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Industrial Spatio-Temporal Distribution of High-Speed Rail Station Area from the Accommodation Facilities Perspective: A Multi-City Comparison

Bingjie Niu, Ping Yin * and Pengxia Shen

School of Economics and Management, Beijing Jiaotong University, Beijing 100044, China
* Correspondence: pyin@bjtu.edu.cn

Abstract: As a new engine of urban development, the high-speed rail (HSR) station area is an emerging location where the service industry is concentrated. This study aims to reflect the development of accommodation facilities in transport hub areas through the spatial distribution and agglomeration characteristics of the lodging industry in HSR station areas. HSR stations in Beijing, Tianjin, Nanjing, Jinan, Kunshan, and Xuzhou are selected. The Geodetector model is applied to analyze the pertinent driving factors. The findings indicate that: (1) The smaller the population size of the city, the closer the high agglomeration area of the accommodation industry in the HSR station area is to the HSR station. (2) The longer the HSR station is open, the stronger the agglomeration intensity of the accommodation industry is. (3) At HSR stations in various cities, the driving factors affecting the accommodation industry are heterogeneous. The interaction between the factors has a synergistic enhancement effect.

Keywords: high-speed rail station; accommodation industry; spatial distribution; agglomeration; driving factors; multi-city

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1. Introduction

With the further optimization and improvement of China's high-speed railway (HSR) network, the impact of HSR on the development of urban socio-economic and industrial structure has received continuous attention [1–3]. In terms of cities, the positive impact of HSR is generated through the spillover effect, and the impact is periodic and spatial-heterogeneous [4]. The increase in the number of HSR stations and routes has ameliorated the urban transport system, optimized the urban economic layout, expanded land demand, and accelerated urban land expansion [5]. Its impact on urban population mobility [6], land use [7], industrial structure [8], housing prices [9], and tourism [10] has become the focus of discussion among scholars. Their efforts have helped us grasp the differences or similarities with the impacts of other transportation modes. For instance, cities connected to the HSR network had considerable increases in job opportunities [11], while airports revealed a positive but not significant influence on employment [12]. Going back to the automobile era, dependence on cars is the primary force driving cities to increase the use of land [13]. Presently, HSR plays this role [14]. The impact of this new transportation on industrial operations is another crucial research topic. Matas et al. [15] found that HSR had a greater impact on services, tourism, and knowledge-intensive activities, because the service industry is sensitive to the flow of production factors [16,17]. To be specific, the opening of HSR can not only strengthen the economic superiority of producer services but also facilitate the processes of labor mobility and urbanization, so as to promote the agglomeration of producer services [11,18]. On the flip side, passengers brought about by HSR have stimulated enormous consumer demand [1]. That kind of change is likely to increase the degree of competition in the service industries, expand the service market, and improve service quality [19,20]. The above phenomenon is obviously reflected in the tourism industry. HSR makes travel more convenient and expands the scope of travel, which often leads to new tourism demand, thus promoting the rapid development of tourism [6,21]. Previous studies have shown that the opening of HSR can indeed increase the frequency of urban travel or the flow of tourists [22,23]. All those perspectives are important, and the results can bring theoretical and practical implications to our work. However, very few have paid attention to HSR stations and examined what happened or will happen around the HSR stations; it has even been 10 years since the question was raised as to whether HSR stations can become generators of new local poles of urban development [24].

Understanding this issue is critical for HSR stations, and urban development as well. In China, the traditional view is that the railway station is just a node of inter-city transport, and that the location of the station area is often of poor quality, chaotic, and crowded. Few people go to the station if they do not take the train [25]. However, now, the high-speed, punctual, and comfortable characteristics of HSR have changed that, and the HSR station has even been regarded as a symbol of the city [26,27]. The space usage, element changing, and regional development of HSR station areas have become current research focuses [28,29]. The study states that the improvement of accessibility is mostly concentrated in the vicinity of the HSR station [30]. Furthermore, the growth rate of land use around the HSR station exceeds that of the entire city [31]. During the initial period, the land cover of the HSR station area increased, and the excellent transport facilities and modern image of HSR attracted enterprises and people to the station area [14]. As more people gathered near the station area, the activity hotspots in a city increased [32]. Commerce and housing are sprouting up all around, generating new activities and employment centers [33]. It has been demonstrated that these urbanization hotspots make the surrounding areas more accessible, which further stimulates economic activity [34]. However, another opinion proposes that the catalytic effect of HSR stations on urban development is not always effective. Taking Europe as an example, Loukaitou-Sideris et al. [35] observed that HSR stations in first- and second-tier cities do play a role in promoting urban development, while the construction of HSR stations in other cities does not bring any catalysis, nor is it accompanied by new urban development. A similar situation occurs in China. The HSR station in the urban center of Hangzhou has a positive impact on the value of nearby residential properties. On the outskirts of Guangzhou, although the government intends to stimulate the development of the station areas, it has not significantly increased housing prices in the short term [36]. The important factors that make the effect difference of HSR stations are the level of urban economic development, the level of city rank, and the location of the HSR stations [16].

As an important place for urban recreation reception, the evolution of the spatial distribution pattern of accommodation industry can reflect the changing law of urban spatial structure [37]. Previous studies have strongly certified that the transportation hub is the primary location for the distribution of commercial accommodation business [38]. The construction of subways has also been proven to attract numerous hotels in peripheral areas that choose to locate near the subway station [39]. However, there is no discussion on the distribution of the accommodation industry in the HSR station area. The opening of HSR will bring huge business and travel passenger flow, which means more accommodation needs. Deng et al. have found that HSR stations with higher departure frequencies usually have higher hotel occupancy [16]. In urban areas, the employment of accommodation industry connected by the HSR network has significant growth [11]. According to the example of Three Great Bay Areas, the opening of HSR promoted the agglomeration of accommodation industry in the region [40]. As a typical new urban development area, the HSR station area has the potential to become a rising location for the hotel industry. Therefore, it is necessary to examine the differences in the spatial distribution characteristics of the accommodation industry in HSR station areas in different cities, as well as the influencing factors that cause such differences. The answers to these questions will help to correctly comprehend the actual driving effect of HSR on the tourism accommodation industry. That is of urgent practical significance to promote the rational layout of the HSR station industry and the benign development of the accommodation industry.

