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Research on the mechanism of Beijing-Tianjin-Hebei urban economic synergy based on spatial panel modeling

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Abstract As the economy transitions from high-speed growth to high-quality development, regional economic coordination has become an important strategic opportunity. This paper takes the coordinated development of the urban economies in the Beijing-Tianjin-Hebei region as its backdrop. Based on the calculation of the coordinated development level of the urban economies in the Beijing-Tianjin-Hebei region using a composite system coordination model, the paper constructs a spatial panel model to empirically analyze the impact of selected influencing factors on their coordinated economic development and explores the coordinated development mechanism of the urban economies in the Beijing-Tianjin-Hebei region. The study found that from 2015 to 2024, the economic development level of the Beijing-Tianjin-Hebei region continued to rise, but its economic coordination level remained low, ranging from 0.091 to 0.376, indicating a state of low to moderate coordination. The economic coordination of cities in the Beijing-Tianjin-Hebei region is primarily positively and significantly influenced by the degree of marketization, level of openness to the outside world, government intervention, and regional economic development level ($p < 0.1$), while population density (-0.423) and transportation density (-0.012) have a negative impact on their coordinated economic development. The Beijing-Tianjin-Hebei region should adopt collaborative strategies such as leveraging comparative advantages, defining functional roles, developing industrial chains, and strengthening inter-regional interactions to promote the coordinated economic development of cities in the region.

Index Terms spatial panel model, composite system coordination degree model, Beijing-Tianjin-Hebei cities, economic coordination and development

I. Introduction

The Beijing-Tianjin-Hebei region comprises the three economic entities of Beijing, Tianjin, and Hebei Province. Due to historical reasons, the Beijing-Tianjin-Hebei region is located at the heart of Chinese civilization. The three major economic entities in this region share a high degree of cultural continuity, exhibiting regional integrity and strong cultural affinity. It is a world-class urban region that plays a pivotal role in China's participation in global competition and its efforts to achieve modernization first [1]-[3]. At the macro level, the coordinated development of the Beijing-Tianjin-Hebei region has been elevated to a national strategic level. Given its unique central location, the region has undoubtedly become a key engine for national economic development and a leading area for international competition and cooperation [4]-[6]. At the regional economic level, as an economic circle encompassing two megacities, the Beijing-Tianjin-Hebei region holds a pivotal position and significance in the sustainable development of the entire Bohai Rim region, both in terms of its current economic status and future development potential [7]-[9].

Practice has proven that the sustained development of any city cannot be achieved in isolation. Only by leveraging the radiating effect of core cities on surrounding areas and driving their joint development can a city establish a robust foundation for its own growth, thereby promoting green and sustainable urban development [10]-[12]. For this reason, the coordinated development of the Beijing-Tianjin-Hebei region has made substantial progress in recent years, gradually becoming a model and benchmark for China's regional development. However, concurrently, some issues and contradictions have gradually emerged, such as the significant development disparities among the three regions within the area, the increasingly severe ecological and environmental issues within the region, the growing "megacity syndrome" in Beijing and Tianjin, and the worsening poverty in the capital's poverty belt. These issues directly constrain the formation of the Beijing-Tianjin-Hebei coordinated development mechanism and the achievement of its objectives [13]-[16].

The economic disparity between Beijing, Tianjin, and Hebei is too high, leading to significant differences in the development status of enterprises and industries in the three regions across various aspects such as talent utilization, technology, and finance, with gaps in industrial coordination [17], [18]. The causes of this situation are diverse. For example, Beijing has long focused its urban development planning on internal circulation within its urban areas, without adequately considering the compatibility with surrounding cities and provinces, However, Beijing's development relies heavily on external resources from surrounding provinces and cities. While obtaining various resources from external sources, its urban development and expansion continue to be guided by internal circulation principles, leading to the absorption of surrounding resources. Yet, surrounding provinces have not benefited from Beijing's development, and instead, this has created extensive poverty-stricken areas around Beijing [19]-[23].

