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The Spatio-Temporal Heterogeneity of Financial Agglomeration on Green Development in China Cities Using GTWR Model

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Abstract: By promoting financial agglomerations to support green development in a region is a keyway for China to resolve the sharp contradiction between economic growth and environmental protection. However, existing research only considered the promotion effect of financial agglomerations on green development, but the spatio-temporal non-stationarity of that effect has been overlooked. Using a panel data of 285 prefecture-level cities in China and based on the evaluation of green development by a Driving-Pressure-State-Impact-Response (DPSIR) model, this paper analyzes the spatial correlation of financial agglomeration on green development. The paper also investigates the differences in the spatio-temporal influence of financial agglomeration on green development from both global and local perspectives by employing a Bivariate Local Indicators of Spatial Association (BLISA) model and a Geographically and Temporally Weighted Regression (GTWR) model. The results indicate that: (1) There exists significant spatial dependency between financial agglomeration and green development from 2003 to 2015, with Low-Low (L-L) and Low-High (L-H) spatial clusters as the main cluster types. (2) From the local perspective, the promoting effect of financial agglomerations on green development has showed significant spatial heterogeneity with a gradually decreasing trend from the southeast coast to the northwest inland of China. This work can help to develop policies for supporting green development by formulating differential strategies for financial agglomerations.

Keywords: financial agglomeration; green development; spatial autocorrelation; spatio-temporal heterogeneity; GTWR; China

1. Introduction

How to improve human wellbeing, protect the environment, and promote sustainable development through green economic growth are key goals of the 2030 Global Sustainable Development. Since the international financial crisis in 2008, the environmental degradation caused by rapid economic growth has worsened the health and the wellbeing of humans. The consequence of fast-paced development of traditional industries has led many developing countries all over the world to search for a sustainable way to achieve the balance of economic growth and environmental protection. Although having achieved an economic miracle in recent decades, China, the world's largest developing country, has also become the world's largest carbon emitter. The resource consumption and environmental pollution resulted from the long-term extensive industrial development seems to have reached the limit of environmental carrying capacity [1]. This has caused China to suffer from a serious environmental crisis.

If using the environmental standards of the US Environmental Protection Agency [2], 80% of the population in China would be considered as being exposed to pollution that is higher than the safety standard. In 2014, about 4000 people died from air pollution every day, accounting for 17% of the total number of deaths in China. In 2015 alone, the cost of ecological damage in China was estimated to be 63 trillion yuan (approximately USD $9 billion) and the cost of pollution on economic loss was estimated to be over 2 trillion yuan (USD $28 billion). Together, these accounted for 2.1% of China's Gross Domestic Product (GDP) [3]. Recognizing the severity of this, the Chinese government has committed to promoting green development in response to the global green economy initiative [4]. This committed China to using natural capital to achieve a sustainable development within the carrying capacity of China's ecological environment [5,6].

As a core element in the modern economy, the financial industry has an important influence on green development. Consequently, "financial support for green development" has been determined as a national strategy by the Chinese government in 2013. Similar to other economic activities, financial industry benefits from the scale economy by agglomerated development [7,8]. Agglomerated financial industries are also one of the typical characteristics of a sustainable development of a low-carbon city [9].

Given the aforementioned positions on financial industries as a form of sustainable green development, this paper explores several critical questions as China embarks on further developing financial industries as a green economic development. These questions include: How will the spatial agglomerations of financial industry affect green development? What are the effects? What would be the developmental process? Answers to the above questions can provide needed empirical evidence for China and other developing countries to support green development through promoting financial agglomerations.

Since high-quality economic growth and environmental protection are at the core of green development, this paper focuses on the economic beneficial effects of agglomerated financial industries on green development as related to protecting China's natural environment. The main contributions are as follows. (1) In terms of research objectives, financial agglomeration and green development are brought into a unified analytical framework to explore the complex relationship between the two. This framework not only enriches the connotation of financial agglomeration, but also points to a new path for promoting green development. (2) In terms of method, a geographically and temporally weighted regression (GTWR) model is used to investigate the characteristics of spatio-temporal non-stationarity (means that the influence of financial agglomeration on green development will change with the change of time and space) of financial agglomeration on green development. Results from such model provide reliable and detailed empirical evidences to support the development of relevant policies. (3) In terms of data, because financial agglomeration generally occurs in urban units, each within a small spatial extent, 285 cities in China are used as research subjects. Such a smaller geographic analytical unit is more representative and instructive than using national or provincial samples.

The remaining sections of this paper are as follows: Section 2 introduces the methods, variables, and data used in this study. Section 3 presents the results from empirical analysis carried out in the study. Section 4 concludes the discussion and offers recommendations for future works and the development of relevant policies.

2. Related Literature Review

Since high-quality economic growth and environmental protection are the core elements of green development, studies on financial agglomeration and green development have mainly focused on economic growth and the performance of environmental protection.

On financial agglomeration and economic growth: Existing studies show that there is a strong causal relationship between financial agglomeration and economic growth [10–12]. However, there is not yet a consensus reached on the relationship because of the complexity of all types of influencing factors [13]. There have been three main views formed on this.