Traditional methods, such as the Gini coefficient and density gradient, are better suited for studying industrial concentration on the macroscopic scale, but not on the microscale. In the aspect of the spatial structure of the HSR station area, the most representative one is the "three development zones" theory proposed by Schmidtz [41]. According to the theory, with the increase of the distance from the station, the industries around the HSR station present three development circles: direct correlation, functional complementarity and indirect correlation. The method, which takes the station as the center and the distance as the radius, fully accounts for the geographical principle of spatial accessibility and the attenuation of station radiation with increasing distance. It has developed into a classical theory to guide the industrial layout of the HSR station. We seek to explore the spatio-temporal features of the accommodation industry and the impact of other properties in the HSR station area. That is important for the rational planning of station space. This paper takes the HSR stations in cities of different sizes along the Beijing-Shanghai HSR as the research object. Using point of interest (POI) data and enterprise information on the OTA (Online Travel Agency), we collect the information about the accommodation industry within a radius of 3 km from the station. The kernel density estimation and nearest neighbor index are used to characterize the spatial agglomeration and evolution of the accommodation industry in the HSR station area. In the meantime, the driving factors of industrial distribution are analyzed by using geographical detectors. Finally, corresponding suggestions are put forward for the space optimization of the station area and location selection of the accommodation industry.

We arrange the rest of our paper as follows: Section 2 details the study area, the data and methods used. The spatio-temporal characteristic analysis is introduced in Section 3. Section 4 is the analysis of driving factors. Section 5 presents the discussion and gives suggestions. Section 6 concludes our findings.

2. Data and Methods

2.1. Study Area

The Beijing-Shanghai HSR is one of the main channels of the "Eight Vertical and Eight Horizontal" HSR network in China. It connects the two major urban agglomerations of Beijing-Tianjin-Hebei and the Yangtze River Delta. The types of cities along the line are multiple. After more than 10 years of development, the accommodation industry and related industries in the station areas along the Beijing-Shanghai HSR have reached a certain scale. This provides the foundation for studying the accommodation industry in the HSR station area.

This paper is based on the division standard of the State Council. Cities with a permanent population of more than 10 million in urban areas belong to supersized cities. A city with a permanent resident population of more than 5 million but less than 10 million is a mega city. A city with a permanent resident population of more than 1 million but less than 5 million is a large city. We calculated the urban permanent population size of the cities where the 24 stations of the Beijing-Shanghai HSR were located. We removed cities with a population of less than 1 million. In order to avoid the interference of large obstacles on the distribution of accommodation industry in the study area, we excluded HSR stations with large areas of water, mountains, or other factors that divide the station area. Based on the floorage and platform scale, 6 stations were finally selected (Figure 1). According to the previous literature on the scope of the HSR station area [42], the maximum transfer distance that outbound passengers can endure on average is 3.0 km. Urban growth and land use changes are concentrated in that range [31]. This paper decides to take the circle with the center of the station and a maximum radius of 3.0 km as the scope of the HSR station area. The station area is divided into 6 circle zones at an interval of 0.5 km to help observe the spatial distribution characteristics of the accommodation industry.

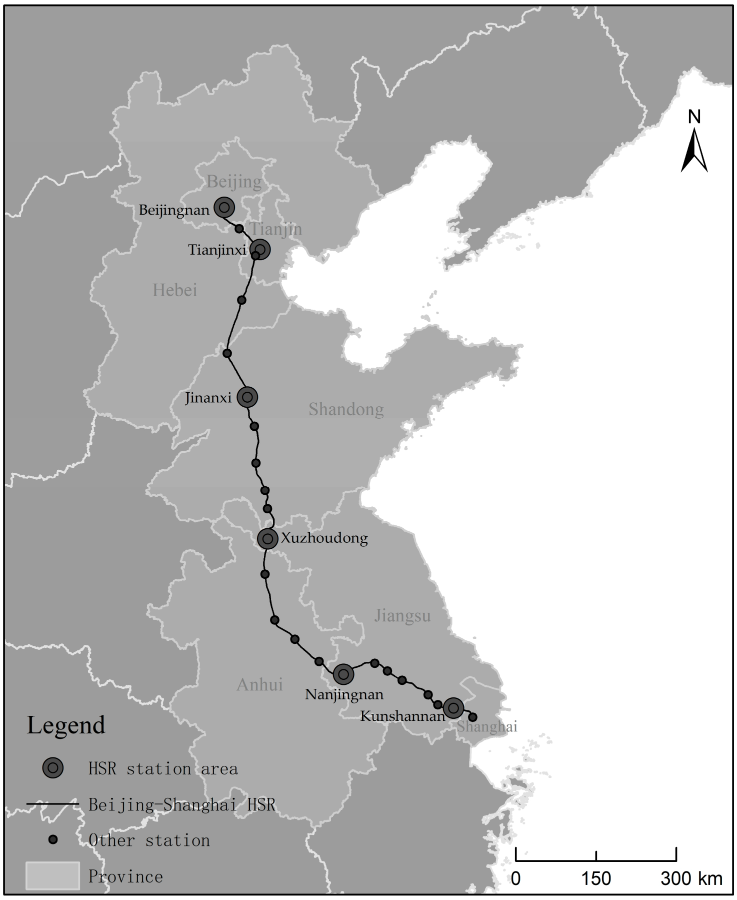

Figure 1. Study area.

