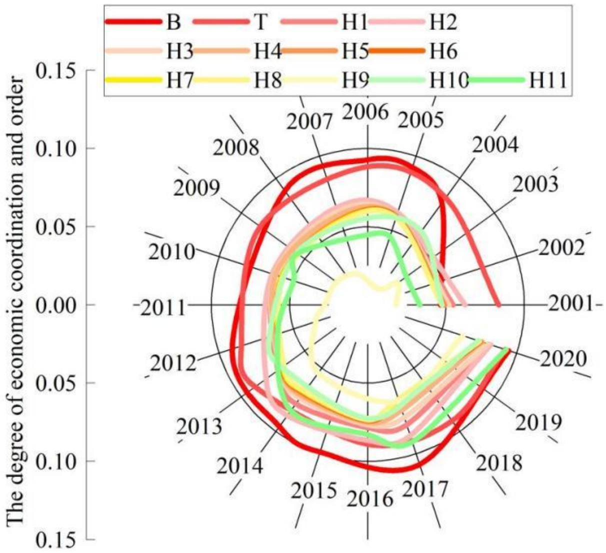


Figure 6: The order degree of resources and environment in 13 cities

3.2.2 Analysis of the degree of economic synergy in the Beijing-Tianjin-Hebei region

Since the cities in Hebei province show very little difference in the overall arrangement of the economic system and the organization of the five key areas of economic development, which are innovation and openness, economic coordination, social integration, and the resource - environment, and they have similar economic development situations, this section analyzes the degree of the Beijing - Tianjin - Hebei regional economic collaborative development from the perspective of Hebei province as a whole. By taking the previous year as the base period, the extent of the economic collaborative development in the Beijing - Tianjin - Hebei region is measured by utilizing the organizational degree of the three economic systems in Beijing, Tianjin, and Hebei. Table 3 shows the results related to the degree of the Beijing - Tianjin - Hebei regional economic collaborative development from 2001 to 2020. The overall level of economic collaborative development in the Beijing - Tianjin - Hebei region lies between -0.031 and 0.039. The values indicating the degree of collaborative development each year are comparatively small. This implies that the level of economic collaborative development in the Beijing - Tianjin - Hebei region is low, and the development process is slow. In the meantime, the extent of collaborative development on an annual basis exhibits both positive and negative figures. This suggests that the state of economic collaborative development within the Beijing-Tianjin-Hebei region is unstable, characterized by a pattern of alternating rises and falls. After a period of several years marked by an inconsistent collaborative relationship, the level of economic collaborative development in the Beijing-Tianjin-Hebei region between 2019 and 2020 steadily became stable and advantageous. As a result, there has been an improvement in the level of economic cooperation in the Beijing-Tianjin-Hebei region.

Table 3: Degree of coordinated development of regional economy(2001~2020)

Year	Beijing-Tianjin-Hebei	Beijing-Tianjin	Beijing-Hebei	Tianjin-Hebei
2001	-0.021	-0.011	0.012	0.039
2002	-0.015	0.02	-0.005	-0.019
2003	-0.016	-0.014	0.011	0.023
2004	-0.013	0.011	-0.012	0.015
2005	0.032	0.052	0.036	0.009
2006	0.016	0.016	0.012	0.02
2007	0.035	0.041	0.027	0.038
2008	-0.018	-0.022	0.014	-0.017
2009	0.035	0.048	0.047	0.01
2010	-0.021	-0.002	0.028	-0.034
2011	0.039	0.053	0.031	0.032
2012	0.034	0.027	0.039	0.035
2013	0.035	0.043	0.058	0.004
2014	-0.031	0.016	0.046	-0.032
2015	-0.017	0.028	0.007	0.017
2016	-0.020	-0.02	0.013	0.028
2017	-0.030	-0.019	0.043	0.027
2018	0.025	0.015	0.037	0.023
2019	0.015	0.013	0.025	0.007
2020	0.020	0.023	0.012	0.024

4 Beijing-Tianjin-Hebei economic synergy mechanism based on industrial development synergy

4.1 Spatial panel model of economic development under industrial development synergy

Prior to building the spatial panel data model, the variables for the panel threshold model are chosen as follows:

(1) Explained variable: quality of economic development (Qua).