First, financial agglomeration can promote economic growth by optimizing the allocation of financial resources thus improving the efficiency of green development. Calderón and Liu (2003) found that financial agglomeration can promote economic growth, and the promoting effect is greater in developing countries than that in industrialized countries [14]. When examining the relationship in India, Sehrawat and Giri (2015) confirmed that the bank-centered financial sector could accelerate economic growth through credit transmissions [15]. The same conclusions appeared in countries such as Sudan, Russia, and Turkey [16,17].

Second, financial agglomeration may lead to agglomeration diseconomy in some cases, thus inhibiting economic growth. Adeniyi et al. (2015) found that financial agglomeration had a significant negative impact on economic growth in Nigeria [18]. Charfeddine and Kahia (2019) verified that financial agglomeration contributed very little to economic growth in the 24 countries in the Middle East and North Africa they had studied [19]. Similar conclusions were also reached for developing countries like India [20,21].

Third, financial agglomeration has an uncertain influence on economic growth under the constraint of spatio-temporal non-stationarity. Some scholars failed to find a detectable causal relationship between financial agglomeration and economic growth [22,23] but others found a complex nonlinear relationship between the two [24–26]. Such relationship could be affected by many factors such as temporal trends of economic development, income levels, regional differences, financial levels, and initial economic growth rates [23,26–29].

On financial agglomeration and the performance of environmental protection: There are three main viewpoints as follow:

First, financial agglomeration is conducive to technological innovations and it improves the performance of environmental protection efforts. Riti et al. (2017) believed that financial agglomeration is helpful in improving the regional environmental quality in 90 countries [30]. Katircioğlu and Taşpinar (2017) demonstrated that financial agglomeration could alleviate the impact of actual output on carbon dioxide emissions in Turkey, both in the short-term and in the long-term [31]. Similar conclusions were found in studies on Indonesia, Austria, Denmark, Germany, Ireland, the Netherlands, Norway, Portugal, the United States, and Malaysia [32–34].

Second, the promoting effect of financial agglomerations on economic growth tends to lead to sharp increases in resource and energy consumption, thereby aggravating environmental pollution and weakening the performance of environmental protection efforts. Al-Mulali et al. (2015) discovered that financial agglomeration can cause the increase of carbon dioxide emissions in 23 European countries [35]. Sharif et al. (2019) suggested that financial agglomeration could be an important cause for environmental degradation of 74 countries [36]. Similar conclusions have also been found in China, Association of Southeast Asian Nations (ASEAN) five countries, and Pakistan [34,37,38].

Third, due to the impact of natural conditions and social factors, there is significant spatial heterogeneity in the relationship between financial agglomeration and the performance of environmental protection efforts in cities of different regions and urbanization stages, resulting in uncertainty in the relationship. For example, Dogan and Turkekul (2016) concluded that there was no causal relationship between financial agglomeration and carbon dioxide emissions in the United States [39], while Jamel and Maktouf (2017) contended a two-way Granger causality between the two in 40 European countries [40].

The analysis above investigates the average effect of financial agglomeration on green development from a global perspective, but ignores the spatial heterogeneity effect in the process of spatio-temporal transformation. Due to different factors such as administrative division, culture, history, initial endowment, and time trend of different cities, the effect of financial agglomeration on green development shows significant differences. Therefore, only analyzing from a global perspective cannot effectively guide urban development. Although some studies adopted the temporally weighted regression (TWR) model or geographically weighted regression (GWR) model to investigate the time effect or spatial effect [41–43], few have considered the temporal heterogeneity and spatial heterogeneity simultaneously. This may be an important reason for the inconsistency in the conclusion of the influence of financial agglomeration on green development.

Nevertheless, existing studies have pointed to the following deficiencies. (1) Few studies have put financial agglomeration and green development into a unified analytical framework when carrying out empirical studies. (2) Little attention has been paid to the differences in the impact of financial agglomeration on green development under the constraint of spatio-temporal non-stationarity, resulting in the inability of developing an effective guidance on regional green development.

3. Data, Methods, and Variables

3.1. Data Sources

In this paper, a set of panel data of 285 Chinese cities above prefectural level from 2003 to 2015 are used as the research subjects. Among them, the economic data comes from *China Urban Statistical Yearbook* [44]; the data of the city's longitude and latitude coordinates are from the National Geomatics Center of China (http://www.ngcc.cn/ngcc/); the climate data come from the National Meteorological Information Center website (https://data.cma.cn/en). Missing data are supplemented by using the interpolation from mean values of adjacent years.

In order to maintain the consistency of statistical coverage, we exclude data with missing values caused by changes in administrative units or by other reasons. We eventually have the panel data that include 285 cities in China for analysis. Taking 2003 as the base period, we use the GDP index of that year to deflate all price variables so as to eliminate the impact of inflation over time.

