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Environmental Protection, Industrial Structure and Urbanization: Spatiotemporal Evidence from Beijing–Tianjin–Hebei, China

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Abstract: The Beijing–Tianjin–Hebei urban agglomeration (BTH) is striving to realize the transformation process from a low-efficiency to a high-quality development mode; however, it still has problems regarding reducing energy consumption and ecological environment pressure. Based on panel data from 2013 to 2017, this paper proposes an evaluation index system based on BTH's "environmental protection–industrial structure–urbanization" system. In the course of applying the coupling degree model (CDM) and the coupling coordination degree model (CCDM) with exploratory spatial data analysis (ESDA) methods, this paper discusses the spatiotemporal process, development level, and spatial agglomeration characteristics of the environmental protection–industrial structure–urbanization system in each city of the BTH area. The findings reveal that the coupling degree of the BTH system is gradually increasing, and that the development level of the BTH subsystem is unbalanced: the coupling coordination level of BTH shows a positive evolution process; however, it is in a stage of low-level collaborative development, and there are obvious differences in the level of BTH coupling coordination in space, revealing the convergence of low–high and high–low types. This paper concludes by putting forward the strategy of optimizing the regional spatial pattern of urban agglomeration and implementing integrated development in order to achieve the desired coupling and coordination effects.

Keywords: environmental protection; industrial structure; urbanization; coordinated development; BTH

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1. Introduction

In recent years, changes in global industrial structure and the acceleration of factor flow have led to continuous improvements in the world's urbanization level [1,2]. Meanwhile, environmental problems such as energy consumption and particulate air pollution caused by population agglomeration have had a significant impact on the world's sustainable development [3,4]. According to a report released by the Global Environment Facility (GET) in 2019, modern cities create 80% of the world's GDP while consuming more than 75% of the world's energy, and generate 70% of all greenhouse gas emissions. Countries around the world are promoting regional environmental improvement by reducing carbon emissions and encouraging technological innovation in renewable energy [5,6], as well as by reversing the trend of environmental deterioration and developing industries with low energy consumption and high added value. In the research on environmental protection and sustainable development goals (SDGs), environmental protection needs to be considered simultaneously with urbanization and industrial structure; however, relevant research is usually conducted from the perspective of the relationship between two issues [7,8], such as environmental quality and urban spatial structure [9–11], eco-environmental benefits and industrial structure [12–14], energy supply and urban security [15], cleaner production and green cities [4], urban residential consumption and carbon emissions reduction [16,17], or environmental improvement and urban and the health of rural resident [18–20]; such comparisons cannot accurately reveal the whole picture, making it difficult to guide the coordinated development of specific regional systems. The existing research results lack discussion of the relationship between the three subsystems. Furthermore, COVID-19 has had a direct impact on life and well-being as well as a long-term impact on the environmental protection–industrial structure–urbanization system. The relationship between environmental protection, industrial structure, and urbanization will continue to be an issue of great concern for future economic growth.

In China, the environmental protection action and SDGs promised by the Chinese government in the United Nations Framework Convention on Climate Change (UNFCCC) in 2015 are extremely challenging to deliver [21], because Chinese cities were formed against the backdrop of priority being given to industrial development in the early stages, while the resource-endowment conditions of different cities are heterogeneous. China has taken the inefficient economic growth development path of "pollution first, then treatment". Considering the sustainable development of the human and ecological environment, China has begun to change the pace and direction of economic development and promote the high-quality development mode of low pollution and low energy consumption [22,23]. In fact, China is the country with the largest contribution to carbon emissions reduction in the world. According to a report of the Ministry of Ecology and Environmental Protection of China (MEEPC), as of the end of 2019, China's carbon intensity had been reduced by about 48.1% compared with 2005, and China's foreign exchange had been completed ahead of schedule in relation to the promised targets in 2020. This is closely related to the environmental linkage governance policy and institutional collective action proposed by China [24,25], and is closely related to the transformation and upgrading of industrial structure [26,27]. The Beijing–Tianjin–Hebei urban agglomeration (BTH) is a typical area for environmental pollution control in China, especially joint prevention and control for air pollution [25,28], and is a showcase to promote urbanization development processes and industrial structure transfer [29]. In this study, BTH is taken as the research area to evaluate and analyze the relationship between environmental protection, industrial structure, and urbanization systems.

Therefore, the main goal of this paper is as follows. From the perspective of system coupling and exploratory spatial data analysis, it reveals the temporal evolution and spatial relationship of the three subsystems in each city in BTH; it subsequently proposes a strategy to optimize the regional pattern and integrated development of urban agglomerations in order to reduce the pressure on resources and on the ecological environment. The structure of this paper is arranged as follows. Section 2 provides details of the research area and the evaluation index system; Section 3 provides details of the research methodology and data sources; Section 4 presents the findings based on the coupling degree model (CDM) and the spatial correlation analysis model; and the findings and their causes are further analyzed in Section 5. The paper concludes with Section 6, which further emphasizes and summarizes the contributions of this research.

2. Research Area and Evaluation Index System

2.1. BTH

To date, many studies have shown that the polycentric structure of regional space can inhibit environmental pollution [10,30]. In particular, cities with a high population density can improve the environmental quality by reducing their polycentric structure [9,31]. Therefore, this paper takes multi-center urban agglomeration as the research object. BTH is one of the three economically developed core areas in China [32]. In 2018, the permanent resident population of BTH reached 112.701 million, accounting for 8.08% of the total population of China, and the number of migrant workers employed in BTH reached 21.88 million. Beijing (BJ), Tianjin (TJ), Baoding (BD) and Langfang (LF) are the core functional areas in BTH. Among them, Beijing's economic development and urbanization rate is the highest, followed by Tianjin. Compared with the first two cities, all other cities in Hebei Province have much lower rates (see Figure 1).