(2) Core explanatory variables: industrial development environment synergy and industrial development capability synergy. Among them, the synergy of industrial development environment is observed through four variables: industrial policy (Pol), industrial innovation (Inn), industrial foundation (Inf), and industrial economy (Env). The synergy of industrial development capability is reflected in nine aspects, including rationalization of industrial structure (Rat), advanced industrial structure (Adv), primary industry agglomeration (Aggl), secondary industry agglomeration (Agg2), tertiary industry agglomeration (Agg3), industrial linkage (Lin), The specialization of tasks within the primary sector (Specialization 1), the specialization of tasks within the secondary sector (Specialization 2), and the specialization of tasks within the tertiary sector (Specialization 3).

(3) Threshold variables consist of the level of economic development (Eco) and the urban magnitude (Size). The level of economic development (Eco) is measured by the ratio of the real gross domestic product (GDP) to the total year - end population of each area. On the other hand, the urban magnitude is ascertained by the total year - end population of the municipal district.

(4) Controlled variables encompass the level of economic progress (Eco), the magnitude of human capital (Hum), the pace of urban growth (Urb), the degree of market - based development (Mar), the size of government expenditure (Gov), and the extent of external openness (For).

Combining the above - described situation of economic collaborative development in the Beijing - Tianjin - Hebei region with the current research, this paper constructs the spatial panel data model of industrial development cooperation's impact on the quality of economic development in the following three forms:

At the beginning, a spatial autoregressive model (SAR) is set up to examine the endogenous interaction influence of the economic development quality in every city, as presented in equation (22).

$$\ln Qua_{it} = \rho W \ln Qua_t + \beta_1 \ln X_{it} + \beta_2 \ln Control_{it} + u_i + \gamma_t + v_{it} \tag{22}$$

In Equation (22), and respectively denote individuals and time. functions as the dependent variable, indicating the natural logarithm of the economic development quality of Region at Time. is the spatial weight matrix. represents the spatial lag term of the economic development quality of each city. is the spatial autocorrelation coefficient.The core independent variable, which indicates the level of industrial development synergy for each city at a given time, is denoted. The control variables are represented by. The coefficients of each independent variable are represented by. The individual - specific effect and the time - specific effect are represented by and respectively. A random error term, which follows an independently and identically - distributed pattern, is.

Secondly, a spatial error model (SEM) is constructed to analyze the interaction impacts among the random disturbance elements of each city, as shown in Equation (23).

$$\begin{gathered} \ln Qua_{it} = \beta_1 \ln X_{it} + \beta_2 \ln Control_{it} + u_i + \gamma_t + \varepsilon_{it} \\ \varepsilon_{it} = \lambda m_t' \varepsilon_t + v_{it} \end{gathered} \tag{23}$$

In Equation (23), denotes the spatial error coefficient. This coefficient indicates the spatial interrelationship among the random error terms associated with the quality of economic development in each city. The other parameters maintain the same meaning as defined earlier.

Third, a Spatial Durbin Model (SDM) is established to examine both endogenous and exogenous interaction effects, as presented in equation (24).

$$\begin{aligned} \ln Qua_{it} = {} & \rho W \ln Qua_t + \beta_1 \ln X_{it} + \beta_2 \ln Control_{it} \\ & + \beta_3 W \ln X_{it} + \beta_4 W \ln Control_{it} + u_i + \gamma_t + v_{it} \end{aligned} \tag{24}$$

In Equation (24), the spatial lag terms of the collaborative level of industrial development and control variables for each city are represented by and respectively. The interpretations of the remaining parameters are consistent with those detailed in the preceding section.

Finally, when the coefficients of the spatial terms in the generalized nested spatial panel data model are all 0, the classical OLS regression model as Eq. (25) can be obtained:

$$\ln Qua_{it} = \beta_0 + \beta_1 \ln X_{it} + \beta_2 \ln Control_{it} + u_i + \gamma_t + v_{it} \tag{25}$$

The meaning of the parameters in Eq. (25) is the same as before.