2.2. Data Collection

In a geographic information system, a POI is a geographical entity that is closely related to economic and social activities and can be described by commercial facilities, bus stations, high buildings, and others [43]. POI data contain geographic coordinate information [44]. POI is inextricably linked to modern (mobile) search, recommender systems, location-based social networks, transportation studies, navigation and tourism systems, urban planning, predictive geo-analytics such as crime forecasting, and so forth [45]. Compared with traditional data, POI data have the advantages of a large sample size and easy access. They can reveal the distribution of the accommodation industry in the station area on a micro-scale more effectively and comprehensively. OTA is an online booking platform of hotels, tourism, tickets, etc. These platforms are an important part of China's tourism market. Despite the fact that they do not own any hotels, they attract tourists and business travelers by offering a wealth of hotel information, price comparisons, discounts, and comments [46]. This provides a channel for us to obtain the opening times of accommodation enterprises.

In this study, we took Amap LBS Service (https://lbs.amap.com/) as the basic data source. According to the POI classification of the platform, we used "accommodation service" as the key word to obtain the POI data of the accommodation industry around the study area. The query time was March 2022. Then, the ArcGIS10.2 was used to spatialize the data. Next, taking each HSR station as the center and 3 km as the radius, the facilities within the circle were extracted. It included all scales of accommodation, such as inns, guesthouses, Airbnb, hotels, economy hotels, star hotels, etc. We used OTA platforms such as Meituan, Ctrip, and Tongcheng-Elong to match the opening date of each accommodation enterprise in the area. The research data on accommodation facilities in each station area were finally obtained after cleaning and correction. In order to ensure the accuracy and authenticity of the data, 10 enterprises were randomly selected from the 6 stations for information verification. After verifying that the actual situation was consistent with the statistical data, the POI database of the accommodation industry in each station area was ultimately constructed (Table 1). This database included the number of accommodation facilities in each station area, and the location and opening time of each facility. Other POI data were also obtained through Amap.

Table 1. Basic information about the research object.

City Size	HSR Station	Population/mil.	Platforms	Tracks	Floorage/hm^2	Accommodation Facilities/num.
Supersized	Beijingnan	17.75	10	20	32	483
	Tianjinxi	10.93	13	26	18	478
Mega	Nanjingnan	7.91	15	28	73	579
	Jinanxi	5.88	8	17	10	291
Large	Kunshannan	1.41	4	12	7.1	215
	Xuzhoudong	2.05	13	28	4.5	94

2.3. Methods

2.3.1. Kernel Density Estimation

Kernel density estimation (KDE) is a nonparametric spatial analysis method [47], which is widely used in the spatial agglomeration analysis of point data. Based on the rule of distance attenuation, it is believed that activities occur more frequently in those denser areas because geographical objects are affected by radiation from the central region. In this paper, KDE is used to reveal the spatial distribution characteristics of the accommodation industry in the HSR station area. The method is mathematically represented as follows:

$$f(X) = \frac{1}{nh^d} \sum\nolimits_{i=1}^{n} K\left(\frac{x - x_i}{h}\right) \tag{1}$$

where $f(X)$ refers to the kernel density of accommodation, n is the number of accommodation enterprises d is the dimension, K represents the spatial weight, and h is the threshold value of distance attenuation, that is, bandwidth. Generally, the farther away from the event x_i, the smaller the spatial weight. $(x - x_i)$ represents the distance from the estimate point x to the event x_i.

2.3.2. Nearest Neighbor Index

Nearest neighbor index (NNI) is used to analyze the agglomeration and dispersion of economic activities. Wang et al. [48] analyzed the agglomeration and dispersion of various retail stores in Changchun based on NNI from the perspective of street centrality. Based on the average nearest neighbor tool in ArcGIS 10.2, this paper first calculated the distance between each factor of interest and its nearest factor, and then calculated the average value of all the nearest neighbor distances. NNI < 1 means the pattern is clustered. Otherwise, the pattern tends to diffuse. The expression is

$$NNI = \overline{D_o} / \overline{D_E} \tag{2}$$

$$\overline{D_0} = \sum_{i=1}^{n} \frac{min(\mathrm{d}_{ij})}{n} \tag{3}$$

$$\overline{D_E} = \frac{1}{2}\sqrt{\frac{A}{n}} \tag{4}$$

where, $\overline{D_0}$ is the actual mean nearest neighbor distance between factor points, $\overline{D_E}$ is the ideal average distance between POI points in accommodation, i and j are arbitrary two POI points, A is regional area, n is the number of elements.

2.3.3. Geodetector Model

The geographical detector model detects the consistency of the spatial distribution pattern of dependent variable and independent variable through spatial heterogeneity. It measures the interpretation degree of dependent variable to independent variable, i.e., q value [49]. The calculation formula is as follows:

$$q = 1 - \frac{\sum_{h=1}^{L} N_h \sigma_h^2}{N\sigma^2} = 1 - \frac{SSW}{SST} \tag{5}$$

$$SSW = \sum_{h=1}^{L} N_h \sigma_h^2,\ SST = N\sigma^2 \tag{6}$$

where, q is the detection value of the influence ability. $h = 1, 2, \ldots, L$ is the strata of variable Y or factor X. N_h and N are the number of units in layer h and the whole area. σ_h^2 or σ^2 is the variance of h or Y. SSW and SST are respectively the sum of variance within the layer and the total variance of the whole region. The range of q is [0, 1]. The larger the q value is, the stronger the explanatory power of the independent variable X to the Y.