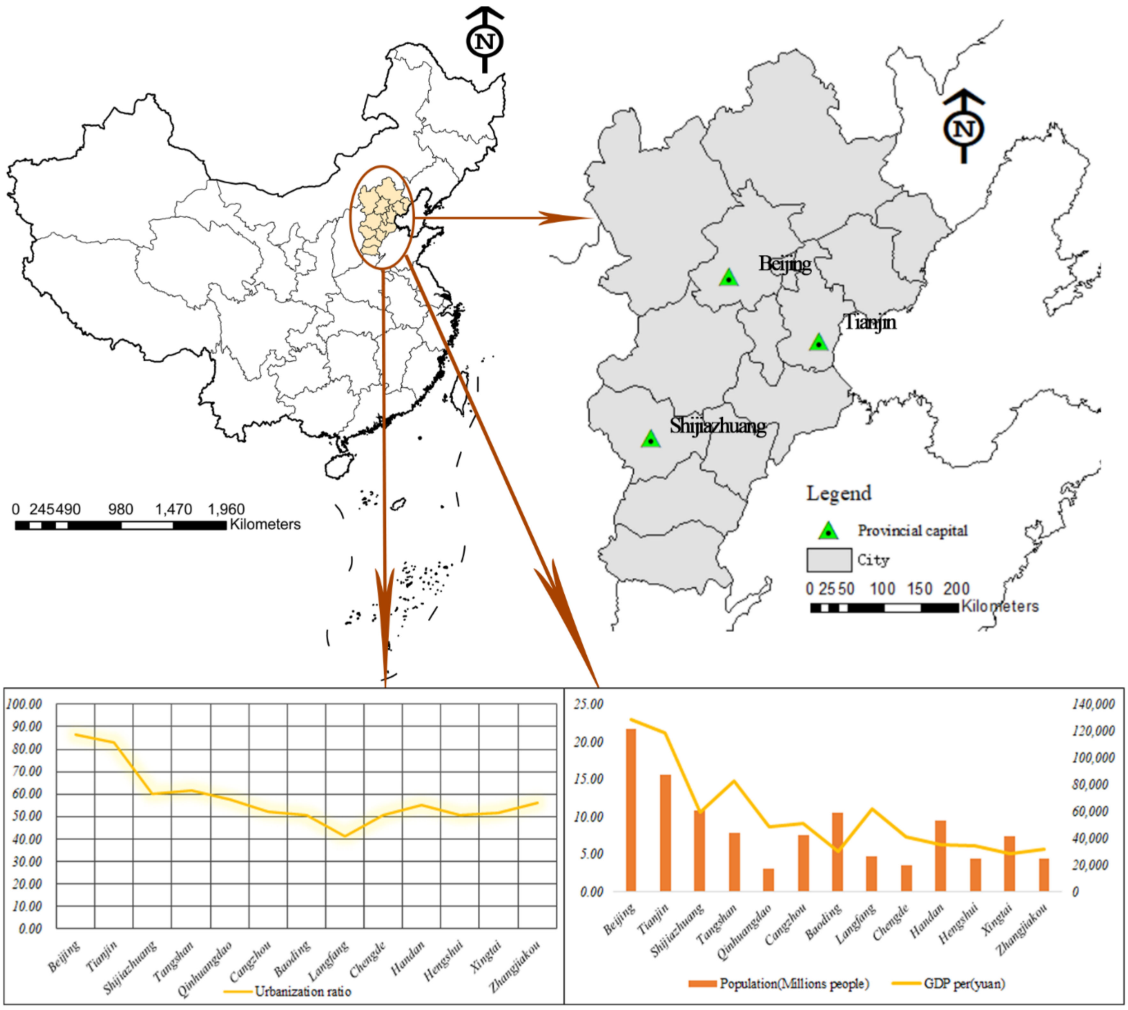

Figure 1. Spatial distribution of BTH.

BTH is the research area of this study for the following reasons. In the environmental reports of 74 cities in China issued by MEEPC in 2013, the air quality of all cities in BTH exceeded the recommended value [33], and the correlation between environmental pollution and economic growth is particularly prominent. In addition, there are regional imbalances in BTH in both industrial structure and urbanization [34], which entails huge constraints and obstacles to the synergy effect and healthy development of the system [20,35]. However, since the Chinese government issued the Beijing–Tianjin–Hebei Coordinated Development Strategy in 2015, the BTH regional coordinated development index increased from 100 in 2010 to 160.13 in 2018, and regional coordinated development achieved remarkable results (NBS, 2019), especially regarding the acceleration of the urbanization process. BTH environmental pollution control and ecological protection continue to increase, urban and rural environmental infrastructure construction has accelerated, and the urban and rural living environment is improving day by day (NBS, 2019). In 2018, the average concentration of PM2.5 (fine particulates with diameters of less than 2.5 μm) in the BTH area decreased by 48% from 2013 (MEEPC, 2019), making it the area with the fastest decline rate among the three major urban agglomerations in China; therefore, it can better represent and reflect the relationship among environmental protection, urbanization, and industrial structure in China.

2.2. The Evaluation Index System

The index system established in this paper is based on analyzing the coupling development and evolution of BTH's environmental protection–industrial structure–urbanization system over time and comparing the differences in regional urban development from the spatial perspective. Referring to the literature pertaining to industrial structure, environmental protection, and urbanization systems, 199 indicators [23,36–39] were found; subsequently, based on the relative importance of the indicators, the top 25 indicators were selected (see Table 1). The environmental protection subsystem is characterized by environmental pollution and governance, the industrial structure subsystem is characterized by industrial output value and employment structure, and the urbanization subsystem is characterized by population, economic, and social urbanization.

Table 1. Evaluation index system and index weight of BTH.

System	Subsystem	Evaluation Indicators	Unit	Weight	Attribute
Environmental protection	Environmental pollution	Industrial wastewater discharge	10,000 t	0.1338	−
		Industrial sulfur dioxide production	Tons	0.0442	−
		Industrial solid waste production	10,000 t	0.0398	−
	Environmental governance	Per capita water resources	M3/person	0.3874	+
		Green coverage rate of built-up area	%	0.0308	+
		Park area per capita in urban areas	M2/person	0.1437	+
		Comprehensive utilization rate of industrial solid waste	%	0.1038	+
		Sewage treatment rate	%	0.0603	+
		Harmless treatment rate of domestic garbage	%	0.0564	+
Industrial structure	Structure of industrial output value	Proportion of primary industry output value in GDP	%	0.1618	−
		Proportion of secondary industry output value in GDP	%	0.0563	+
		Proportion of tertiary industry output value in GDP	%	0.2149	+
	Industrial employment structure	Proportion of employees in primary industry	%	0.1767	−
		Proportion of employees in the secondary industry	%	0.0658	+
		Proportion of employees in tertiary industry	%	0.3244	+
Urbanization	Population urbanization	Population density	Person/km^2	0.0792	+
		Population urbanization rate	%	0.0572	+
	Economic urbanization	Per capita GDP	Yuan	0.11335	+
		Per capita retail sales of consumer goods	Yuan	0.1227	+
		Per capita social fixed asset investment	Yuan	0.0814	+
		Per capita disposable income of urban residents	Yuan	0.1132	+
	Social urbanization	Number of college students per 10,000	Person	0.1353	+
		Number of beds in medical and health institutions per 10,000 people	Bed	0.0124	+
		Number of buses per 10,000 people	Vehicle	0.1864	+
		Per capita urban road area	M2/person	0.0787	+