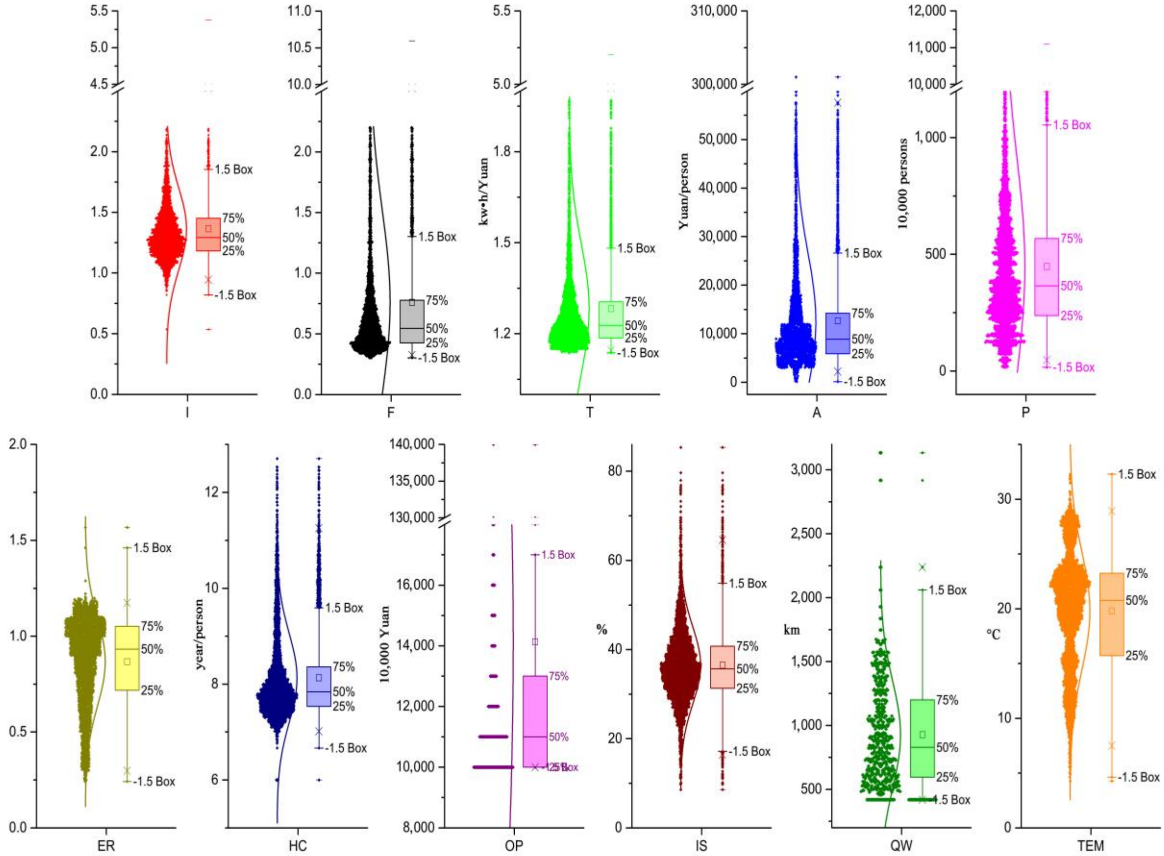
Descriptive statistics of the model variables are shown in Figure 1. According to the boxplots of variables, the original data of GD, P, HC, and IS are basically normal distributed without serious outliers. The mean values of the original data of FA, T, A, OP, and QW are larger than their median, which is in line with the characteristics of positive skewness distribution. The mean value of the original data of ER and TEM is less than the median, satisfying the characteristics of negative skewness distribution. Therefore, all variables in the model are logarithmically processed to make them closer to normal distribution, thus reducing model bias.

According to variance inflation factor (VIF) analysis (See Table A1 in Appendix A), the maximum value of VIF is 3.250 and the minimum value is 1.140, both of which are less than the critical value 10, indicating that there is no serious collinearity between variables. Based on the correlation coefficient analysis (See Table A1 in Appendix A), the maximum value of correlation coefficient between variables is 0.694, the minimum value of correlation coefficient is 0.005. Most of the coefficients are significant at the confidence level of 10%, representing that there is no problem of highly correlated or unrelated between variables. Therefore, the multicollinearity can be ignored in the following analysis.

3.2. Methods

3.2.1. BLISA Model

If the first law of geography stands, all geographical elements are said to be interrelated with the closer the geographical distance is between two places, the stronger the spatial correlation will be between attributes describing the places [45]. Hence, this paper uses a BLISA model to test the spatial autocorrelation between financial agglomeration and green development. The test can be divided into global spatial autocorrelation test, which describes the characteristics of a spatial distribution of geographical elements as a whole, and local spatial autocorrelation test, which focuses on the characteristics of local spatial distributions [46].



Notes: GD represents green development; FA represents financial agglomeration; P represents population size; A represents the affluence; T represents technology progress; ER represents environmental regulation; HC represents human capital; OP represents the opening up level; IS represents industrial structure; QW represents location conditions; TEM represents climatic factors.

Figure 1. Boxplots for the model variables.

Existing studies generally use the univariate Moran's index to test the spatial autocorrelation of geographical factors. However, when analyzing the spatial autocorrelation of two variables, bivariate Moran's index has a higher applicability. Bivariate global Moran's I can be calculated as follow [47]:

$$I = \sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}(x_i - \overline{x})\left(y_j - \overline{y}\right) / s^2 \sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}, \quad (1)$$

where i and j represent different cities; n is the number of samples; W is the spatial weights matrix; x and y respectively represent financial agglomeration and green development of different cities; $\overline{x}$ is the average national urban financial agglomeration, $\overline{y}$ is the average national urban green development; s^2 is the sample variance; I is the bivariate global spatial autocorrelation coefficient, representing the overall spatial distribution correlation between financial agglomeration and green development in different cities.