4.2 Analysis of the quality of economic development under the synergy of industrial development

4.2.1 Specific effects tests for spatial panel data models

This research separately performs a combined non - significant likelihood ratio test (LR test) on the individual fixed effects and time fixed effects of both the spatial autoregressive model and the spatial error model. The results are shown in Table 4. In both the spatial autoregressive model and the spatial error model, the time fixed effects exhibit statistically highly significant differences (P = 0.000). Moreover, the individual fixed effect within the spatial error model exhibits a notable difference at the 10% significance level (P = 0.074). As a result, the null hypothesis positing the collective non - significance of the individual fixed effects in the spatial autoregressive model is discarded. Conversely, the null hypothesis regarding the collective non - significance of the time fixed effects is upheld. This suggests that a spatial autoregressive model incorporating time fixed effects can be developed. Upon acknowledging the initial assumption about the overall insignificance of individual fixed effects and time fixed effects, one can build a spatial error model that incorporates two - way fixed effects for both individual and temporal elements.

Table 4: LR test results

Spatial panel data model	Fixed effects	Test statistics	Degrees of freedom	P value
SAR	SFE	355.277	15	0.284
	TFE	113.78	12	0.000
SEM	SFE	370.572	15	0.074
	TFE	104.057	12	0.000

4.2.2 Selection of a spatial panel data model

To uphold the scientific validity of the research and analysis, even though the results of the prior test analysis suggest discarding the non - spatial panel model and choosing either the spatial autoregressive model or the spatial error model, it is still crucial to further investigate the possibility of extracting other spatial econometric models from the data. In light of this, this paper can consider the spatial Durbin model (SDM). By conducting Wald and LR hypothesis tests on it, we can determine whether it can be simplified to a spatial autoregressive model or a spatial error model. The outcomes of the Wald test and the LR hypothesis test for the spatial Durbin model are shown in Table 5. In the case of the individual fixed - effects model, the p - values of both the Wald test and the LR hypothesis test exceed 0.1000. This result validates the notion that the spatial Durbin model can be simplified to either a spatial autoregressive model or a spatial error model. Although the test results in the previous subsection do not support the use of a spatial autoregressive model or a spatial error model with an individual fixed - effects model, the spatial Durbin model is still selected. This occurs because it incorporates the spatial interaction impacts found in both the spatial autoregressive model and the spatial error model. Additionally, for the time fixed - effects model and the individual - time two - way fixed - effects model, the P - values of the Wald test and the LR test are lower than 0.0500. As a result, the null hypothesis stating that the spatial Durbin model can be simplified to a spatial autoregressive model or a spatial error model is rejected. Based on the outcomes of the aforementioned analysis, it was decided to employ the spatial Durbin model to carry out a spatial effect investigation on the mechanism of economic synergy among the cities in the Beijing - Tianjin - Hebei region.

Table 5: The Wald test and LR hypothesis test results of the spatial Durbin model

Method of calibration	SFE	TFE	STFE
Wald(Lag)	7.0254	79.5241***	18.0265**
	(0.6812)	(0.000)	(0.0360)
LR(Lag)	7.4981	63.9843***	19.5247***
	(0.4025)	(0.000)	(0.000)
Wal(Error)	4.0251	80.9865***	15.8752**
	(0.6417)	(0.000)	(0.04789)
LR(Error)	4.1587	68.1479***	18.5243**
	(0.8064)	(0.000)	(0.0225)

Note: The significance levels are indicated in parentheses. *, ** and *** respectively indicate significance at the levels of 10%, 5% and 1%. The same below.

4.2.3 Economic synergy mechanisms based on spatial panel data models

A dynamic spatial Durbin model is constructed by integrating the lag terms between the explanatory variables and the explanatory variables in both the temporal and spatial aspects, building upon the static spatial Durbin model. The “geography - economy - technology (W)” weight matrix is still utilized as the spatial weight matrix for this model. Table 6 shows the regression results of both the static and dynamic spatial Durbin models.