3. Spatio-Temporal Characteristic Analysis

3.1. Spatial Distribution Pattern

The kernel density analysis was conducted on the accommodation facilities in the six station areas to depict the spatial distribution characteristics. The results are shown in Figure 2. In an overview of all station areas, the location of the accommodation industry is different, which is associated with the respective geographical environment and planning characteristics of the station area.

In the supersized city group, the city where Beijingnan railway station is located has the largest permanent resident population. The distribution of lodging facilities in the study area shows a relatively dense agglomeration phenomenon, that is, cluster districts are sprinkled throughout each circle. Judging from the points with the highest kernel density, they mostly appear in the periphery circle (2–3 km). The KDE value of the core circle (0–1 km) is higher, while that of the middle circle (1–2 km) is generally lower. In the Tianjinxi railway station area, the density values are fairly low in most areas. There are only two obvious higher-density plots distributed in the periphery circle. In addition, a higher density point appears in the middle circle of the station area.

In the mega city group, the high-density KDE values of lodging facilities are primarily concentrated in the northern part of the Nanjingnan railway station area. High-density districts occur in each circle. Specifically, the higher density points are located in the core circle and the periphery circle. The aggregation scale of the core circle is larger. The KDE analysis result of Tianjinxi railway station is similar to that of Nanjingnan railway station, forming a significant cluster point at a distance of 0.5–1 km to the southeast of the station. There is also a high-density spot at the edge of the station area.

For the large city group, the geographical concentration of the accommodation industry in the Kunshannan railway station area is notable. The cluster points are scattered in each circle. High density value districts are around the hub, and each of them is located in the core circle. In other locations, the degree of agglomeration is relatively low. In the Xuzhoudong railway station area, the distribution of the high-density KDE values of the accommodation industry is the most concentrated. Only two agglomeration points are formed at a distance of 500 m from the station.

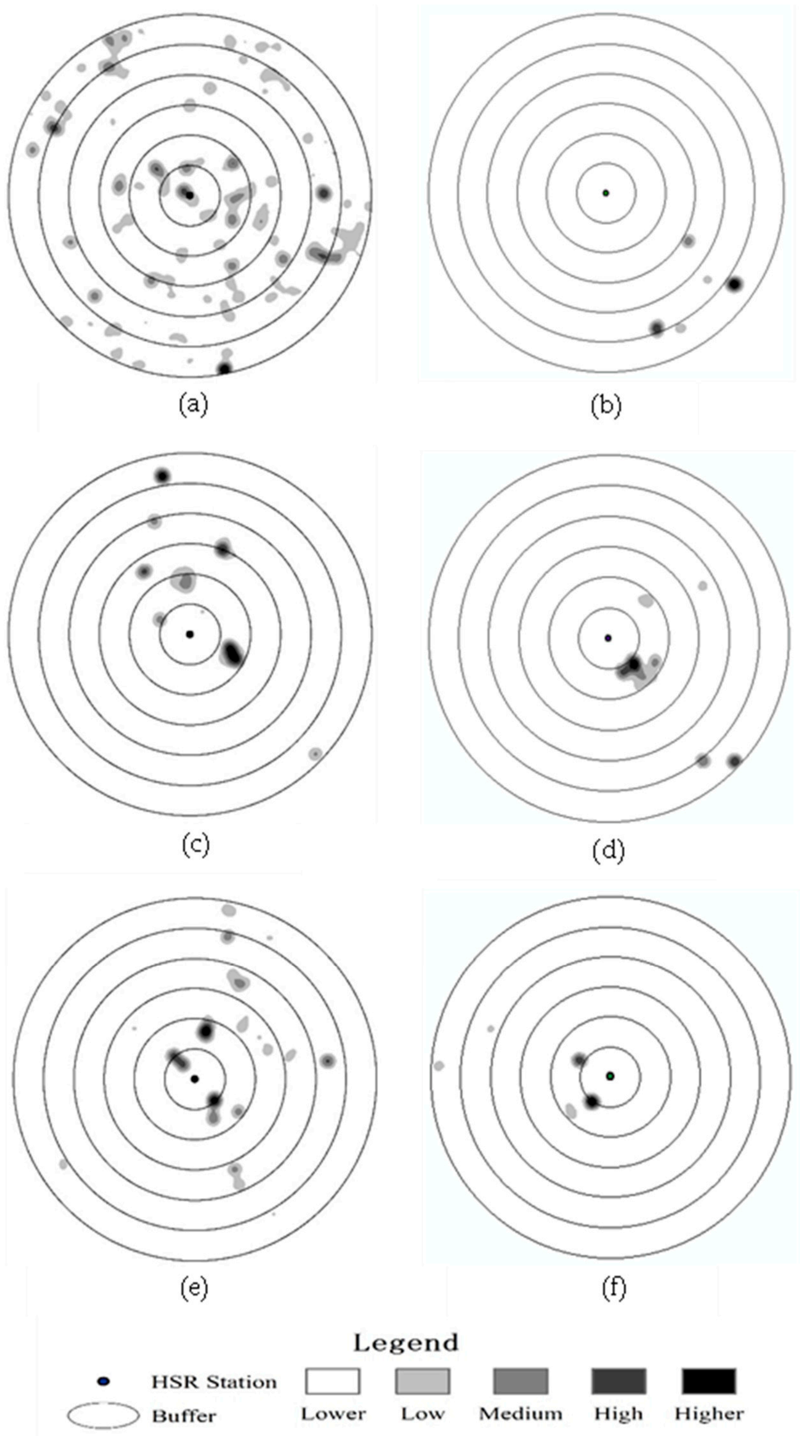

Figure 2. Kernel density estimation results of accommodation facilities: (**a**) Beijingnan; (**b**) Tianjinxi; (**c**) Nanjingnan; (**d**) Jinanxi; (**e**) Kunshannan; (**f**) Xuzhoudong.