In view of the differences between the data, it is important to objectively weight the evaluation index to ensure the validity of the evaluation results. In this paper, the standardized method is used for dimensionless processing [20], and the entropy method [39], which is an objective weighting method, is used to determine the weight coefficient through the difference between indicators and overcome the subjective evaluation of multiple indicators caused by human factors.

3. Methodology and Data Sources

3.1. Methodology

3.1.1. CDM

The coupling degree is a physics concept. The mathematical model of the coupling degree among the three subsystems was used to construct and calculate the development of the environmental protection–industrial structure–urbanization coupling system [40,41], as follows:

$$C = \left\{ \frac{f(x)\cdot g(y)\cdot h(z)}{\left(\frac{f(x)+g(y)+h(z)}{3}\right)^3} \right\}^{\frac{1}{3}} \quad (1)$$

Here, C is the degree of coupling, C ϵ [0, 1]; the closer the C value is to 1, the better the coupling state of the three systems, while the smaller the coupling degree value is, the lower the system's degree of coordination; f(x), g(y), and h(z) are the degree of development of the industrial structure subsystem, the environmental protection subsystem, and the urbanization subsystem, respectively.

3.1.2. CCDM

The CDM describes the degree of coordination among the three subsystems of environmental protection, industrial structure, and urbanization; it is significant in relation to constraining the development of environmental protection, industrial structure, and urbanization to promote the coordinated development of the three systems. However, because there may be development gaps in coordinated regions, the degree of coupling cannot describe the differences in development between regions and cannot reflect the degree of coordinated development among the three systems. Therefore, a model of the CCDM is constructed:

$$D = \sqrt{CT} \quad (2)$$

$$T = \alpha f(x) + \beta g(y) + \gamma h(z) \quad (3)$$

Here, D is the degree of coupling coordination, C is the degree of coupling, T is the development degree of the system, and α, β, and γ are the weight values of the industrial structure, environmental protection, and urbanization subsystems, respectively. The CCDM not only describes the degree of coupling coordination among the three subsystems of industrial structure, environmental protection, and urbanization, it characterizes the degree of development of the three systems as well.

3.1.3. Moran's I Index

Unlike traditional econometric statistics, spatial autocorrelation analysis is mainly used to explore the spatial distribution of data, and the analysis results depend on the spatial distribution of data. Spatial autocorrelation can be understood as similar variable attributes and values in areas with similar locations. For high–high and low–low clusters, it is called "positive spatial autocorrelation." For high–low clusters, it is called "negative spatial autocorrelation," and if the distribution of high and low values is irregular and completely random, there is no spatial autocorrelation:

$$I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i - \overline{x})(x_j - \overline{x})}{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i - \overline{x})^2} \quad (4)$$

Here, w_{ij} is the spatial weight matrix, which is used to measure the distance between region i and region j. The global Moran's I examines the agglomeration of the entire spatial sequence. Moran's I value is between −1 and 1, with $I > 0$ signifying positive spatial autocorrelation and $I < 0$ signifying negative spatial autocorrelation. The closer the I value is to 0, the more the spatial distribution is random, with no spatial autocorrelation.

3.2. Data Sources

In order to gain a deeper understanding of the evolution trend of the coordination degree of the BTH environmental protection–industrial structure–urbanization coupling system, this paper regards the BTH cities as a region, and constructs a three-dimensional panel data set including city, time, and indicators. Taking into account the timeliness and availability of data, the data in this article mainly come from the Statistical Yearbooks from 2014 to 2018 for Beijing (BJ), Tianjin (TJ), Shijiazhuang (SJZ), Tangshan (TS), Qinhuangdao (QHD), Cangzhou (CZ), Chengde (CD), Handan (HD), Hengshui (HS), Xingtai (XT), and Zhangjiakou (ZJK); the Economics Statistical Yearbooks for Baoding (BD), Langfang (LF), and ZJK; the National Economic and Social Development Statistical Bulletins from 2013 to 2017 for BJ, TJ, and Hebei Province; the Solid Waste Environmental Prevention and Control Information Announcements; and the China Urban Construction Statistical Yearbooks from 2013 to 2017. Where data for a specific year or a single indicator were missing, interpolation was used to supplement the missing data.

4. Results

4.1. Coupling Degree of the "Environmental Protection–Industrial Structure–Urbanization" System in BTH

Based on the BTH environmental protection, industrial structure and urbanization subsystem development measurements, the CDM was used to measure the coupling degree of the overall system. Figure 2 describes the coupling degree of the three subsystems of BTH cities at different development stages. The greater the connection coordination degree value, the higher the system coordination degree.

As shown in Figure 2, the coupling degree of the BTH environmental protection–industrial structure–urbanization system has gradually evolved in an orderly direction from 2013 to 2017. The coupling degree of the whole BTH system was consistent with the development trends of the industrial structure subsystem and the urbanization subsystem, basically maintaining an orderly growth. Considering the development differences for the different coupling degrees of cities, it can be seen that the coupling development differences among regions are large. The average coupling degree of the environmental protection–industrial structure–urbanization system in BJ, TJ, and SJZ was higher than 0.97, and for XT, BD, HS, CD, and CZ it was lower than 0.87, while for TS, QHD, HD, ZJK, and TS it remained unchanged.

Therefore, we chose the core cities of BJ and TJ, SJZ (the capital city of Hebei Province located in the south of BTH), ZJK (the middle coupling degree and close to BJ and TJ), and XT (the relatively low coupling degree) for further analysis.