Table 6: Regression results of Dubin models in static and dynamic Spaces

Variable	Static SDM			Dynamic SDM		
	SFE	TFE	STFE	SFE	TFE	STFE
Qua	-	-	-	0.859*** (0.000)	0.119** (0.047)	0.092* (0.067)
W Qua	0.109** (0.045)	0.092* (0.063)	0.251* (0.084)	0.257*** (0.000)	0.195* (0.086)	0.229*** (0.000)
POL	0.005* (0.087)	0.063** (0.035)	0.061** (0.039)	0.941*** (0.000)	0.019 (0.624)	0.072 (0.509)
Inn	0.148** (0.030)	0.112 (0.459)	0.211*** (0.000)	2.969*** (0.000)	0.450*** (0.000)	0.139 (0.302)
Inf	0.182*** (0.000)	0.226*** (0.000)	0.178*** (0.000)	2.449*** (0.000)	0.170** (0.037)	0.139* (0.078)
Env	-0.229*** (0.000)	-0.226*** (0.000)	-0.201*** (0.000)	0.131*** (0.000)	0.192*** (0.000)	0.165*** (0.000)
Rat	-0.051 (0.659)	-0.109*** (0.000)	-0.019 (0.803)	-0.055 (0.365)	-0.131*** (0.000)	-0.242*** (0.000)
Adv	5.412* (0.093)	-3.521 (0.435)	5.399* (0.072)	91.572*** (0.000)	-0.055 (0.867)	-2.151 (0.357)
Agg_1	0.029*** (0.000)	0.019*** (0.000)	0.015** (0.031)	0.009 (0.354)	0.031*** (0.000)	0.039*** (0.000)
Agg_2	-0.015*** (0.000)	-0.001 (0.638)	-0.129** (0.032)	0.109*** (0.000)	0.022*** (0.000)	0.025*** (0.000)
Agg_3	0.018*** (0.000)	0.005 (0.662)	0.022*** (0.000)	0.015*** (0.000)	0.019** (0.000)	0.031*** (0.000)
Lin	0.157*** (0.000)	0.119*** (0.000)	0.121*** (0.000)	0.765*** (0.000)	0.062 (0.357)	0.253*** (0.000)

Div_1	0.083 (0.658)	0.038 (0.561)	0.095** (0.035)	0.039 (0.428)	0.141*** (0.000)	0.188*** (0.000)
Div_2	0.088* (0.062)	0.171*** (0.000)	0.089* (0.087)	0.131*** (0.000)	0.219*** (0.000)	0.362*** (0.000)
Div_3	-0.129** (0.035)	-0.069 (0.571)	-0.079 (0.856)	2.918*** (0.000)	-0.091 (0.937)	-0.297*** (0.000)
W POL	-0.9603 (0.292)	2.383* (0.084)	1.208 (0.635)	33.527*** (0.000)	1.601 (0.254)	0.091 (0.115)
W Inn	0.021 (0.842)	-0.348 (0.523)	0.270 (0.635)	3.963*** (0.000)	0.653* (0.068)	0.238 (0.324)
W Inf	0.124 (0.416)	0.009 (0.456)	0.089 (0.778)	3.306*** (0.000)	0.059 (0.632)	0.291 (0.672)
W Env	0.005 (0.847)	-0.029 (0.803)	0.071 (0.632)	4.522*** (0.000)	0.363* (0.026)	0.151 (0.457)
W Rat	-0.123 (0.326)	-0.059 (0.624)	-0.237 (0.065)	5.369*** (0.000)	-0.263 (0.409)	-0.309 (0.635)
W Adv	-34.501*** (0.000)	21.527** (0.031)	33.463*** (0.000)	469.716*** (0.000)	-25.652* (0.034)	-25.498* (0.054)
W Agg_1	0.032*** (0.000)	0.058*** (0.000)	0.029 (0.386)	-0.038** (0.033)	0.041* (0.062)	0.049* (0.025)
W Agg_2	-0.017** (0.036)	0.004 (0.523)	-0.019* (0.064)	0.158*** (0.000)	-0.005 (0.864)	-0.020 (0.281)
W Agg_3	0.039** (0.031)	0.006 (0.702)	0.035* (0.064)	0.032* (0.084)	0.025 (0.184)	0.005 (0.231)
W Lin	0.019 (0.604)	0.143 (0.564)	0.197* (0.075)	-4.143*** (0.000)	-0.383*** (0.000)	-0.125 (0.594)
W Div_1	0.155 (0.321)	0.087 (0.594)	0.291* (0.083)	2.232*** (0.000)	0.177 (0.852)	0.685*** (0.000)
W Div_2	0.251 (0.128)	0.224 (0.635)	0.475*** (0.000)	-2.896*** (0.000)	0.415** (0.049)	0.825*** (0.000)
W Div_3	-0.153 (0.458)	-0.337* (0.066)	0.191 (0.632)	2.951*** (0.000)	0.038 (0.249)	0.491 (0.731)
Eco	0.047 (0.741)	0.336** (0.024)	0.262 (0.154)	1.254*** (0.000)	0.631*** (0.000)	0.601* (0.063)
Hum	0.309*** (0.000)	0.142 (0.354)	0.666*** (0.000)	4.339*** (0.000)	-0.103 (0.186)	-0.208 (0.562)
Urb	1.497*** 0.000)	1.198*** (0.000)	-1.058*** (0.000)	21.379*** (0.000)	-1.209*** (0.000)	-3.135*** (0.000)
Mar	0.069*** (0.000)	0.069*** (0.000)	-0.057** (0.031)	0.896*** (0.000)	-0.061* (0.089)	-0.020 (0.436)
Gov	-0.108 (0.254)	0.338*** (0.000)	-0.071 (0.309)	-0.047 (0.264)	0.408*** (0.000)	0.920*** (0.000)
For	-0.021 (0.306)	0.001 (0.831)	-0.003 (0.462)	0.397*** (0.000)	-0.009 (0.634)	-0.025 (0.905)
R^2	0.9503	0.0481	0.3849	0.7867	0.7872	0.7306