3.2. Temporal Evolution Feature

To explore the spatial agglomeration degree of accommodation enterprises in HSR station areas over the years, this paper uses the average nearest neighbor index analysis tool in ArcGIS 10.2 to analyze the accommodation industry in each HSR station over the years. Table 2 displays the NNI results for the lodging facilities in each station area. Since there is only one accommodation facility in the station area of Xuzhoudong HSR station in 2011, data analysis cannot be done, so it is a null value.

Table 2. Results of NNI analysis.

Station	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Beijingnan	0.863 ***	0.819 ***	0.785 ***	0.753 ***	0.738 ***	0.721 ***	0.685 ***	0.706 ***	0.692 ***	0.684 ***	0.661 ***
Tianjinxi	0.926	0.794 ***	0.750 ***	0.620 ***	0.624 ***	0.626 ***	0.553 ***	0.479 ***	0.436 ***	0.425 ***	0.427 ***
Nanjingnan	0.629 ***	0.655 ***	0.481 ***	0.463 ***	0.410 ***	0.512 ***	0.383 ***	0.375 ***	0.377 ***	0.364 ***	0.354 ***
Jinanxi	103.211	2.107	2.107	1.288	1.037	0.816 **	0.529 ***	0.471 ***	0.429 ***	0.434 ***	0.395 ***
Kunshannan	0.779 ***	0.676 ***	0.685 ***	0.674 ***	0.704 ***	0.601 ***	0.571 ***	0.558 ***	0.450 ***	0.364 ***	0.337 ***
Xuzhoudong	/	130.166	4.761	1.145	0.600 ***	0.507 ***	0.440 ***	0.460 ***	0.382 ***	0.354 ***	0.358 ***

Note: *** and ** indicate statistical significance at the 1% and 5% level, respectively.

First of all, in the first five years of the observation period, we can make out that not all stations have NNI values much below 1. The result indicates that the distribution pattern of the accommodation industry in the station area is not clustered at the early stage of HSR operation. In particular, the NNI values of Beijingnan HSR station, Nanjingnan HSR station, and Kunshannan HSR station are less than 1 in all years, passing the significance test with a 1% level of confidence. It means that the accommodation industry of these three stations has formed an agglomeration distribution state in the first year of the HSR opening. The agglomeration degree is increasing with each passing year.

In the Tianjinxi HSR station area, the accommodation facilities were dispersed at random in 2011. One year later, the distribution pattern turned into cluster, and the degree of agglomeration reached the maximum in 2020. During 2011–2014, the hospitality industry at Jinanxi railway station was in a dispersed state. In 2015, the distribution was in a random mode, and in 2016, the accommodation industry entered a cluster status after further opening for business. At this time, only the significance test with a 5% confidence level was passed. Afterwards, the accommodation industry developed rapidly and the level of agglomeration was constantly improving. The Xuzhoudong railway station experienced a comparable circumstance. In 2012 and 2013, the distribution followed a dispersed pattern. It changed into a random pattern in 2014. It has been clustered since 2015. After 2016, like at other stations, the degree of agglomeration has increased year by year.

In addition, comparing with the later period data of each station area, the agglomeration degree of the lodging industry has enormous alteration in 2016–2018. By 2020, the NNI value had become stable. Even the agglomeration of accommodation facilities in some stations has diminished. At the end of the study period, the concentration intensity of Kunshannan railway station was the highest (NNI = 0.337), while that of Beijingnan railway station was the lowest (NNI = 0.661). It acts in cooperation with the clustering feature in Figure 2.

4. Driving Factors Analysis

4.1. Selection and Treatment of Driving Factors

The HSR station is not only a node in the transportation network, but also a place full of urban activities. In the area, the accommodation industry and other types of economic activities came into being with the establishment of the hub. The spatial distribution of accommodation industry in the HSR station area is not independent. It is closely related to other industrial factors [50]. The industrial development of the HSR station area is mainly driven by passenger flow demand. Therefore, this paper refers to Wang Shaojian's classification of industries in the HSR station area [51]. Eight industries related to the paper were selected from the category labels of POI data in Amap (Table 3). Among them, the basic service industry (including living service, catering service, and shopping service) refers to the industry that meets people's basic living and travel demands. It has certain characteristics of rigid demand. These industries provide service for all kinds of high-speed rail passengers and surrounding residents. The derivative industry has obvious business features. It is mainly derived from the high-speed rail effect. Such industries (including business residence, enterprise and financial insurance) can be regarded as the supplement and expansion of HSR station functions, while the relevant service industry is the embodiment of the city's basic functions. The industry is relatively less affected by the traffic node function of HSR stations. The facilities related to the accommodation industry are sports leisure and scenic spots.

We divide the station area into a 500 m × 500 m grid. The grid is the basic research unit. After spatial processing, the number of facilities in every grid is classified by natural breaks. The grading result is assigned to the grid as the value of the independent variable (X). The dependent variable (Y) is the number of hospitality facilities in the grid. We use Geodetector to explore the extent to which X explains Y in this part.

Table 3. Index system of driving factors.