4.1.1. Beijing (BJ)

From 2013 to 2017, the coupling degree of BJ's overall system was consistent with the development trend of the industrial structure subsystem and the urbanization subsystem, maintaining basically orderly growth. The development degree of BJ's environmental protection subsystem was unstable from 2013 to 2017, and the industrial structure development degree was above 0.8. The development degree of the urbanization subsystem was lower than that of other subsystems, although it remained on an upward trend.

According to observational data, the added value of the tertiary industry in BJ in 2017 accounted for 80.6% of GDP (the proportion of employees in the tertiary industry was 80.6%; these two figures have been increasing over time) and the industrial structure system maintained a good development trend. The development of BJ's urbanization subsystem increased, with a growth rate of about 7%. BJ's per capita GDP reached CNY 128,994, per capita retail sales of consumer goods reached CNY 53,325.65, per capita social fixed asset investment was CNY 41,222.18, and annual per capita disposable income of urban residents in 2017 was CNY 62,406, about twice the average disposable income in Hebei. As a result, the level of economic urbanization continued to increase. In addition, BJ's healthcare and education spending reached a leading level. BJ's environmental protection–industrial structure–urbanization coupling degree has to a large extent developed steadily based on the improvement of the development degree of the industrial structure subsystem and the urbanization subsystem.

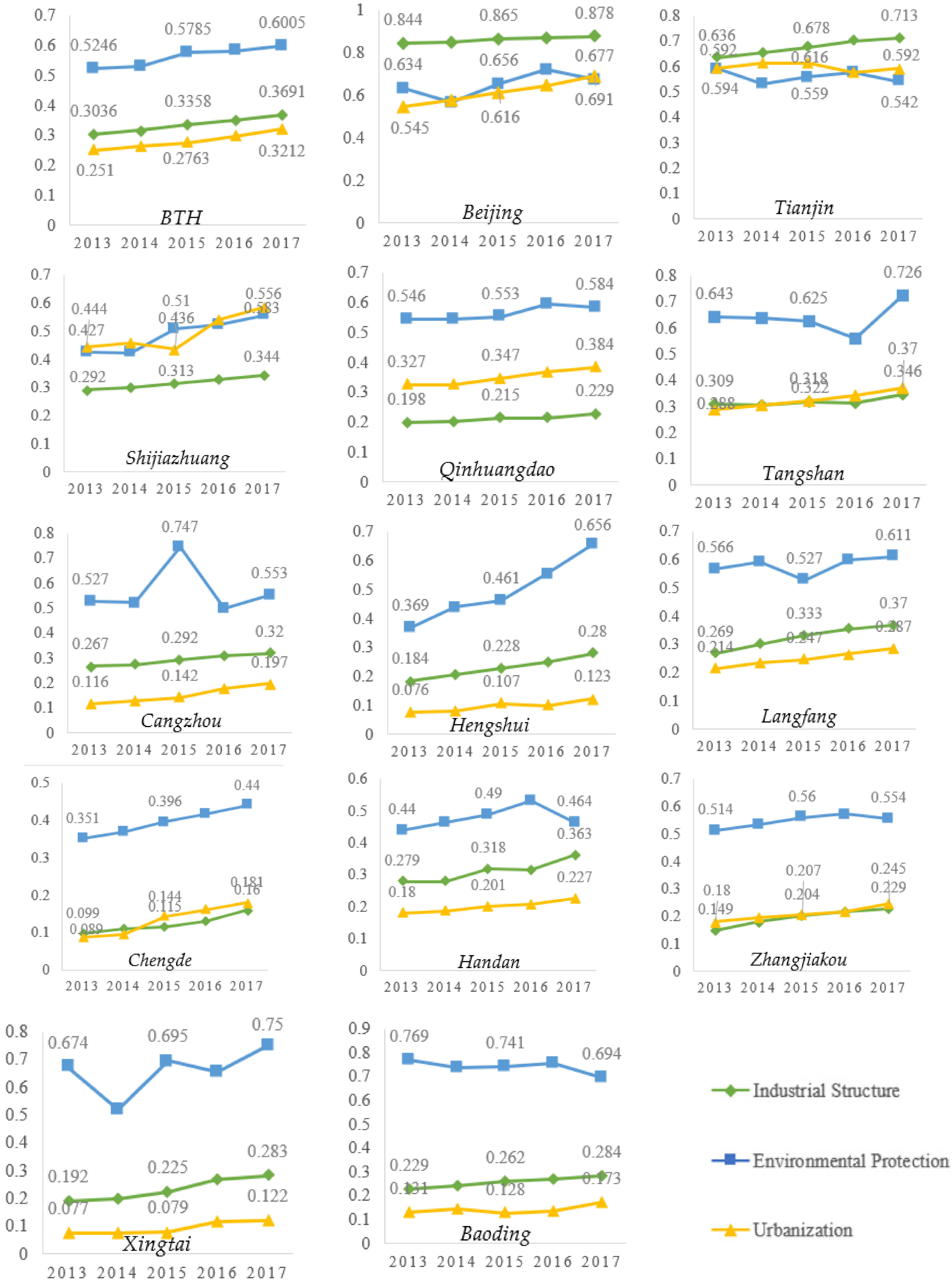

Figure 2. Environmental protection–industrial structure–urbanization system coupling degree (2013–2017).

4.1.2. Tianjin (TJ)

Although the coupling degree of TJ's environmental protection–industrial structure–urbanization system declined from 2013 to 2017, the decline was small and generally stable. The value of the system's coupling degree was above 0.97. The development degree of TJ's environmental protection subsystem and urbanization subsystem fluctuated between 2013 and 2017; the fluctuation range was not large, and the development degree of the industrial structure subsystem rose. Comparing the development degree of the three subsystems of industrial structure, environmental protection, and urbanization, they were all between 0.4 and 0.7. The stable growth of these systems guaranteed the stability of the overall system coupling degree of TJ.

From the comparison of the evolution trend of the system's coupling degree, TJ was the city with the smallest difference in the development degree of environmental protection, industrial structure, and urbanization subsystems among all cities, and the development of the three systems was stable at a relatively high level. The added value of the tertiary industry in TJ accounted for 58.2% of GDP. In terms of environmental protection, the comprehensive utilization rate of general industrial solid waste reached 98.93%, and the sewage treatment rate and the harmless treatment rate of domestic garbage reached 92.5% and 96%, respectively. In the chemical subsystem, the number of college students per 10,000 people was about 330, and the number of beds in medical and health institutions per 10,000 people was about 43.8, which represents a relatively high level.