Zhang et al. [24] analyzed the economic development and environmental impacts of Hebei Province under the Beijing-Tianjin-Hebei coordinated development strategy. Over the four years from 2014, the proportion of Hebei Province's GDP from the tertiary sector increased, and PM2.5 concentrations decreased between 2014 and 2017. However, Hebei Province still needs to accelerate economic growth to narrow the gap with Beijing and Tianjin. Deng et al. [25] combined panel data and spatial Durbin models to conclude that high-quality economic development in the Beijing-Tianjin-Hebei urban agglomeration exhibits significant urban disparities. Hebei Province's urban economic development lags far behind that of Beijing and Tianjin, and there are also significant differences among cities within Hebei Province. Collaborative innovation among cities in the Beijing-Tianjin-Hebei region can effectively enhance economic development both internally and in surrounding areas. Zhao et al. [26] studied the spatiotemporal development of Beijing-Tianjin-Hebei urban coupling and coordination using the importance method based on inter-indicator correlation criteria. Since 2000, economic development indicators have continued to grow, with growth in the four years following 2015 exceeding that of the initial five years by four times; however, the three factors of economy, ecology, and environment in Beijing-Tianjin-Hebei cities are not balanced. Huang and Liu [27] utilized a heterogeneous random frontier model to analyze the economic development of cities in the Beijing-Tianjin-Hebei region, finding that growth primarily stemmed from investment. Economic efficiency exhibited regional and municipal disparities, attributed to factors such as economic agglomeration, human capital structure, industrial structure, urban infrastructure, information technology levels, policy systems, economic openness, and government intervention. They recommended reducing government intervention, optimizing human capital structure, and improving infrastructure to achieve sustainable urban economic development. According to Huang et al. [28], factors such as prominence, urban Gini coefficient, population size, dispersion, and land input also influence the economic efficiency of cities in the Beijing-Tianjin-Hebei region. Jie et al. [29] pointed out that while the coordinated development of cities in the Beijing-Tianjin-Hebei region has shown a negative trend, this trend is gradually reversing. The issue of coordinated development between the economy and population is significant, and the mechanisms for coordinated development still need to be improved, with appropriate fiscal and tax coordination mechanisms to be established. Similarly, Yufeng [30] reported that population changes and economic growth in the Beijing-Tianjin-Hebei region are significantly out of sync, but this imbalance can be improved by optimizing the industrial structure in highly concentrated economic areas. Zhang et al. [31] noted under social network analysis that the tourism economy within the Beijing-Tianjin-Hebei urban agglomeration has been steadily improving and exhibits obvious spatial heterogeneity. With the support of information technology and tourism cooperation centers, the tourism economic development of Beijing, Tianjin, and Shijiazhuang will benefit surrounding cities.

In the aforementioned studies, most analyses are based on spatial panel data, and the spatial panel model is a model specifically designed for analyzing spatial panel data. Compared to general regression models and spatial regression models, it enhances the validity of parameter estimation, better integrates the spatio-temporal distribution characteristics of the research object, and identifies its influencing factors and patterns [32], [33]. Therefore, utilizing spatial panel models to explore the mechanisms of coordinated economic development in the Beijing-Tianjin-Hebei urban agglomeration, promoting regional economic development, achieving a complementary industrial structure, narrowing the economic gap among the three regions, and enhancing the overall regional competitiveness holds significant practical significance.

The study constructs an evaluation index system for the economic development of cities in the Beijing-Tianjin-Hebei region from five aspects: economic level, economic structure, economic driving force, economic efficiency, and infrastructure level. The entropy method is used to determine the weights of the indicators. Using panel data from the Beijing-Tianjin-Hebei region from 2015 to 2024 as the research object, the composite system coordination degree model is selected to analyze the trend of orderliness changes in the economic subsystems of Beijing, Tianjin, and Hebei, and to obtain the overall economic coordination degree results of the Beijing-Tianjin-Hebei region, thereby measuring its economic coordination level. Subsequently, using economic density, population density, transportation density, communication facilities, marketization, openness to the outside world, and government intervention as explanatory variables, and the economic coordination level of cities in the Beijing-Tianjin-Hebei region as the dependent variable, a spatial panel model is employed to explore the impact of each variable on the economic coordination of cities in the Beijing-Tianjin-Hebei region and to uncover the development mechanisms of economic coordination. Finally, the direction for high-quality economic coordination development in the Beijing-Tianjin-Hebei region is identified, aiming to provide insights for the economic coordination development of the region and serve as a reference for relevant departments in formulating policies.

II. Measurement and analysis of economic coordination among cities in the Beijing-Tianjin-Hebei region

II. A. Construction of the indicator system

II. A. 1) Selection of indicators

Referring to policy guidelines and existing research on indicator system design, and adhering to the main principles of indicator system construction, we ultimately selected 24 indicators from five aspects—economic level, economic structure, economic momentum, economic efficiency, and infrastructure level—to examine the economic development level of cities in the Beijing-Tianjin-Hebei region. The economic development level evaluation indicator system is shown in Table 1. The data for the Beijing-Tianjin-Hebei economic evaluation indicator system is sourced from the statistical yearbooks of the three regions.