Bivariate local Moran's I can be calculated as follow [48]:

$$I_i = s_i \sum_{j=1}^{n} w_{ij} s_j, \quad (2)$$

where s represents the variance standardized value of financial agglomeration and green development in different cities; I_i is the bivariate local spatial autocorrelation coefficient, representing the local spatial correlation between financial agglomeration and green development in different cities. The definitions of other notations are the same as before.

According to the financial agglomeration level of city i and the green development level of city j, there are four types of local spatial clusters: an H-H (High-High) cluster means that both levels are high; an L-L cluster means that both levels are low; an L-H cluster means that the former is high while the latter is low, an H-L (High-Low) cluster means the opposite of an L-H cluster.

H-H clusters and L-L clusters reflect that the financial agglomeration level of city i and the green development level of city j are positively spatially autocorrelated, whereas an L-H cluster or an H-L cluster means that the two are negatively spatially autocorrelated. The significance of Moran's I indicates whether the relationship holds with a statistical significance.

3.2.2. GTWR Model

Since a GTWR model takes into account both the non-stationary effect of space and time [49], it is adopted to explore the spatio-temporal heterogeneity of the impact of financial agglomeration on green development under the constraint of spatio-temporal differences. By establishing a three-dimensional (longitude, latitude, and time) elliptical coordinate system in which temporal dimension is the vertical (third) dimension in addition to the two horizontal spatial dimensions of longitudes and latitudes, the model can describe the influence of space and time by using the regression coefficients associated with explanatory variables [50].

The expression of the GTWR model is [51]:

$$lnGD_i = \varphi_0(lon_i, lat_i, t_i) + \sum_{k=1}^{k} \varphi_k(lon_i, lat_i, t_i) x_{ik+} \varepsilon_i, \tag{3}$$

where $\varphi_0(lon_i, lat_i, t_i)$ represents the intercept item of city i in period t; k is the number of explanatory variables; $\varphi_k(lon_i, lat_i, t_i)$ means the regression coefficient of the kth explanatory variable in the t period; other variables are defined as above.

3.3. Model Variables

3.3.1. Dependent Variable (GD)

There are two main methods for evaluating green development as suggested in existing studies. One is by using an indicator system evaluation method, which covers a wide range of indicators. It can reflect the progress of green development based on a wide variety of different aspects of economy and society [52]. However, it may cause the problem of redundancy if a large number of variables are included in the analysis [53]. In addition, indexes used as model variables can be selected subjectively, which may cause biases inevitably. The other potential problem is the data envelopment analysis (DEA) method may contain undesired output, which may be due to the calculation of green development efficiency based on input–output relations of included variables. Nevertheless, this method requires less data and has strict logic [6,54,55], but the biggest defect is that the index dimension is simple. Hence, it is difficult to fully express the connotation of the complex nature of green development.

According to the connotation of green development, we select a DPSIR model to evaluate green development [56,57]. The DPSIR model aims to establish the causal chain of driving forces, pressures, states, impacts, and responses [58], so as to effectively reflect the interrelationship among factors in the system. Therefore, the paper constructs an indicator system from five aspects, that is, driving forces of green development, pressures of green development, state of green development, responses to green development, and impacts by green development. The index system and calculation method can be seen in Yuan et al. (2019) [57].

3.3.2. Independent Variables (FA)

Existing studies generally use the number of financial practitioners or the output values of the financial industry to describe the degree of financial agglomeration [59,60]. Given that the development of financial agglomeration may also be closely related to the macroeconomic conditions and the level of financial development, using a single indicator is not sufficient to accurately reflect financial agglomeration [61]. In view of this, we construct a financial agglomeration index from the aspects of financial environment, financial scale, financial depth, and financial width (the index system and calculation method can be seen in [57]).

Financial environment of a city represents its level of economic development and information construction. Financial scale shows the financial scale and potential for financial development in a city. Financial depth of a city refers to the city's increase of financial assets, which reflects its degree of activity of urban financial services [62,63]. Financial width of a city indicates the channel width through which financial media can put city residents' savings into various aspects of the national economy, and is mainly used to measure the richness of urban financial products and the innovation of financial instruments of the city [64,65].

3.3.3. Control Variables

The Stochastic Impacts by Regression on Population, Affluence and Technology (STIRPAT) model assumes that population size and affluence are important causes for environmental problems. Industrial technologies further magnify damages to environment. Accordingly, it is necessary to contain population size, affluence, and technological progress in the model to isolate the effects of financial agglomeration on green development [66]. Drawing from relevant literature [67–69], we adopt the total population at year-end of a city as its population size (P), its per capita GDP (A) as the affluence, and its industrial general output as the technology progress (T).