4.1.3. Shijiazhuang (SJZ)

The environmental protection–industrial structure–urbanization coupling degree of SJZ was relatively high, above 0.95. However, compared to BJ and TJ, the development of the three systems of environmental protection, industrial structure, and urbanization in SJZ was not very high (all below 0.6). Although the development of the three subsystems showed a similar growth trend to the overall coupling, a lower degree of development had a higher degree of coupling, reflecting the shortcomings of the coupling degree measurement model.

The proportion of secondary industry's added value to the GDP of Shijiazhuang (47.5%) and the proportion of employees in the tertiary industry (34.3%) can be seen from the observational data, and is quite different from the industrial structure of BJ and TJ in that one industry had a major advantage. The level of urbanization in SJZ grew rapidly in 2015. Its per capita GDP and per capita retail sales of consumer goods reached 8% and 23%, respectively. The development rate of the urbanization subsystem was 0.583 in 2017, representing a leading position in Hebei Province. The green coverage rate in the built-up area of Shijiazhuang City was 44.42%, the per capita green area of urban parks was 17.05 square meters, and the discharge of industrial wastewater remained largely unchanged.

4.1.4. Zhangjiakou (ZJK)

ZJK's environmental protection–industrial structure–urbanization coupling degree was at a medium level and showed a slow growth trend during 2013–2017, and the development value of the industrial structure subsystem and the urbanization subsystem were both low, maintaining a stable level. The development degree of ZJK's environmental protection subsystem showed an upward, then downward trend from 2013 to 2017, although the decline was not obvious. The development degree fluctuated between 0.5 and 0.6, remaining mostly stable. ZJK's industrial structure subsystem and urbanization subsystem had a low degree of development, around 0.2. It can be seen that the low development of the industrial structure subsystem and the urbanization subsystem led to ZJK's coupling degree not being high.

ZJK has done a good job in environmental protection. The production of industrial sulfur dioxide decreased by 38% in 2017, the total amount of industrial wastewater discharge was about half of the previous year, and the sewage treatment rate and the harmless treatment rate of domestic garbage reached 100%. ZJK's government has increased investment in environmental governance, created an environmental protection culture in long-term environmental governance, and improved the effect of environmental governance investment, making it a leader in environmental protection among similar cities. However, its industrial structure and urbanization system have grown slowly. In terms of social urbanization, the number of college students per 10,000 people was about 98, and the disposable income of urban residents in 2017 was CNY 28,512, which is not high.

4.1.5. Xingtai (XT)

The coupling degree of the environmental protection–industrial structure–urbanization system in XT was very unstable. There were many sequential rises and falls during 2013–2017, and the overall system coupling degree was low, between 0.7 and 0.8. In addition to the lowest level of environmental protection development in 2014, the development trend of XT was opposite to the overall environmental protection–industrial structure–urbanization system coupling. While the development degree of XT's industrial structure subsystem and urbanization subsystem increased, the increase was small and the development values were below 0.3 and 0.1, respectively. This development level was not high enough, leading to XT's environmental protection–industrial structure–urbanization overall system coupling being the lowest.

According to observations, XT's urbanization subsystem development degree was 0.122 in 2017, representing the city with the lowest BTH development degree (0.57 less than that of the highest BTH city), and the development degree over the five years was only around 0.1, which is low. The development of the industrial structure subsystem improved in 2015. The primary industry's added value as a proportion of GDP declined, with that of secondary and tertiary industries increasing and the industrial structure developing towards a good trend; however, the level of industrial structure development remained low at 0.3 or less. It can be seen from the data that XT, where the environmental protection–industrial structure–urbanization system had the lowest coupling degree, had a very unstable evolutionary trend. It was at the lowest value of 0.695 in 2015 and reached the highest value of 0.79 in 2016. The unbalanced development of the environmental protection subsystem directly affected the development trend of the coupling degree of the overall system.

4.2. Coupling Coordination Degree of the "Environmental Protection–Industrial Structure–Urbanization" System in BTH

This section will further describe the coupling and coordination degree of the environmental protection–industrial structure–urbanization system in BTH. Because the three subsystems are equally important to the coupled development of the overall system, this study takes f(x), g(y), and h(z) as the weights of α, β, and γ, which are the development degrees of the three subsystems, each as one third. Based on the CCDM findings, the relative changes in the coupling coordination degree of the three systems in each city from 2013 to 2017 are depicted in Figure 3. The gradual change from dark red to dark green represents the transition from low to high coupling coordination.