Table 1: Economic development level evaluation index system

Primary indicator	Secondary indicator	Index unit
Economic level A1	Regional GDP B1	100 million yuan
	Per capita GDP B2	Yuan per person
	GDP growth B3	%
Economic structure A2	The added value of the second production industry accounts for the proportion of GDP B4	%
	The added value of the third industry for the proportion of GDP B5	%
	The proportion of workers in the second production industry B6	%
	The proportion of the third industry workers B7	%
	Urbanization rate B8	%
	Urban and rural income ratio B9	%
Economic power A3	The whole club will invest in fixed assets B10	100 million yuan
	Total import and export B11	$100 million
	Foreign direct investment B12	$100 million
	Total retail sales of consumer goods B13	100 million yuan
	Consumption level of urban residents B14	100 million yuan
	Consumption level of rural residents B15	100 million yuan
Economic benefit A4	Local revenue ratio B16	%
	The per capita disposable income of urban residents B17	Yuan per person
	The per capita disposable income of rural residents B18	Yuan per person
	Urban and rural savings deposits B19	Yuan per person
Infrastructure level A5	Road mileage B20	Square kilometer
	Total passenger volume B21	10,000 tons
	Total weight of transport B22	10,000 tons
	Amount of water B23	100 million cubic meters
	Power consumption B24	100 million kilowatt hour

II. A. 2) Indicator weights

Using the entropy method, the weights of the economic development assessment indicators for the Beijing-Tianjin-Hebei region were allocated. The weights of the economic development assessment indicators for cities in the Beijing-Tianjin-Hebei region are shown in Figure 1. The weights for economic level, economic structure, economic dynamism, economic efficiency, and infrastructure level are 0.102, 0.308, 0.190, 0.103, and 0.296, respectively. Among these, the economic structure and infrastructure level of Beijing-Tianjin-Hebei cities contribute the most to their economic development level.

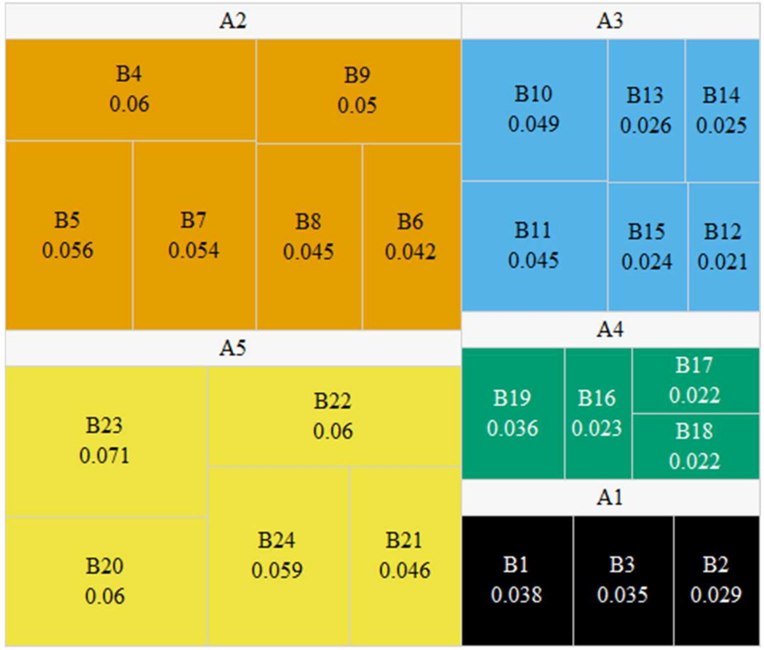

Figure 1: The weight of the evaluation index for urban economic development

II. B. Composite System Synergy Model

Currently, there is a significant disparity in the level of economic development between Hebei, Tianjin, and Beijing. At present, the coordination of economic development in the Beijing-Tianjin-Hebei region may be reflected in the convergence of the magnitude of changes in the development levels of the three economic subsystems of Beijing, Tianjin, and Hebei over time. Therefore, it is considered most appropriate to use the composite system coordination model to measure the current level of economic coordination in the Beijing-Tianjin-Hebei region.

By calculating the orderliness of the system and combining it with the principle of order parameters in synergetics, we can construct a composite system synergy model. In actual development, if the orderliness of some subsystems in a composite system improves relatively quickly, while the orderliness of other subsystems improves relatively slowly or does not improve at all, or even declines, then the overall synergy of the composite system is relatively poor. Based on the above approach, the synergy of a system can be quantified through the interaction between the rates of increase in the orderliness of each subsystem. Therefore, at the initial time t_0, the orderliness of each subsystem is denoted as $O_i^0(e_i)$, where $i=1,2,3,\ldots,k$. At time t_1 during the evolutionary process, the orderliness of each subsystem is $O_i^1(e_i)$ for $i=1,2,3,\ldots,k$. Let C denote the coordination degree of the composite system, then the coordination degree model of the composite system can be derived as follows:

$$C_1=\theta\sqrt{\left|\prod_{i=1}^{n}\left[O_i^1-O_i^0\right]\right|} \tag{1}$$

For C, $C\in[-1,1]$, and the larger the value of C, the better the coordination of the composite system. Among them,

$$\theta=\frac{\min\left[O_i^1-O_i^0\right]}{\left|\min\left[O_i^1-O_i^0\right]\right|},i=1,2,\ldots,n \tag{2}$$

For θ, simply put, θ is 1 only when all order increments within that time period are greater than 0. If there is a system with an order increment less than 0, then θ is -1. This indicates that we consider the system's coordination to be good only when all subsystems are in an upward state. If any subsystem's order increment is decreasing at this time, it indicates that the subsystem is becoming chaotic internally, and also that the overall coordination level of the system is relatively poor. It is also worth noting that, in the model, the measurement of subsystem order increments is based on data from the baseline period and the development period. Therefore, the level of coordination we obtain is relative to the baseline period.