The factors influencing green development in modern society are many and complex. Referencing existing research, this paper adds the following control variables to benchmark the models. The percentage of industrial sulfur dioxide removed, the percentage of industrial fumes removed, the percentage of industrial solid wastes utilized, the percentage of city sanitary wastewater treatment, and the rate of city domestic harmless garbage treatment are selected to reflect the environmental regulation intensity (ER) [70]. In addition, average years of schooling is used as a proxy variable for human capital (HC) [71]. The proportion of the actual utilized foreign direct investments in GDP is used to represent the opening up level (OP) [72]. The proportion of tertiary industry value in GDP to describe the industrial structure (IS) [73]. The shortest distance from each city to an important port (The important ports are the eighteen port cities declared by the China State Council in 1984, including Shenzhen, Zhuhai, Xiamen, Shantou, Dalian, Qinhuangdao, Tianjin, Yantai, Qingdao, Lianyungang, Nantong, Shanghai, Ningbo, Wenzhou, Fuzhou, Guangzhou, Zhanjiang, and Beihai.) is chosen to describe location conditions (QW) [74]. The average annual temperature is selected to measure the climatic factors of each city (TEM) [75].

4. Results

4.1. Spatial Autocorrelation Test

4.1.1. The Global Spatial Autocorrelation between Financial Agglomeration and Green Development

In order to further test the spatial autocorrelation of financial agglomeration and green development, we adopt bivariate Moran's I (implemented in Geoda1.12) to measure the bivariate global Moran index of model variables and the associated statistical significance. Meanwhile, to verify the robustness, the univariate global Moran index value and its significance of financial agglomeration and green development are also given in this paper (Table 1).

Table 1. Global Moran's *I* statistics and their significance.

Year	Univariate FA	Univariate GD	Bivariate FA and GD
2003	0.085 ***	0.0519 **	0.063 ***
2004	0.057 ***	0.063 ***	0.059 ***
2005	0.065 ***	0.069 ***	0.063 ***
2006	0.042 **	0.047 **	0.043 ***
2007	0.040 **	0.078 ***	0.047 ***
2008	0.048 **	0.076 ***	0.052 ***
2009	0.063 ***	0.115 ***	0.071 ***
2010	0.047 **	0.078 ***	0.050 ***
2011	0.051 **	0.060 ***	0.057 ***
2012	0.092 ***	0.081 ***	0.067 ***
2013	0.069 ***	0.057 **	0.065 ***
2014	0.033 **	0.057 ***	0.045 **
2015	0.049 **	0.055 **	0.056 ***
Mean	0.076 ***	0.079 ***	0.070 ***

Note: ** $p < 0.05$, *** $p < 0.01$.

The univariate global Moran index of financial agglomeration and green development is shown to be positive from 2003 to 2015 and passes the significance test at 1% or 5% levels. This means financial agglomeration and green development show a trend of spatial agglomeration. The calculated value of bivariate global Moran index of the two is significantly positive at 1% significance level, indicating that financial agglomeration has significant spatial spillover effect on green development in neighboring regions. With the passage of time, the spillover effect shows a fluctuating upward trend (Figure 2). Both univariate and bivariate global Moran's *I* analyses prove that financial agglomeration and green development have significant spatial autocorrelation.

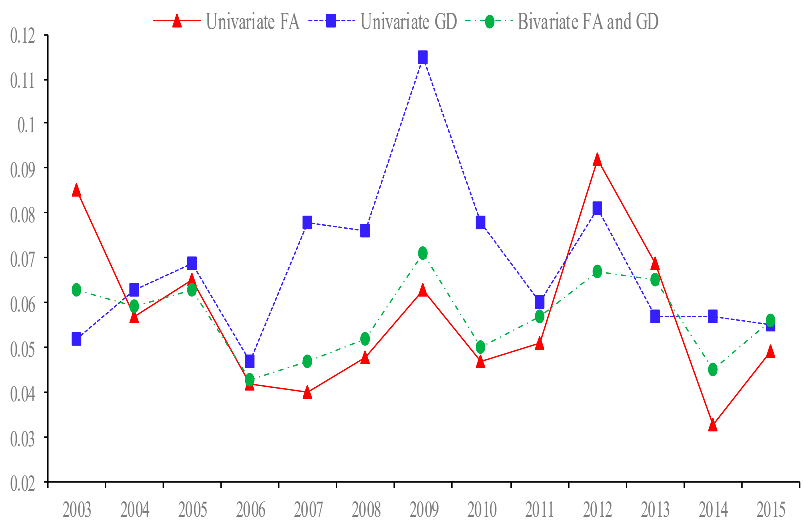


Figure 2. Univariate and bivariate global Moran trend graphs.

4.1.2. The Local Spatial Correlation between Financial Agglomeration and Green Development

The bivariate global spatial autocorrelation test can measure the level of spatial dependence and temporal non-stationarity on the whole but cannot describe the spatial non-stationarity. To this end, by using bivariate local Moran's *I* as implemented in Geoda1.12, we adopt the bivariate local Moran test and BLISA to explore the local spatial correlation patterns of financial agglomeration and green development. To observe the trend over time, BLISA results from 2003, 2009, 2015 and the mean values from 2003 to 2015 are selected for visualization, as shown in Figure 3. ArcGIS10.2 is used to draw the local spatial autocorrelation BLISA graph at the level of significance $p < 0.1$(Figure 3).

To observe the features of the four types of BLISA clustering patterns, the number of cities in different types is further counted (Table 2).

Table 2. Statistics of BLISA clustering of financial agglomeration and green development.