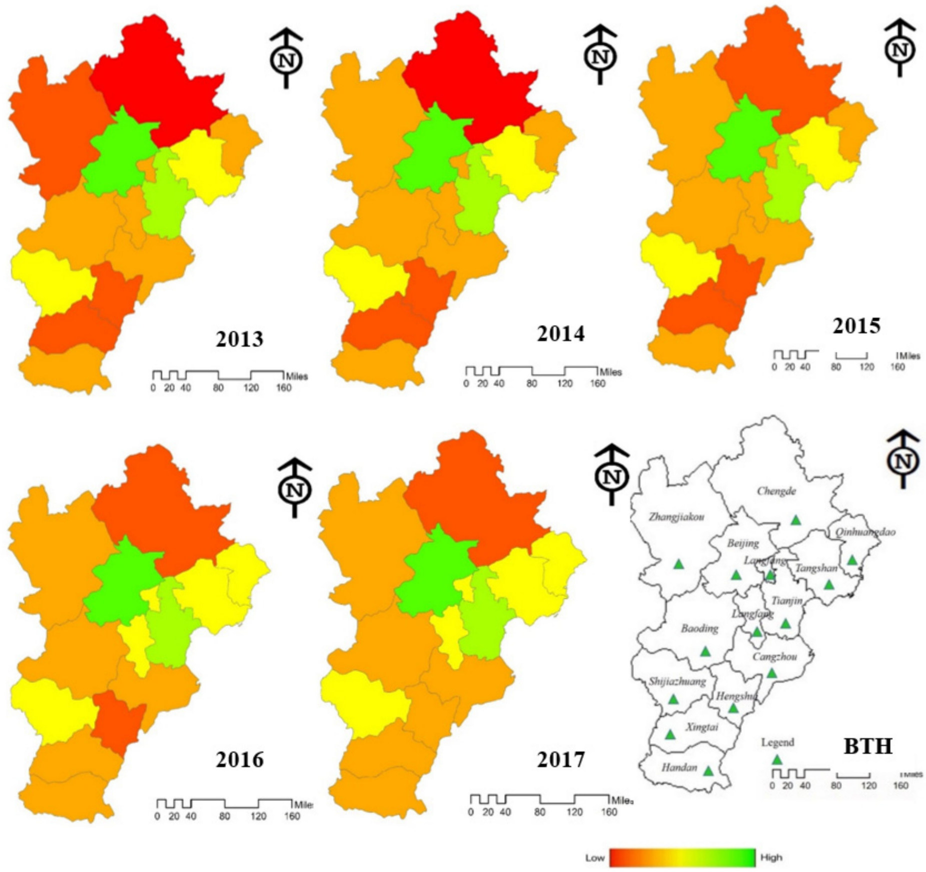

Figure 3. BTH's environmental protection–industrial structure–urbanization system coupling and coordination degree distribution (2013–2017).

According to the measured data, the environmental protection–industrial structure–urbanization coupling coordination degree in BTH is between 0.55 and 0.65. In 2013, some core cities had high coupling coordination degrees (BJ, TJ, SJZ, TS), while the degree of coupling and coordination of surrounding cities was at a low level, forming a "Beijing–Tianjin gap belt" pattern. In 2017, the number of core cities with a high degree of coupling and coordination remained unchanged, while the degree of coupling and coordination of surrounding cities improved significantly. From 2014, the overall system coupling and coordination of BTH has been gradually improving, indicating that the development of the three subsystems of BTH's environmental protection, industrial structure, and urbanization tend to be synchronized, which is reflected in low-level synchronization. BTH needs to control environmental quality at the same time as optimizing the industrial structure and promoting the urbanization level of cities.

Figure 4 reveals that the coupling coordination degree of the environmental protection–industrial structure–urbanization system in BTH has significantly improved. Although there are cities with low coupling coordination degrees, most cities are in the range of barely and moderately coordinated (Figure 5). BJ has been in a highly coordinated state (from 0.814 in 2013 to 0.862 in 2017), with TJ is in second place (from 0.779 in 2013 to 0.782 in 2017), representing moderately coordinated. The surrounding cities have developed rapidly. For example, QHD and LF have achieved a leap from barely coordinated to moderately coordinated, and XT and ZJK have achieved a leap from mildly disordered to barely coordinated. From the perspective of development type, most cities in Hebei Province are lagging in industrial structure and urbanization. For example, CZ, BD, HD, HS, and XT have low urbanization development indexes, and are hindered in urbanization development. The industrial structure development indexes of BJ and TJ are relatively high, while the environmental protection and urbanization development indexes are low, which shows that environmental protection and urbanization are lagging.

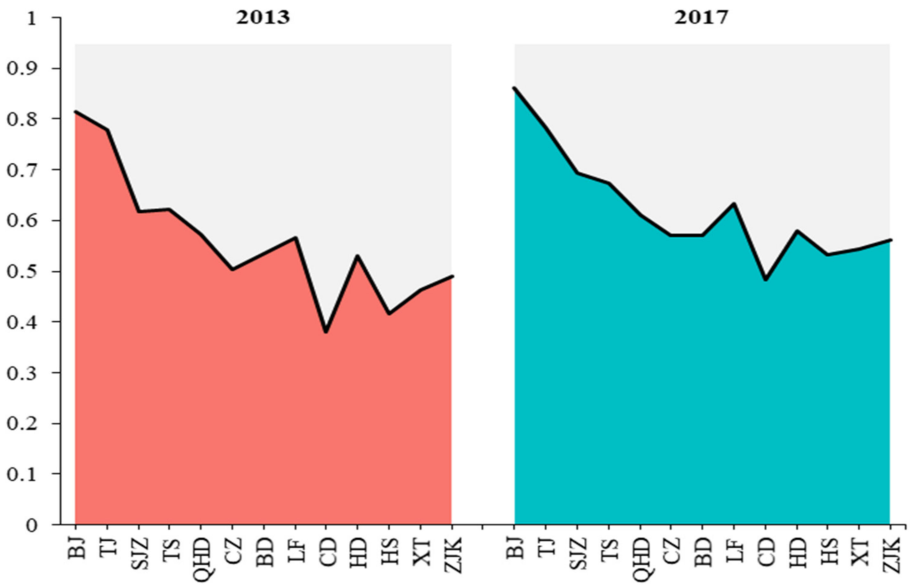

Figure 4. Environmental protection–industrial structure–urbanization system coupling and coordination value of BTH [2013 (**Left**) vs. 2017 (**Right**)].

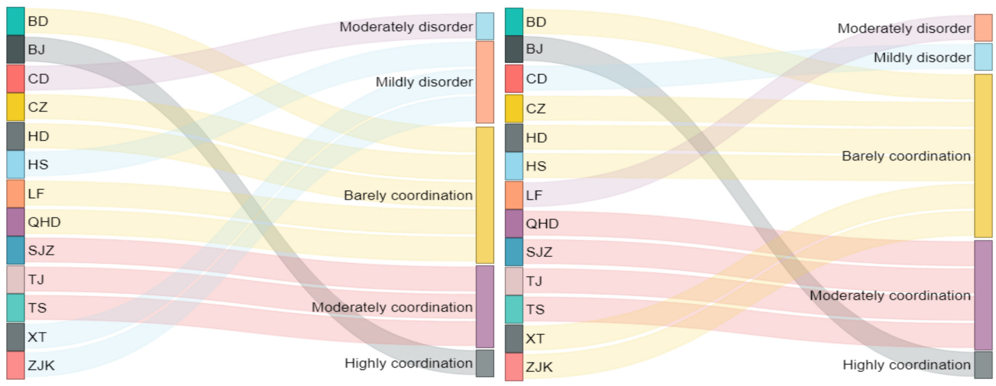

Figure 5. Environmental protection–industrial structure–urbanization system coupling and coordination level of BTH [2013 (**Left**) vs. 2017 (**Right**)].