The spatial interaction factor and the time - lag factor of the explanatory variable, the economic development quality (Qua), exhibit statistically significant disparities at various levels ($P < 0.100$). This suggests that an externality impact exists regarding the economic development quality among the 13 cities in the Beijing - Tianjin - Hebei area. Put differently, there exists a favorable mechanism that boosts the quality of economic development among regions sharing similar geographical, economic, and technological development levels. This mechanism can facilitate the reciprocal improvement of economic development quality. Among the 13 cities in the Hebei region, there is an externality impact on the quality of economic development. At the same time, the quality of economic development also exhibits a time - lag phenomenon. This suggests that the enhancement of development quality is a step - by - step process, progressing from the accumulation of quantity to the transformation of quality.

Among the core explanatory variables, the level term, spatial interaction term, and time lag term of industrial development synergy successfully passed the significance test. Regarding the synergy of the industrial development environment and the synergy of the industrial development capacity, a comprehensive analysis ought to be carried out on the economic synergistic development mechanism that underpins the Beijing-Tianjin-Hebei region.

When it comes to the industrial development environment, the synergy levels, spatial interactions, and time - lag factors of industrial policy (POL), industrial innovation (Inn), industrial foundation (Inf), and industrial economy (Env) all show a significant difference at the 1% level. This indicates that the improvement of the synergy between industrial policy and innovation in the 13 cities of the Beijing - Tianjin - Hebei region has not only improved the quality of their own economic development but also promoted the economic growth of cities that are geographically and technologically close to them. Furthermore, it is clear that the interactions and collaborations within the industrial setting exert a more enduring impact on the quality of economic advancement. The outcomes of development, which are indirectly driven by enhancements in multiple environmental aspects, usually become apparent in the long - run future.

Concerning the potential for industrial development, there are remarkable differences ($P < 0.100$) in the levels of the advancement of the industrial structure (W Rat), including its level, spatial interaction, and temporal lag terms. Additionally, the agglomeration of the secondary (Agg2) and tertiary (Agg3) industries, industrial linkage (Lin), and the division of labor between the primary (Div1) and tertiary (Div3) industries also show distinct difference levels.On the other hand, for the level, spatial interaction, and temporal lag terms of industrial rationalization (Rat), the agglomeration of the primary industry (Agg1), and the division of labor in the secondary industry (Div2), their spatial interaction and time - lag terms are significant at the 1% level. Nonetheless, there isn't any significant short - term alteration. As a result, it becomes clear that the advanced evolution of the industrial structure is mainly marked by the rapid growth of the service sector. This growth not only propels the transformation and improvement of the industrial structure, along with the increase in the concentration and specialization degrees within the service industry, but also leads to a shift in the quality of the overall economic development of the region and similar areas. Moreover, the clustering of the secondary industry has notably enhanced the quality of economic development in the region and exerted a radiating influence on adjacent cities. Nevertheless, the favorable influence of labor division in the secondary sector on economic progress typically manifests in adjacent areas rather than within the industry itself. For instance, the choice to transfer non - capital functions has compelled the majority of industrial firms to relocate from Beijing. In the short run, this has had an adverse effect on Beijing's regional economic development. However, it has raised the degree of industrial labor specialization in the areas where these businesses have moved, thus boosting the level of economic advancement. Additionally, over the long run, it has played a part in the betterment of the industrial economy and the reconfiguration and optimization of Beijing's regional economic framework.