Year	H-H Cluster	L-L Cluster	L-H Cluster	H-L Cluster
2003	19	38	17	7
2004	12	33	18	9
2005	12	28	19	13
2006	18	21	24	7
2007	19	34	36	8
2008	17	29	33	8
2009	22	39	33	9
2010	23	37	27	7
2011	11	32	19	11
2012	21	40	28	8
2013	21	27	26	8
2014	20	31	28	7
2015	18	28	25	6

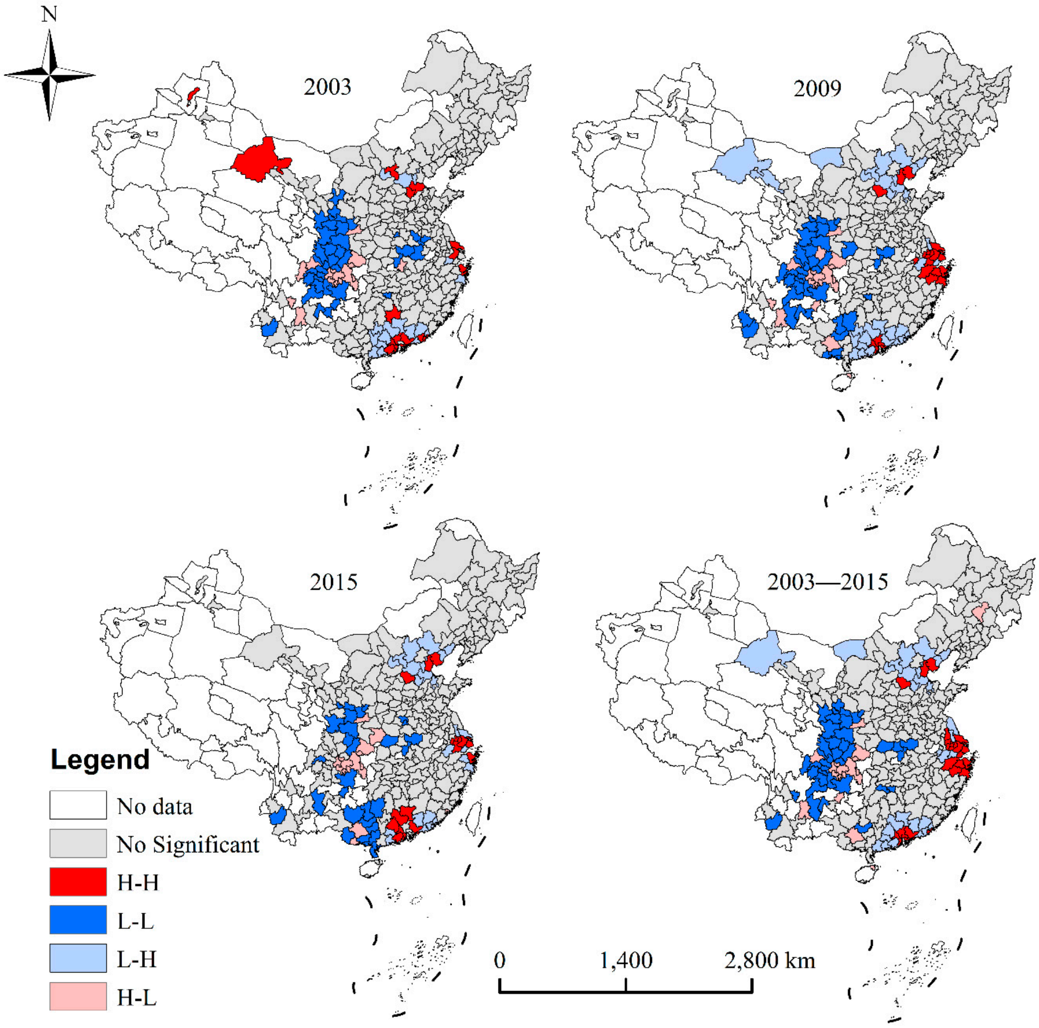


Figure 3. BLISA clustering of financial agglomeration and green development.

In the study period, high financial agglomeration–high green development (H-H) clusters, low financial agglomeration–low green development (L-L) clusters, low financial agglomeration–high green development (L-H) clusters are the three main types of local spatial correlation patterns, while only a few high financial agglomeration–low green development (H-L) clusters emerged.

Other observations include: (1) From 2003 to 2015, the number of H-H clusters are mostly around 20 cities, accounting for about 20% of the examined regions. These areas are mainly concentrated in the Beijing-Tianjin-Hebei city cluster, the Yangtze River Delta and the Pearl River Delta, where the centers of China's financial agglomeration are located. They have rich financial resources to significantly impacts that green development have on neighboring areas. (2) L-L clusters are the main pattern during the study period at the proportion of about 38% of all examined cities. (3) L-H cluster areas account for more than 30% of the cities with statistical significance. They are mainly located in the peripheral areas of the Beijing-Tianjin-Hebei city cluster, the Yangtze River Delta and the Pearl River Delta regions. That also includes most areas in Hebei, the border areas of Jiangsu, Zhejiang, and Anhui, and the two sides of Guangdong. Among them, the most significant change is that the peripheral areas of the Beijing-Tianjin-Hebei city cluster jumped from insignificant areas to be L-H cluster areas in 2009. (4) The average number of H-L clusters from 2003 to 2015 is about 8 cities. They are mainly situated in and around large industrial cities like Changchun, Wuhan, Chongqing, Panzhihua, Chengdu, and Xi'an. The above analyses demonstrate that the influence of financial agglomeration on green development has spatio-temporal non-stationarity.