4.3. Spatial Correlation Analysis in BTH

Figure 6 shows partial Moran scatter diagrams of the coordinated development of the environmental protection–industrial structure–urbanization system in BTH in 2013 and 2017, respectively, taking the release of the "Beijing–Tianjin–Hebei Coordinated Development Strategy" as the node and showing a before and after analysis based on this. The BTH coupling coordinates the changes in the spatial correlation model of the development level. BTH cities are distributed in the four quadrants of the Moran scatter chart. The first quadrant is a high–high agglomeration area, which means that the environmental protection–industrial structure–urbanization system coupling coordination degree between this area and the adjacent area is relatively high, and the spatial correlation is manifested as a diffusion effect. The second quadrant is a low–high agglomeration area, indicating that the regional environmental protection–industrial structure–urbanization system has a low degree of coupling and coordination, while adjacent areas have a high degree of coupling and coordination. The spatial correlation of this quadrant is represented as a transitional area. The third quadrant is a low–low agglomeration area, which represents a region's environmental protection-industrial structure-urbanization system coupling coordination degree relative to neighboring areas being relatively low, and the spatial correlation showing a low-speed growth. The fourth quadrant is the high–low agglomeration area, indicating that the regional environmental protection–industrial structure–urbanization system coupling coordination degree is high, and that the coupling coordination degree of adjacent areas is low, with the spatial correlation of this quadrant manifesting as a polarization effect.

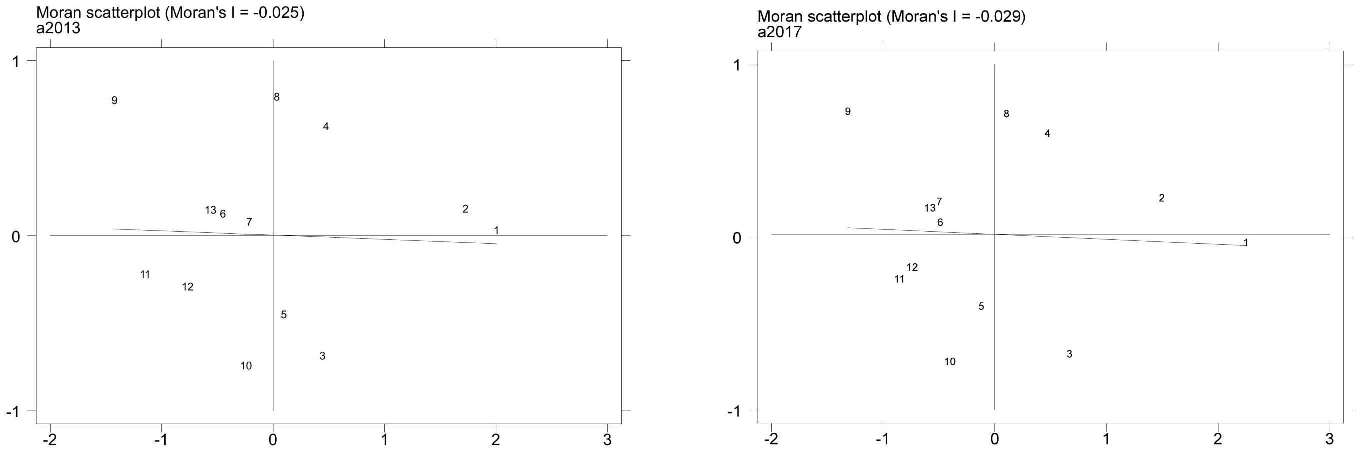

Figure 6. Spatial distribution of BTH environmental protection–industrial structure–urbanization system coupling and coordination level in 2013, 2017 (Moran's I).

This paper divides the thirteen BTH cities into four types of agglomeration areas. The Moran scatter diagram can intuitively reflect the spatial correlation characteristics of the coupling and coordination of the environmental protection–industrial structure–urbanization system in this region [2]. It can be seen from Figure 6 that the coupling coordination degree of the individual urban environmental protection–industrial structure–urbanization systems for the thirteen cities in BTH is mostly distributed in the second and third quadrants, namely the low–high and low–low types. Because the number of BTH cities is thirteen, the negative correlation between regions is not obvious; however, the negative Moran index indicates that the BTH environmental protection–industrial structure–urbanization system coupling coordination degree is relatively high, and the distribution of low areas is relatively concentrated. They are spatially convergent between low–high and high–low. The Moran index changed from -0.025 in 2013 to -0.029 in 2017, indicating that the significance of spatial agglomeration is slowly increasing, though not obvious. Based on the four quadrants, BTH cities are divided into four types: high–high type; low–high type; low–low type; and high–low type. The different types of agglomeration areas and their differences are shown in Table 2.

Table 2. BTH environmental protection–industrial structure–urbanization system coupling coordination degree/local spatial clustering.

Agglomeration Area	Typology	2013	2017
High–high	Diffusion effect area	BJ, TJ, TS, LF	TJ, TS, LF
Low–high	Transitional area	CZ, BD, CD, ZJK	CZ, BD, CD, ZJK
Low–low	Low-speed growth area	HD, HS, XT	QHD, HD, HS, XT
High–low	Polarization effect area	SJZ, QHD	BJ, SJZ

5. Discussion

5.1. Beijing–Tianjin–Hebei Coordinated Development Strategy

As mentioned in the introduction, after the Beijing–Tianjin–Hebei Coordinated Development Strategy was introduced one province and two cities jointly established a top-level design and planning system. For example, these three places established a joint prevention and control system for air pollution, signed a water resources compensation agreement, and promoted cleanliness. Coordinated prevention measures such as energy transformation have been introduced as well. On the other hand, these three places have established a "2+4+N" core of the industrial structure adjustment space carrier and jointly issued a series of policies such as the Industrial Transfer Guide in BTH. These measures have led to the continuous rise of the collaborative development index (NBS, 2019), resulting in the environmental protection, industrial structure, and urbanization system development of these three places being improved to a certain extent.

However, while recognizing that the degree of collaborative development of BTH has been constantly improving, it is noted that there are still significant differences in urban construction and development in BTH. Affected by natural resources and historical conditions, the level of regional urbanization driven by BTH population urbanization has been continuously improving, representing more than three times the national average level (MEEPC, 2017). A large amount of population agglomeration leads to the cross-regional transmission and migration of pollutants such as air pollution and water pollution among cities [4,42]. On the other hand, the industrial structure transformation of BTH's core cities such as BJ and TJ aggravates the environmental governance difficulties of BTH [43,44].