Upon integrating the analyses from the second and third chapters to assess the economic spatial interlinkage and the extent of economic collaborative progress in the Beijing - Tianjin - Hebei region from 2001 to 2020, it is clear that Beijing leads in terms of the overall standard and quality of economic development. Tianjin comes in second, followed by Hebei Province.In terms of the industrial development level, Beijing has the smallest share of the primary industry, the largest share of the tertiary industry, and a well - organized industrial framework. Even though the development levels of various industries in Tianjin are lower than those in Beijing, Tianjin holds distinct advantages in terms of its economic location and wields stronger industrial competitiveness.Hebei Province, influenced by factors such as geographical position and historical development, faces issues like a severe imbalance in industrial structure, over - production capacity, and a lack of core competitiveness.As a result, this paper asserts that in order to promote the healthy development and long - term stability of the Beijing - Tianjin - Hebei regional economy in the future, the three provincial - level administrative areas should actively remove administrative barriers, promote the creation of a regional strategic coordination system, and attain high - quality economic collaborative growth through in - depth mutual assistance and cooperation at the regional economic level. Moreover, within the development plans of the specific industrial framework, the three provincial - level administrative regions should adopt the principle of market - driven technological advancement. They ought to actively strengthen their cooperation in scientific and technological innovation. By jointly establishing an integrated marketplace for elements of innovation such as the movement of talent and technology transactions, they can arouse the inherent innovative potential of the region. This will promote the high - standard development of cooperative innovation in the region and fully actualize the core role of innovation in economic advancement.

5 Conclusion

Since the establishment of the market - oriented economic system, although the overall economic development level in the Beijing - Tianjin - Hebei region has been ascending (the global Moran index I value surpasses 0.000) and the internal interconnection of economic development has intensified over time, a significant internal disparity still persists. In terms of comprehensive economic development, Beijing takes the lead, followed by Tianjin, while Hebei lags behind. Due to the economic coordination order degree of Beijing (from 2001 to 2020 it was 0.034 to 0.055) and the social comprehensive order degree (from 2011 to 2020 it was 0.51 to 0.11) always being discontinuously ahead of Hebei, the coordinated development degree of the three economic systems in the Beijing-Tianjin-Hebei region showed extremely unstable development characteristics, fluctuating and rising or falling within the range of -0.031 to 0.039 from 2001 to 2020.

In the regression analysis of the spatial panel data model focusing on industrial development synergy, the quality of economic development in the Beijing - Tianjin - Hebei region is characterized by a spatial interaction term and a spatio - temporal lag term. These terms display significant differences at the 1% significance level. Additionally, the level term, spatial interaction term, and spatio - temporal lag term of the synergy within the industrial development environment also display statistically significant differences at the same level. In the industrial development capability, there are level terms, spatial interaction terms and spatio-temporal lag terms of industrial structure advancement, secondary/tertiary industry agglomeration and industry association, primary/tertiary industry division of labor $P<0.100$, and there are spatial interaction terms and spatio-temporal lag terms of industry rationalization, primary industry agglomeration and secondary industry division of labor that are significant at the 1% level.

Taking into account the characteristics of the overall economic growth in the Beijing - Tianjin - Hebei region and the industrial progress of the three provincial - level administrative units, this paper argues that the core of the healthy development of the future mechanism for the economic coordinated development of the Beijing - Tianjin - Hebei urban areas is the in - depth promotion of the strategic development coordination process and the coordinated linkage of innovative industries.

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