4.2. The Local Non-Stationary Impact of Financial Agglomeration on Green Development

4.2.1. Model Fitting

To further identify the impacts of financial agglomeration on green development in different cities and over different time periods under the constraint of spatio-temporal heterogeneity, this paper re-estimates the impact by using a GTWR model with spatio-temporal non-stationary. The regression results of the TWR model and the GWR model are also presented and comparatively analyzed to verify the effectiveness of the GTWR model (Table 3).

The R^2 of the GTWR model is 0.675, which is higher than that of the TWR model (0.555) or that of the GWR model (0.569), indicating that the GTWR model has the highest explanatory power. The residual standard error of the GTWR model is 0.103, and the residual sum of squares is 39.684, which is significantly lower than that of the TWR model and the GWR model. This proves that the error of the GTWR model is the minimum. The AIC value of the GTWR model is significantly lower than that of the TWR model or that of the GWR model, representing that the GTWR model is the most suitable to use. In addition, from the perspective of regression standard deviation, the prediction error of the GTWR model is the smallest, meaning its prediction ability is better than those of the other two models. Based on the above analysis, the GTWR model is likely the optimal for explaining the relationship between financial agglomeration and green development.

4.2.2. Local Spatio-Temporal Non-Stationary Results

According to Table 3, the upper quartile and the lower quartile of the regression coefficients of financial agglomeration have the same direction as those in the results of the global regression model. This suggests that the model results are robust. The results also show that financial agglomeration has a significant positive spillover effect on green development, which supports the conclusion derived from the SPDM model. The differences in the effect of three models are probably related to the different aspects of non-stationarity considered by each model. In order to clearly identify the spatial heterogeneity of the impact of financial agglomeration on green development, we visualize the average annual regression coefficients of financial agglomeration in the GTWR model by using ArcGIS10.2 (Figure 4).

Table 3. Estimation results of spatio-temporal non-stationarity.

Variables	TWR Model				GWR Model				GTWR Model			
	Upper Quartile	Median	Lower Quartile	Range	Upper Quartile	Median	Lower Quartile	Range	Upper Quartile	Median	Lower Quartile	Range
lnFA	0.579	0.62	0.796	0.217	0.23	0.312	0.399	0.169	0.236	0.391	0.567	0.331
lnP	0.046	0.088	0.125	0.079	0.14	0.266	0.422	0.282	0.069	0.231	0.381	0.312
lnA	0.584	0.705	0.754	0.17	0.761	0.969	1.162	0.401	0.715	1.015	1.288	0.573
lnT	0.391	0.435	0.561	0.17	0.165	0.324	0.494	0.329	0.195	0.396	0.672	0.477
Constant term	−0.346	−0.29	−0.241	0.105	−0.598	−0.489	−0.333	0.265	−0.653	−0.498	−0.314	0.339
Diagnostic information R^2	0.555				0.569				0.675			
Residual standard error	0.131				0.11				0.103			
Residual sum of squares	63.673				61.407				39.684			
AIC	−4539.566				−4673.856				−6291.351			
Regression standard deviation	0.131				0.129				0.103			
Bandwidth	0.48				276.846				480.397			

Based on the distribution of the regression coefficients, the overall effect is significantly positive, and the spatial trend is gradually decreasing from the southeast coastal regions to the northwest inland regions. On one hand, there is an outward gradient decreasing trend along the three core regions: the Beijing-Tianjin-Hebei city cluster, the Yangtze River Delta cluster, and the Pearl River Delta cluster. On the other hand, the central and western regions are shown to be the regions where financial agglomeration supports green development only weakly. This is consistent with the conclusion derived at by local spatial autocorrelation test. The main reason for this is that China is a country with a vast territory that has significant differences in environmental conditions, resource endowments and socio-economic development among different regions.

The Beijing-Tianjin-Hebei city cluster, the Yangtze River Delta cluster, and the Pearl River Delta cluster have always been the core areas of China's economic development. Their prominent geographical advantages are their proximity to the seaports and their convenient internal and external links to inland regions. In addition, the developed economic conditions in these three areas make their financial agglomeration levels to be higher than those of other areas. Therefore, these areas can be considered as the cores of their respective "core-periphery" structures with their neighboring areas. Not surprisingly, they lead with the highest regression coefficients of financial agglomeration on green development that are characterized by gradient changes from each core to its periphery.