II. C. Results of urban economic coordination

After calculating the weights of the economic evaluation indicators for the Beijing-Tianjin-Hebei region, this section employs a composite system synergy model to calculate the urban economic synergy levels of the Beijing-Tianjin-Hebei region from 2015 to 2024, with 2014 as the base year. The levels of synergy in a composite system are as follows: [-1, 0] indicates no synergy, (0, 0.3] indicates low synergy, (0.3, 0.7] indicates moderate synergy, (0.7, 1) indicates high synergy, and 1 indicates perfect synergy.

First, the economic coordination level of the Beijing-Tianjin-Hebei region was calculated. Based on the composite system coordination model, the entropy method was used to obtain the weights of each indicator and calculate the orderliness of the economic subsystems of Beijing, Tianjin, and Hebei. Finally, with 2014 as the base year, the measurement results of the economic coordination level of the three regions (composite system coordination) were obtained.

The trend in the orderliness of the economic systems of the three regions from 2015 to 2024 is shown in Figure 2. Overall, the orderliness of the three subsystems fluctuated between [0.228, 0.675]. The orderliness of the Beijing economic subsystem, Tianjin economic subsystem, and Hebei economic subsystem all showed a gradual improvement trend from 2015 to 2024. This may be attributed to the fact that, under the backdrop of the information age, the state has continuously introduced favorable policies, emerging industries have continued to develop, traditional industries have gradually transitioned toward digital enterprises, and local regions have enhanced their economies from their own perspectives in accordance with national policies, creating new economic growth points and promoting the continuous improvement and balance of various elements within their respective economic subsystems.

The orderliness of the subsystems is ranked as follows: Beijing Economic Subsystem > Tianjin Economic Subsystem > Hebei Economic Subsystem. This indicates that the Beijing Economic Subsystem plays a leading role within the Beijing-Tianjin-Hebei economic system. For the Tianjin economic subsystem, the overall increase is smaller than that of Beijing. The largest increase occurred between 2015 and 2017, with a total growth rate of 92.5% over four years. After 2017, the increase slowed down. Compared with Beijing, the gap in orderliness between the Tianjin economic subsystem and the Beijing economic subsystem continued to widen between 2020 and 2024. The Hebei economic subsystem is the weakest link in the Beijing-Tianjin-Hebei economic system, with its economic orderliness having been the lowest among the three subsystems over the past decade, and the gap with the Beijing economic subsystem continuing to widen.

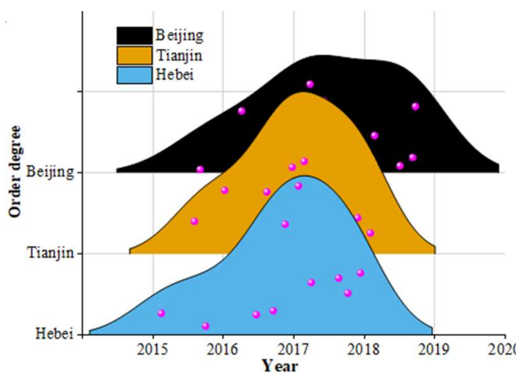

Figure 2: The trend of the economic system order degree of the three areas

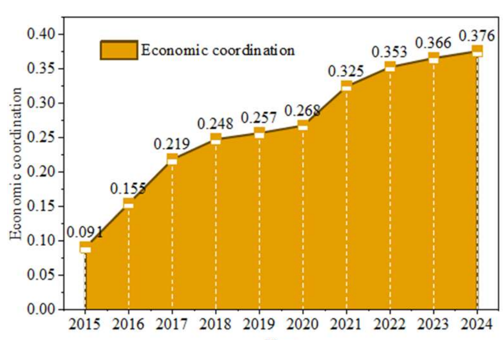

Figure 3: The coordination of economic systems in three regions

Finally, an analysis of the level of economic coordination among Beijing, Tianjin, and Hebei is conducted. The overall changes in the economic coordination level of the Beijing-Tianjin-Hebei region from 2015 to 2024 are shown in Figure 3.

Although the coordination level of the Beijing–Tianjin–Hebei economic system has been on the rise over the past decade, the overall coordination level has remained relatively low. From 2015 to 2020, the coordination index ranged between 0.091 and 0.268, below 0.3, indicating a state of low coordination. After 2020, the coordination level exceeded 0.3, reaching 0.376 by 2024. A coordination level within the range (0.3, 0.7] is classified as a general coordination state. Therefore, it can be observed that despite the continuous improvement in the economic coordination level of the Beijing–Tianjin–Hebei region in recent years, its coordination degree remains relatively low, and the development process is relatively slow.