Index Type	Code	Detection Factor	Detection Indicator
Basic industry	X_1	Living service	Number of corresponding facilities in the grid
	X_2	Catering service	
	X_3	Shopping service	
Derivative industry	X_4	Business residence	
	X_5	Enterprise	
	X_6	Financial insurance	
Relevant industry	X_7	Sports leisure	
	X_8	Scenic spot	

4.2. Single Factor Analysis

The distribution of other industries in the station area can further reveal the main driving factors that form the existing spatial structure of the accommodation industry in each station area. According to the results of factor detection in each station area (Table 4), we found that the data of catering service, shopping service, and business residence are significant in each station area. It indicated that those three elements are the common driving factors. However, it appears that the primary motivating factors vary depending on the station.

Table 4. Detection results of influencing factors in station area.

Station	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
Beijingnan	0.356 ***	0.365 ***	0.293 ***	0.329 ***	0.265 ***	0.178 ***	0.012	0.188
Tianjinxi	0.255 **	0.163 *	0.211 ***	0.214 **	0.116 *	0.193 ***	0.166 ***	0.044
Nanjingnan	0.539 ***	0.486 ***	0.321 ***	0.624 ***	0.240 ***	0.227 ***	0.641 ***	0.042
Jinanxi	0.117	0.320 ***	0.280 ***	0.524 ***	0.104	0.219 ***	0.426 ***	0.031
Kunshannan	0.490 ***	0.684 ***	0.351 ***	0.281 ***	0.160 **	0.294 **	0.776 ***	0.121*
Xuzhoudong	0.519 ***	0.535 ***	0.308 ***	0.148 ***	0.118	0.073	0.228 ***	0.166 ***

Note: ***, ** and * indicate statistical significance at the 1%, 5%, and 10% level, respectively.

Specific to each station, the dominant factors driving the distribution of the accommodation industry in Beijingnan railway station are catering service, living service and business residence. However, sports leisure facilities and scenic spots do not embody its interpretive force in the station area. At Tianjinxi railway station, the values of significant driving factors are lower than those of other stations. Among them, life service is the most active. Business residence and shopping service come next. X_8 still has no driving effect here. At Nanjingnan railway station, sports leisure, business residence, and living services ranked the top three in terms of factor explanatory power, with p values exceeding 0.5. At Jinanxi railway station, the core driving factors for the distribution of lodging facilities are business residence and sports leisure. The only location where life service does not effectively interpret is in that station area. At Kunshannan railway station, X_7 exhibits a strong driving force and the explanatory power of catering service is also outstanding. Uncommonly, scenic spot become significant here. At Xuzhoudong railway station, the most important factors affecting the growth of the lodging business are catering service and living service. Enterprise and financial insurance are irrelevant in this situation. Although the driving force of the scenic spot is weak, it is significant.

Comparing the influencing factors of various stations, the factor with the greatest driving function is different. It implies that different HSR station areas have different preferences for where the accommodation industry should be located. The business residence has a strong driving force for the distribution of the lodging industry at Beijingnan, Tianjinxi, Nanjingnan and Jinanxi. It shows that in cities with a huge population, the distribution of the accommodation industry in the station area is closely related to the location of business residence. In contrast, in large cities such as Kunshan and Xuzhou, the main driving factors for the expansion of the accommodation industry in the HSR station area are living service, catering service and shopping service. However, the impact degree of enterprise and scenic spot is weak in all stations.

4.3. Factor Interaction Analysis

Interaction detection can evaluate the combined action of two factors. It can point out whether to strengthen or weaken the degree of interpretation. The results showed that the q-value of interaction was greater than that of the single factor, showing a non-linear or bifactor enhancement relationship. That means the combination of any two industries will greatly enhance the impact on the spatial distribution of the accommodation industry in the HSR station area. Figure 3 shows the interaction results of the driving factors.

At Beijingnan railway station, $X_2 \cap X_4$ has the largest interpretation value of 0.728. It means that catering service and business residence play the most important role in promoting the spatial distribution of the accommodation industry in the area. Interactions with q values greater than 0.6 are $X_1 \cap X_2$, $X_2 \cap X_3$, $X_2 \cap X_5$, $X_3 \cap X_4$, $X_3 \cap X_5$, and $X_3 \cap X_6$. Among them, X_2 and X_3 interact most frequently, further reflecting the important driving role of catering service and shopping service. At Tianjinxi railway station, the q value of $X_1 \cap X_3$ unexpectedly reaches 0.939, which indicates that the living service and shopping service have a significant impact on the spatial distribution of the accommodation industry in this station area. The q values of $X_1 \cap X_2$, $X_1 \cap X_8$, $X_2 \cap X_6$, $X_2 \cap X_7$, $X_2 \cap X_6$, $X_3 \cap X_6$, and $X_5 \cap X_6$ outweigh 0.6. Among the high interaction values, catering services and financial insurance are the most popular. About Nanjingnan railway station, except for $X_5 \cap X_8$ and $X_6 \cap X_8$, the q values of other combinations are greater than 0.6. The interaction of living service, catering service, enterprise, financial insurance and sports leisure is higher than 0.9. In addition, the combined driving effect of interaction with X_2 or X_3 is also significantly enhanced. Focusing on Jinanxi railway station, the highest interaction value belongs to $X_4 \cap X_7$ (>0.9). It shows that the co-development of business residence and sports leisure industry will greatly promote the prosperity of accommodation enterprises in the station area. The results of q values higher than 0.7 are $X_1 \cap X_2$, $X_1 \cap X_4$, $X_2 \cap X_5$, $X_3 \cap X_4$, $X_3 \cap X_7$, $X_4 \cap X_5$, and $X_5 \cap X_7$. From Figure 3e, it is clear that the interaction of X_2 or X_7 with other factors significantly improved the explanatory power. The q values of $X_1 \cap X_2$, $X_1 \cap X_4$, $X_1 \cap X_7$, $X_2 \cap X_4$, $X_2 \cap X_5$, $X_2 \cap X_6$, $X_2 \cap X_7$, $X_3 \cap X_7$, and $X_7 \cap X_8$ are greater than 0.9. This fully reflects the driving effects of catering service and sports leisure. At Xuzhoudong railway station, $X_1 \cap X_3$ has the greatest explanatory effect, and the q value is 0.948. In addition, X_2, X_5, X_7, and X_8 also play an important role in interaction. This represents that the spatial distribution of the accommodation industry is closely related to the living service, catering service, shopping service, enterprises, sports and leisure, and scenic spots in the station area.