5.2. The Reasons for the Differences

5.2.1. Core City Function Weakens the Development of Small and Medium Cities

In the coordinated development of the BTH environmental protection–industrial structure–urbanization system, the first step is to clarify the city's positioning [45], which includes the establishment of the social position of multiple connections in the social network as well as its the political position regarding allocation of public resources in the administrative area, regulating social behavior, promoting cultural diversity and inclusiveness, realizing the cultural positioning of integration and reconstruction, and realizing the ecological positioning of resource sharing and environmental co-governance.

In the BTH regional positioning, BJ, as a core city, has the functions of a political center, a cultural center, an international communication center, and a center for technological innovation. The concentration of regional functions places the provision of public services in a state of overload, creating problems related to infrastructure and resource capacity [38,46]. To a certain extent, the policy planning and system design issued by the Chinese government has focused on designing the structural and functional transformation of core cities. Under the siphoning effect of public resources, some functions of Beijing as a megacity have not been effectively alleviated, further widening the gap between cities.

5.2.2. The Development Logic of Urbanization's Economic Benefits Being Superior to Environmental Protection Leads to Regional Competition

Local governments represent local interests and make decisions on major projects in various regions. It is not uncommon for local governments to compete for economic growth and for political promotion [47]. This urbanization development logic that prioritizes benefits such as the pursuit of self-maximizing development interests interferes with regional economic development. When cross-domain public affairs are inconsistent with regional development goals, local governments consider the sustainable development of their jurisdictions more than that of the surrounding areas [38]. For example, in order to seize high-quality resources in Tianjin and Hebei, fierce competition and local protection will likely spread. This phenomenon is reflected in the collective action dilemma regarding air pollution control in BTH [25]. The economic-first development model has made the development of core cities too advanced, and the coordinated development of small and medium-sized cities is out of line with the actual situation, resulting in the city's carrying capacity not being improved [38,48]. In an environment of increasingly fierce economic competition, the population of cities in Hebei Province is relatively small, and the infrastructure construction is relatively imperfect. In the pursuit of economic development, too little attention is paid to the matching of population urbanization and social urbanization, which decreases the quality of overall urbanization development.

5.2.3. Similarities in Regional Industries Lead to Lower-Quality Urbanization Development

Regional differences make the development of a single element of a city unique and exclusive; however, most cities compare themselves to other cities in the same position and adopt similar methods to pursue development goals, making the development of urban subsystems converge. For example, the layout and construction of urban industries are the same, leading to a serious waste of resources and the failure to adapt to the characteristics of the city, as well as causing the phenomenon of urban industry in regions having the same structure and overcapacity. According to relevant calculations, the similarity rate of the industrial structure in various provinces is over 90%, and the traditional industries of Hebei Province remain dominant; these similarities in industrial development have triggered homogeneous competition between cities [49], and the loose spatial structure leads to insufficient urban land use intensiveness [50,51]. When the circular model of urban construction is insufficient, the surrounding areas will be developed from a low starting point at the same time, and it will be difficult to support high-level, fast-running and intensive urban facilities, resulting in low efficiency of urbanization.

6. Conclusions

Based on research on the coupled development of BTH's environmental protection–industrial structure–urbanization system, this paper has measured and analyzed the three systems of environmental protection, industrial structure, and urbanization in BTH cities from 2013 to 2017. Based on the analysis of the development differences within BTH, the following conclusions can be drawn.

First, as time progresses, the environmental protection–industrial structure–urbanization system coupling and coordination level in BTH is gradually improving. From a time sequence perspective, within the sample timeframe of the study the coupling degree and coordination degree of the environmental protection–industrial structure–urbanization system in BTH were on an upward trend, particularly after 2015.

Second, the development level of the individual environmental protection–industrial structure–urbanization subsystems in BTH is uneven. Although the overall situation of BTH's coordinated development is good, there are internal contradictions. The three subsystems of BJ and TJ have high development values, and the difference in subsystem development is about 0.1. The degree of development of the environmental protection subsystem of the cities in Hebei Province is roughly the same as that of Beijing and Tianjin, while the industrial structure and the level of urbanization are far lower than those of BJ and TJ. At the same time, the difference in the degree of development of urban industrial structure, urbanization, and environmental protection in Hebei Province is between 0.3 and 0.6, meaning that its industrial structure and urbanization are lagging.

Third, the environmental protection–industrial structure–urbanization system has a constraint effect. From the perspective of the coordinated development of BTH coupling, CD's industrial structure, environmental protection, and urbanization development degrees were 0.16, 0.44, and 0.18, respectively. These three low development levels led to the coupling and coordination of the city being the lowest among BTH cities. The industrial structure and urbanization level of XT were 0.28 and 0.12, respectively, and the environmental protection development degree was 0.75. Therefore, although XT's environmental protection is doing well, the industrial structure and urbanization have lowered the coordination level of the overall system.

Fourth, there are obvious spatial differences in the coupling and coordination level of the environmental protection–industrial structure–urbanization system in BTH. The level of BTH coupling and coordination has an agglomeration effect manifested mostly as low–high and low–low concentrations. There is a significant gap between BJ, which is highly coordinated, and CD, which is mildly disordered. TJ, TS, QHD, SJZ, and LF are at the moderately coordinated level, while ZJK, BD, CZ, HS, HD and XT are at the barely coordinated level. There is heterogeneity among regions. Most cities in Hebei Province are at the moderately or barely coordinated level. BTH has two core cities in BJ and TJ, and

Hebei Province is surrounded by BJ and TJ. Cities in the province serve BJ and TJ, with different sectors assuming different responsibilities and levels of cooperation in BJ and TJ. It is precisely this spatial structure that, while bringing more opportunities and benefits to Hebei, makes its scattered and one-sided development pattern weak.

Therefore, with the increasing demand for human settlement and sustainable development, BTH needs to pay attention to the coupling relationships within the environmental protection–industrial structure–urbanization system, build a smooth industrial network and structure among cities, and enhance the efficiency of optimal allocation of resources among regions. Adhering to the conception of green development [52], BTH needs to accelerate the ecological transformation of industrial structure and increase the proportion of high-tech and knowledge-intensive industries.

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