III. Factors influencing the coordinated economic development of cities in the Beijing–Tianjin–Hebei region

III. A. Model Construction

III. A. 1) Spatial Panel Model

The generalized nested space panel data model is:

$$\begin{aligned} y_{it} &= \alpha y_{i,t-1} + \rho w_i' y_t + x_{it}' \beta + d_i' x_t \delta + u_i + \gamma_t + \varepsilon_{it} \\ \varepsilon_{it} &= \lambda m_i' \varepsilon_t + v_{it} \end{aligned} \tag{3}$$

In the equation, $i = 1, 2, \ldots, n$, $t = 1, 2, \ldots, T$, $y_{i,t-1}$ is the first-order lagged term of the explained variable y_{it}, and w_i' denotes the i th row of the spatial weight matrix W corresponding to the explained variable, then we have $w_i' y_t = \sum_{j=1}^{n} w_{ij} y_{jt}$, where $d_i' x_t \delta$ denotes the spatial lag term of the explanatory variable, and d_i' denotes the i th row of the spatial weight matrix corresponding to the explanatory variable, u_i and γ_t represent individual effects and time effects, respectively, ε_{it} and v_{it} are random disturbance terms that follow an independent and identically distributed distribution, and m_i' denotes the i th row of the spatial weight matrix corresponding to the random disturbance terms. By imposing restrictions on parameters such as $\alpha, \rho, \delta, \lambda$, different forms of spatial panel data models can be constructed.

When $\lambda = 0$ and $\delta = 0$, equation (3) simplifies to:

$$y_{it} = \alpha y_{i,t-1} + \rho w_i' y_t + x_{it}' \beta + u_i + \gamma_t + v_{it} \tag{4}$$

Equation (4) examines the spatial endogenous interaction effects of the explanatory variables in regions other than region i on the explanatory variables in region i. The model is referred to as a spatial autoregressive model (SAR). The above equation is a dynamic spatial autoregressive model. If $\alpha = 0$, it is converted to a static spatial autoregressive model. If u_i is correlated with x_{it}, it is a fixed effects model. If they are uncorrelated, it is a random effects model.

When $\alpha = 0$, $\rho = 0$ and $\delta = 0$, equation (3) simplifies to:

$$\begin{aligned} y_{it} &= x_{it}' \beta + u_i + \gamma_t + \varepsilon_{it} \\ \varepsilon_{it} &= \lambda m_i' \varepsilon_t + v_{it} \end{aligned} \tag{5}$$

Equation (5) examines the spatial interaction effects between random disturbance terms, and the model is referred to as a spatial error model (SEM). If u_i is correlated with x_{it}, it is a fixed effects model. If they are not correlated, it is a random effects model.

When only $\lambda = 0$, equation (3) simplifies to:

$$y_{it} = \alpha y_{i,t-1} + \rho w_i' y_t + x_{it}' \beta + d_i' x_t \delta + u_i + \gamma_t + v_{it} \tag{6}$$

Equation (6) above examines the endogenous interaction effects among the explained variables. Additionally, the explained variables in region i may also be influenced by both their own exogenous explanatory variables and the exogenous explanatory variables from other regions. Equation (3) simultaneously examines both endogenous and exogenous interaction effects, with the model referred to as the spatial Durbin model (SDM). If u_i is correlated with x_{it}, it is a fixed effects model. If they are uncorrelated, it is a random effects model.

In addition to the above three forms of spatial panel data models, other spatial mixed models such as spatial autocorrelation (SAC) can be obtained by imposing conditions on parameters. However, spatial autoregression, spatial error, spatial autocorrelation, and spatial Durbin models are currently the most widely used model forms in academic research on spatial effects. This paper also sets up spatial panel data models for the influence of various variables on the coordinated economic development of Beijing–Tianjin–Hebei cities based on these models.

III. A. 2) Data Model Settings

Establishing a spatial autoregressive model (SAR) to examine the endogenous interaction effects on the quality of economic development in Beijing-Tianjin-Hebei cities:

$$\begin{aligned}\ln Ec = \rho W \ln Qua_t + \beta_1 \ln X_{it} \\ + \beta_2 \ln Control_{it} + u_i + \gamma_t + v_{it}\end{aligned} \tag{7}$$

In the equation, i and t represent individuals and time, respectively. $\ln Ec$ is the dependent variable, representing the logarithm of the quality of economic synergy among cities in the Beijing-Tianjin-Hebei region. W is the spatial weight matrix, and $W \ln Qua_t$ is the spatial lag term for economic synergy among cities. ρ is the spatial autocorrelation coefficient, and $\ln X_{it}$ is the core explanatory variable. $Control_{it}$ denotes the control variables, β denotes the coefficients of the explanatory variables, u_i and γ_t denote the individual effects and time effects, respectively, and ε_{it} denotes the random disturbance term that follows an independent and identically distributed (i.i.d.) distribution.