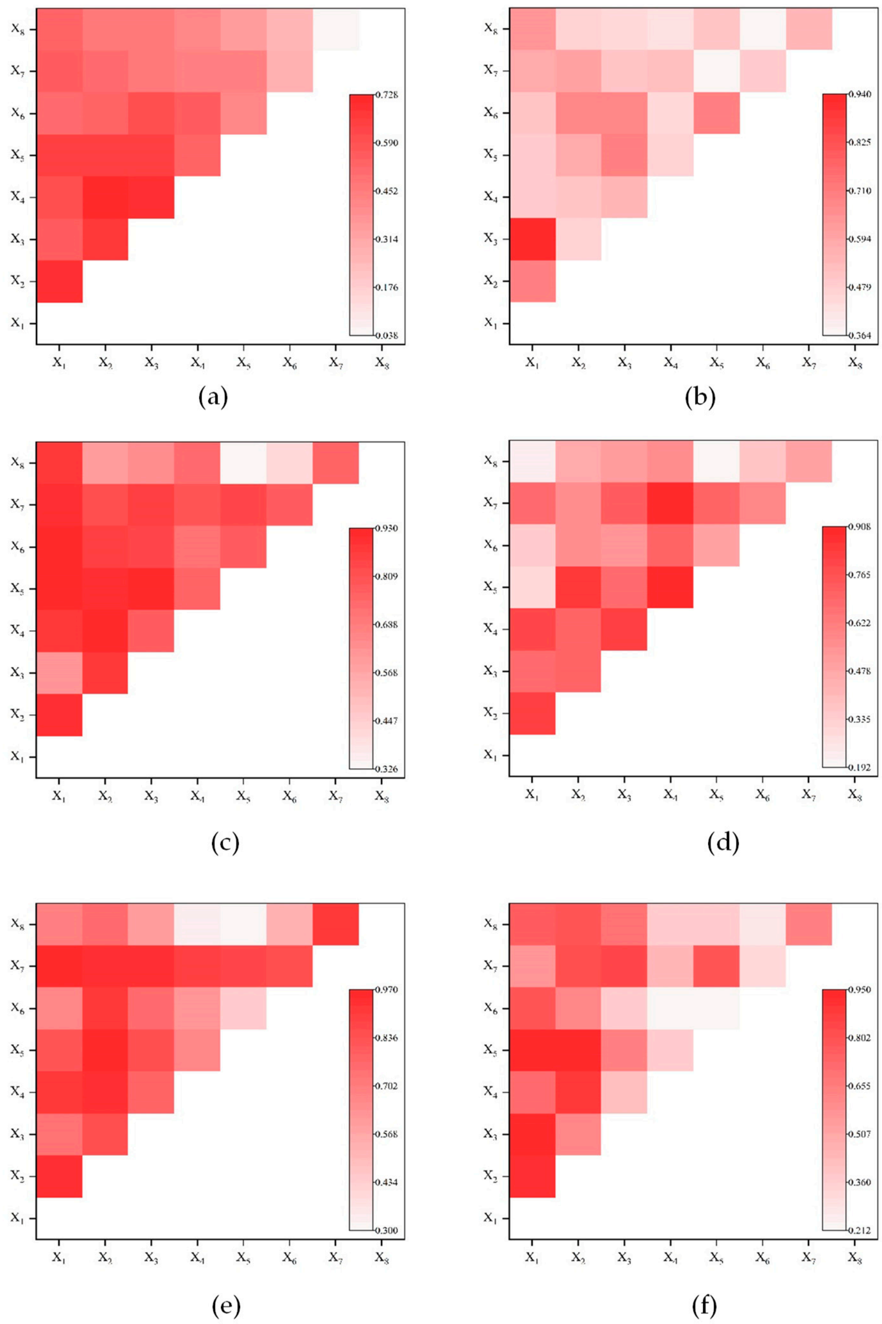

Figure 3. Interaction detection results: (**a**) Beijingnan; (**b**) Tianjinxi; (**c**) Nanjingnan; (**d**) Jinanxi; (**e**) Kunshannan; (**f**) Xuzhoudong.

5. Discussion

Although the transportation hub is an important location for the distribution of the accommodation industry, the HSR station area developed due to transportation technology innovation has not received sufficient attention. This paper analyzes the spatial distribution and agglomeration evolution characteristics of the accommodation industry in the HSR station area, and also explores the differences in influencing factors in cities of different sizes.

Research on the spillover effect of HSR stations shows that the operation of HSR increased the light intensity for areas within a 4 km radius of HSR stations by 27% [52]. However, the types of economic activities have not been distinguished. The results obtained in our study make up for the lack of research to a certain extent. This paper finds that the accommodation industry is distributed in each circle of the HSR station area. However, in smaller cities, the accommodation industry is more concentrated in the core circle (0–1 km), which refines the research on the spatial structure of the HSR station area. In supersized cities, the accommodation industry is more concentrated in the periphery circle (2–3 km). These findings can be useful for HSR station area land use, planning, and optimization in cities of different sizes. The characteristics of industrial structures are highly dependent on local planning decisions. Construction planning must take into account the local demand [7]. Without appropriate planning, the urban functions of the station area cannot be realized effectively. Governments in different cities should guide the rational distribution of industries to avoid inefficient land use.

Even though Wang et.al proposed that only a few newly constructed HSR stations can attract energetic urban activities [53], our research found that the development of the station area industry is a process of accumulation, whether it is newly established or remodeled. In some cities, the accommodation industry is gathering rapidly. In other cities, it will take several years for the accommodation industry to produce an agglomeration effect. However, in the end, the industrial distribution at all stations will show a cluster pattern, and the degree of agglomeration increases as time goes on. In location selection, accommodation facilities should refer to the current stage and degree of industrial agglomeration, so that enterprises can strive for positive agglomeration effects in the station area. This can be referred to the lodging industry of subway stations [39].

The spatial distribution of the accommodation industry in the HSR station area is affected by multiple factors. In cities of all sizes, living service, catering service and shopping service have a significant impact on the accommodation industry. Separately, in super large cities with a population of more than 10 million, the business functions of the HSR station area are relatively prosperous. The location of the accommodation industry is relatively consistent with the distribution of business residences. This finding confirms the view of Han and Song [38]. In mega cities, the role of sports leisure is highlighted. In large cities with a population of less than 5 million, scenic spots have a weak influence on the location selection of the lodging facilities, but the ultimate driving factor is the fundamental service and sports leisure facilities. Relevant departments shall make reasonable plans for the station area industry based on the city scale. For cities with a larger population, the industrial types in the station area should be reasonably allocated from the main driving factors. The distribution of the accommodation industry should fully consider the interaction between the basic service industry and derivative service industry. For cities with a smaller population, based on the development of basic service facilities, accelerating the development of derivative services can effectively improve the scale of the station accommodation industry. Enterprises, business residences, and financial insurance facilities can be taken as key construction objects.

6. Conclusions

This paper explores the characteristics and evolution of industrial spatial structure in transport hub regions from the perspective of the accommodation industry. KDE, NNI and Geodetector are the methods used. The spatial distribution structure, spatial agglomeration characteristics, and relevant driving factors of the accommodation industry in HSR station areas in different cities are compared and analyzed. The main conclusions of this study are as follows.

Firstly, the spatial distribution structure of the accommodation industry is different in transport hub areas of different cities. Located in the HSR station area of a supersized city, the high kernel density points of the accommodation industry occurred in the periphery circle. In the HSR station area of the mega city, the gathering points of the accommodation industry are distributed in the core circle and the periphery circle. However, the higher kernel density value of the accommodation industry in the HSR station area in large cities is mainly located in the core circle. The spatial distribution of the accommodation industry in different station areas is different, which may be related to the specific planning of local government. On the whole, the smaller the population size of the city, the closer the high agglomeration area of the accommodation industry in the HSR station area is to the HSR station. It has something in common with the view that accommodation services are mainly concentrated in the core circle [51].

Secondly, the longer the HSR station is opened, the stronger the agglomeration intensity of the accommodation industry is. In the year when the HSR station was opened, the spatial distribution of the accommodation industry had already shown a concentrated distribution. However, the development of the lodging industry in some HSR stations is slow, and it takes several years of accumulation to move from discrete distribution to clustered distribution. In general, the larger the population of the city, the sooner the accommodation industry in the station area enters the cluster distribution. This is related to the urban function level and the development orientation of the HSR station. In the later stage, the variation range of the agglomeration degree of the accommodation industry will gradually narrow. According to Deng et al. [16], the level of urban economic development, the level of urban rank and the location of HSR stations are important factors affecting the regional development of HSR stations. That is further confirmed in the conclusion of this paper. We found that the larger the population, the smaller the concentration of the accommodation industry in the HSR station area. That is, the scope of economic activities in HSR station areas of large cities is larger.

Thirdly, there are notable variations in the influencing factors of the accommodation industry at HSR stations in different cities. The interaction between the factors has a synergistic enhancement effect. In supersized cities, living service, business residence and shopping service are the main factors driving the formation of the spatial structure of the accommodation industry. In mega cities, sports leisure, business residence and catering service have the greatest influence. In big cities, sports leisure, catering service, living service and shopping service have a great driving effect on the development of the accommodation industry. It is worth noting that tourism resources represented by scenic spots are not always considered in the location selection of the station accommodation industry. That confirms the research of Fang et al. [54]. Attractions only show its influence in the HSR station area of big cities. Previous findings suggest that commercial lodging facilities are mainly located in transportation hub centers and in entertainment and leisure areas [38]. This study also draws consistent conclusions. In general, in supersized cities, the spatial distribution of the accommodation industry in the HSR station area is closely related to the location of commercial residential buildings. In big cities, sports leisure and basic service facilities such as living, catering and shopping all affect the spatial distribution of the accommodation facilities. The function of commercial residences is not very important here.

In summary, using spatial big data, this paper analyzed the spatial distribution, evolution, and industrial driving factors of the accommodation industry in the HSR station areas of various cities with the help of GIS tools. Relevant conclusions provided a valuable reference for the spatial optimization, industrial layout and project development in the perimeter zone of transportation hubs. Moreover, our research provided a universal industrial analysis tool that would be applied to various scales, such as stations, historical districts, cities, etc.

This study also has some limitations. First of all, the analysis is only conducted from the perspective of a kind of industry. There is no distinction about the size and capacity of accommodation industry either. In addition, this paper only discusses the industrial factors of lodging industry spatial distribution and does not involve non-industrial factors such as accessibility, environment, policy, or distance between stations and cities. In future research, based on the existing research, we can comprehensively analyze the factors that may affect the accommodation facilities in the station area, clarify its mechanism, and provide more effective references for station area planning.

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