When all the spatial term coefficients in the generalized nested spatial panel data model are zero, the classical OLS regression model is obtained:

$$\ln Ec = \beta_0 + \beta_1 \ln X_{it} + \beta_2 \ln Control_{it} + u_i + \gamma_t + v_{it} \tag{8}$$

The parameters in the formula have the same meanings as in the preceding text.

III. B. Variable Selection

(1) Dependent variable (Ec): Economic coordination among cities in the Beijing-Tianjin-Hebei region, measured using the composite system coordination model in the previous section.

(2) Explanatory variables: Economic density (Ecd), population density (Pod), transportation density (Road), telecommunications infrastructure (Tel), marketization (Mkd), openness to the outside world (Open), and government intervention (Lngov). These are measured using GDP/land area, permanent resident population at year-end/land area, highway mileage/permanent resident population at year-end, total postal and telecommunications services/highway mileage, total imports and exports/GDP, and the logarithm of the ratio of government fiscal expenditure to GDP.

(3) Control variables: Foreign direct investment (FDI), regional economic development level (Lnpgdp), year (Year), and city (City). Foreign direct investment and regional economic development level are measured using foreign direct investment/GDP and the logarithm of per capita GDP, respectively.

Based on the availability and validity of statistical data, this study selects cities in the Beijing-Tianjin-Hebei region as the sample observation objects. The time range for each sample is 2015–2024, and the statistical data from key economic indicators are organized into panel data for analysis. The selected variables draw their raw data from the statistical yearbooks of Beijing, Tianjin, and Hebei provinces, as well as the China Urban Statistical Yearbook, covering cities such as Beijing, Tianjin, Shijiazhuang, Tangshan, Qinhuangdao, Handan, Xingtai, Baoding, Zhangjiakou, Chengde, Cangzhou, Langfang, and Hengshui.

III. C. Analysis of empirical results

III. C. 1) Regression Results Analysis

Using the Panel Corrected Standard Error (PCSE) method, a regression analysis was conducted to examine the factors influencing the economic synergy development of cities in the Beijing-Tianjin-Hebei region. The regression results of the model are presented in Table 2. Model (1) represents the OLS model regression results, while Model (2) employs the PCSE method, which accounts for heteroskedasticity and autocorrelation across groups, resulting in a robust estimation. Additionally, since the Moran's I indices for the coordinated economic development of cities in the Beijing-Tianjin-Hebei region are all non-zero, this indicates that there is spatial correlation in economic coordination. Traditional regression analysis may overlook the influence of spatial effects, leading to biases in the model's interpretation. Therefore, in addition to conducting a general panel model regression on the factors influencing the economic synergy development of cities in the Beijing-Tianjin-Hebei region, this paper also estimated the aforementioned panel SAR model, with the results shown in Models (3) and (4). Model (4) includes additional control variables compared to Model (3). A Hausman test was conducted prior to all model regressions, and the results rejected the null hypothesis of random effects, indicating that these four models should be estimated using a fixed-effects model. The second column shows the t-statistics adjusted for heteroskedasticity-robust standard errors, where ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

The regression coefficients for Models (1) and (2) are nearly identical, with the difference lying in the t-statistics. The results of Models (3) and (4) show that the spatial autoregressive coefficients are positive but fail to pass the significance level test, indicating that there is a positive spatial spillover effect on economic coordination among cities in the Beijing-Tianjin-Hebei region, but the economic coordination between cities has limited mutual influence, with small spillover effects. Based on the robustness of the regression results, this paper primarily uses Model (4) for analysis, with other regression results serving as references.

The improvement in economic density and communication infrastructure in Beijing-Tianjin-Hebei cities has a promotional effect on their collaborative development in economic terms, but it is not statistically significant ($p > 0.1$). The improvement in population density and transportation density has a significant inhibitory effect on the economic collaborative development of Beijing-Tianjin-Hebei cities. Holding other factors constant, an increase of 1 unit in population density and transportation density reduces the degree of economic collaborative development by 0.412 and 0.011 units, respectively. Increases in marketization, openness to the outside world, and government intervention significantly promote the degree of coordinated economic development among cities in the Beijing-Tianjin-Hebei region. Holding other conditions constant, each increase of 1 unit in these factors increases the degree of economic coordination by 0.230, 0.034, and 0.085 units, respectively.

Based on the regression results of the controlled variables, the level of regional economic development has a significant positive impact on the degree of economic synergy among cities in the Beijing-Tianjin-Hebei region, while foreign direct investment also promotes synergy in economic terms.

Table 2: Regression result of model

	(1)OLS FE	(2)PCSE FE	(3)SAR FE	(3)SAR FE
Ecd	0.000621	0.000621	0.000275	0.000562
	0.701	0.528	0.204	0.456
Pod	-0.411**	-0.411**	-0.236	-0.412**
	-3.292	0.518	-1.325	-2.362
Road	-0.012***	-0.012***	-0.006**	-0.011**
	-6.332	-5.676	-2.632	-3.675
Tel	0.030***	0.030***	0.025	0.029
	3.475	1.189	1.331	1.264
Mkd	0.252***	0.252*	0.261**	0.230*
	3.521	1.675	2.329	1.583
Open	0.036***	0.037*	0.003	0.034*
	3.288	1.509	0.072	1.548
Lngov	0.084**	0.084**	0.105***	0.085**
	2.323	2.462	2.579	2.647
Fdi	0.265*	0.265*		0.264
	2.488	1.574		1.511
Lnpgdp	0.063***	0.063***		0.069***
	4.301	3.589		3.285
Constant	-0.575**	-0.631**		
	-3.129	-2.334		
Spatial			0.067	0.039
			0.819	0.486
N	13	13	13	13

III. C. 2) Results of spatial effect decomposition

According to the relevant theories of spatial econometrics, the regression coefficients of spatial panel models do not adequately reflect the specific effects of independent variables on dependent variables. Therefore, it is necessary to use the theory of spatial effect decomposition to reflect their impact. This paper conducts a spatial effect decomposition of the SAR model, and the results of the spatial effect decomposition of the SAR model are shown in Table 3. Economic density factors have a positive effect on the economic synergy development of both the host city and neighboring cities in the Beijing-Tianjin-Hebei region, but these effects did not pass the significance level test and the results were not significant ($p > 0.1$). The direct effect coefficients for population density and transportation density are -0.423 and -0.012, respectively, and they passed the 5% significance level test, indicating that increases in population density and transportation density have an inhibitory effect on the economic synergy development of cities in the Beijing-Tianjin-Hebei region. Factors such as marketization level, openness level, government intervention, and regional economic development level all have significant direct effects on the economic synergy of cities in the Beijing-Tianjin-Hebei region, but their spillover effects are not significant. Communication factors and foreign direct investment have positive effects on the economic synergy of cities in the Beijing-Tianjin-Hebei region, but neither passed the significance level test.

Table 3: The decomposition result of the SAR model space effect

	Direct effect	Overflow effect	Total effect
Ecd	0.000629	0.000015	0.000644
	0.531	0.103	0.494
Pod	-0.423**	-0.203	-0.626**
	-2.472	-0.421	-2.189
Road	-0.012***	-0.001	-0.013***
	-3.379	-0.683	-2.168
Tel	0.029	0.002	0.031
	1.306	0.325	1.248
Mkd	0.224**	0.011	0.235**
	2.499	0.498	2.237
Open	0.036*	0.002	0.038*
	1.151	0.152	1.449
Lngov	0.082**	0.004	0.086**
	2.656	0.504	2.321
Fdi	0.305	0.012	0.317
	1.668	0.407	1.686
Lnpgdp	0.068***	0.003	0.071***
	3.164	0.501	0.281

IV. Pathways for coordinated economic development among cities in the Beijing-Tianjin-Hebei region

This chapter proposes a path for the coordinated development of the Beijing-Tianjin-Hebei urban economy based on an analysis of its current level of coordination and its influencing factors. To achieve coordinated development in the Beijing-Tianjin-Hebei region despite economic disparities, the Beijing-Tianjin-Hebei urban agglomeration must leverage its comparative advantages, define its functional roles, establish industrial chains, strengthen inter-regional collaboration, and create a platform for resource sharing and a complete industrial chain. Elements should flow freely among cities according to market principles, enabling complementary functional advantages, equal cooperation, and coordinated development among cities, thereby reducing disparities both between and within regions.

IV. A. Leveraging the diffusion effect of core cities

First, leverage the spillover effects of core cities to reduce disparities between regions. Currently, the disparities between regions in the Beijing-Tianjin-Hebei area primarily stem from the fact that the “siphon effect” of core cities far outweighs the “trickle-down effect.” The key to the coordinated development of the Beijing-Tianjin-Hebei region should still be focused on relieving Beijing of its non-capital functions, while reasonably aligning and absorbing the socioeconomic development levels and existing resource and capital reserves of other cities. This involves identifying key areas of collaboration and leverage points, uncovering economic growth opportunities, and fostering positive interaction between cities while promoting the sustainable development of secondary cities. The radiating role of core cities should be fully leveraged, with a tiered approach to radiation. For example, Beijing's radiation scope should cover the entire Beijing-Tianjin-Hebei region, while Tianjin and Shijiazhuang's radiation scope should encompass the entire Hebei Province. The radiation of the five major regions should be advanced in a tiered manner, achieving diffusion and radiation from top to bottom to effectively integrate regional resources. Strengthening economic cooperation between different regions should aim for complementary advantages and resource sharing, ensuring the effective transfer of capital and productive forces to minimize economic development gaps between regions.

IV. B. Clarify the city's development positioning

Second, clarify the development positioning of cities and reduce disparities within the region. The disparities among cities within the Beijing-Tianjin-Hebei region are primarily due to local conditions and development philosophies. Enhancing complementarity and coordination among cities within the region is the primary means of achieving integrated development.

To address the differences among cities within the region, efforts should be made to strengthen economic ties between cities and explore regional industrial potential, identify gaps, and enhance coordination. This will facilitate a transition from industrial homogeneity to industrial specialization and complementary industrial support systems, forming highly compatible industrial chains. This approach aims to achieve a new situation where stronger regions support weaker ones, wealthier regions assist poorer ones, and more developed areas lead less developed areas, thereby narrowing economic disparities.

IV. C. Strengthening organizational coordination

Third, strengthen organizational coordination and achieve integrated reform of supporting systems. The government should give full play to its guiding and coordinating functions to change the current situation of inconsistent policies in transportation, energy, trade, industry, investment, education, and taxation in the Beijing-Tianjin-Hebei region. First, take transportation integration as the foundation to create modern and convenient travel conditions throughout the region. Second, try to implement a pilot project for integrated household registration in the Beijing-Tianjin-Hebei region to change the current urban-rural dual structure. Third, establish a resource compensation mechanism for the Beijing-Tianjin-Hebei region based on the establishment of a joint development and interest compensation fund. Fourth, establish a regional education and research management system to achieve technical-economic integration and education-research integration. Fifth, establish and improve intergovernmental coordination mechanisms, such as setting up authoritative arbitration institutions, to quickly resolve disputes, reduce conflicts and friction, strengthen exchanges and cooperation, and achieve mutual benefit and win-win outcomes.

IV. D. Breaking down administrative barriers

Fourth, break down administrative barriers and reduce obstacles to the flow of various factors. To promote coordinated economic development in the Beijing-Tianjin-Hebei region, it is necessary to combine the roles of government leadership and market entities. Within the framework of government top-level design, administrative barriers should be broken down to fully leverage market coordination in resource allocation, thereby achieving the free flow of various factors within the market. The human resources market and the financial market play a significant role in promoting the coordinated development of the Beijing-Tianjin-Hebei region. Building an integrated human resources system is a key node in the regional integration of the Beijing-Tianjin-Hebei region. We should gradually form a new development pattern for talent where there is free flow of talent, resource sharing, and win-win cooperation among different regions. Strengthening financial integration and promoting capital flow are the driving forces behind the coordinated development of the Beijing-Tianjin-Hebei region. First, financial innovation should be promoted across the region to leverage synergies between different regions. Second, a financial information sharing platform should be established to achieve complementary advantages between different regions. Finally, financial collaboration and cooperation should be actively promoted to establish an orderly, integrated, and complementary financial resource allocation system.

V. Conclusion

This paper employs a composite system synergy model to measure the level of economic synergy among cities in the Beijing-Tianjin-Hebei region. To investigate the mechanisms underlying economic synergy in the region, a spatial panel model is used to explore the factors influencing the coordinated development of urban economies in the Beijing-Tianjin-Hebei region. Finally, pathways for their economic synergy are proposed. The main conclusions are as follows:

(1) From 2015 to 2024, the economic development levels of cities in the Beijing-Tianjin-Hebei region showed an upward trend. The orderliness of the economic subsystems in the three regions ranged from [0.228, 0.675]. Among them, Beijing and Tianjin led in terms of the comprehensive level and growth rate of economic development quality, while cities in Hebei Province exhibited significant differences.

(2) The economic coordination level of cities in the Beijing-Tianjin-Hebei region from 2015 to 2024 was between 0.091 and 0.376, indicating a relatively low overall economic coordination level. Specifically, the coordination level from 2015 to 2020 was below 0.3, representing a low coordination level, while the coordination level from 2021 to 2024 was below 0.7, indicating a general coordination state. This indicates that despite the elevation of Beijing-Tianjin-Hebei regional coordination to a national strategy, the three regions have not yet achieved true economic coordination, and there remains significant room for improvement in the economic coordination of the Beijing-Tianjin-Hebei region.

(3) Factors such as marketization level, openness to the outside world, government intervention, and regional economic development level all have a positive impact on the economic coordination of cities in the Beijing-Tianjin-Hebei region. However, increases in population density and transportation density do not enhance economic coordination, with direct effect coefficients of -0.423 and -0.012, respectively. Economic density, communication infrastructure, and foreign direct investment also positively influence the economic coordination of cities in the Beijing-Tianjin-Hebei region, but these effects are not statistically significant ($p > 0.1$).

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