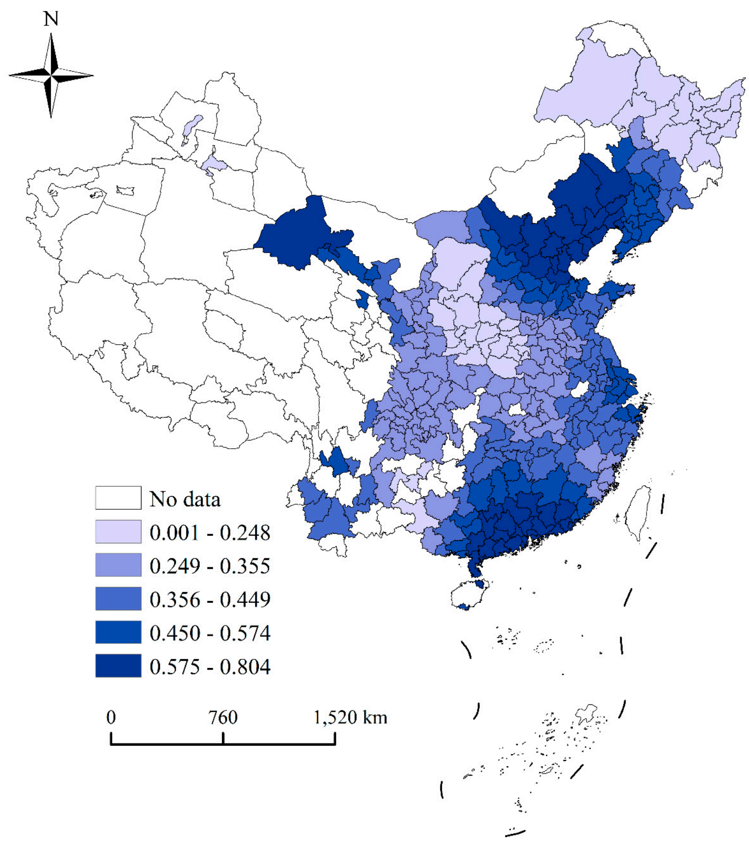


Figure 4. The local non-stationary influence of financial agglomeration on green development.

5. Discussion

5.1. Research Findings

From the analyses discussed, we have the following observations:

1. Over the studied period, financial agglomeration and green development show significant spatial autocorrelation and the degree of spatial dependence demonstrates a fluctuating and rising trend

over time. Among these results, the numbers of cities in L-L clusters and L-H clusters account for more than 60% of the examined cities with statistically significant spatial dependence.

2. Under the consideration of the local non-stationarity of time and space, financial agglomeration can still promote green development. Nevertheless, such effect shows significant spatial heterogeneity, which presents a gradually decreasing trend from the southeast coastal regions to the northwest inland regions.

5.2. Policy Implication

1. The government should allow and encourage the spillover effect of financial agglomeration and formulate differential strategies to support green development. This is not only conducive to green economic growth, but also can reduce fossil energy consumption and pollution, thus promoting sustainable development.

First, since financial agglomeration has significant spillover effects on the green development of adjacent regions, the peripheral areas of core financial agglomerations, the government should give priority to encourage regional financial agglomeration and allow the forming of multipolar financial centers. By boosting the connection of different gradient financial networks, the green development in regions adjacent to financial agglomerations can be promoted.

Second, different strategies should be developed for financial agglomerations to support green development according to different local spatial autocorrelation types. For H-H and L-L clusters, the positive spatial spillover effects should not only be maintained, but also be enhanced through structural adjustments and technological innovations. For L-H and H-L clusters, the causes of negative spillover effects should be explored through field research, thereby developing strategies to adjust the negative spillover effect into positive.

2. The government should pay more attention to the spatio-temporal differences in the way financial agglomeration influences green development. It would be beneficial to form a development pattern of "using points to drive shafts, using shafts to drive surfaces", or the pattern of "extending from points to lines, then from lines to surfaces". This is helpful to strengthen the ties between cities as well as between urban and rural areas, alleviate the gap between the rich and the poor, hence achieving regional sustainable development. Due to the decreasing trend from the southeast coastal regions to the northwest inland regions influenced by spatial heterogeneity, the government should continue to encourage the southeast coastal regions to build international financial centers through suitable policies or tax strategies.

At the same time, the positive spatial spillover effects of the advantageous financial agglomeration zones should be further brought into play. It is necessary to gradually build sub-regional financial centers along the east, west, south, and north, and continuously expand outward to form an axial financial agglomeration zone. Using the advantages of axial financial agglomeration zone of the southeast coastal regions, dense axial financial agglomeration zones of different grades should be established, and finally a plane-like financial agglomeration network covering the whole country should be constructed through modern information technology. Thus, the goal of promoting China's green development to achieve a spatially linked pattern can be achieved.

5.3. Limitation and Further Research

On the one hand, there exist obvious regional differences in the levels of effects that financial agglomeration has on green development [76]. This is mainly due to the different economic development, urban size, and city administrative rank [57,77,78], which lead to the regionally differentiated influences of financial agglomeration on green development. Accordingly, in future studies, it is necessary to analyze in-depth how financial agglomeration affects green development under the constraints of different levels of economic development, urban sizes, and city administrative ranks to facilitate the formulation of localized policies.

On the other hand, this paper has comprehensively showed the impact of financial agglomeration on green development. However, the results have not yet confirmed how financial agglomeration influences green development mechanically. Although many of the existing studies have analyzed the mechanism of industrial agglomeration from various aspects [79–82], up to now, none have discussed the influential paths of financial agglomeration on green development theoretically or empirically. Therefore, future research can be devoted to exploring the paths with which financial agglomeration affecting green development, thereby providing scientific references for local governments to promote green development through financial agglomeration.

Additionally, Thrift (1994) pointed out that most of the information on which financial agglomeration relies on is non-standardized information [83]. Most of this information is ambiguous, unclear, and hard to understand. After being transmitted, non-standardized information may introduce ambiguity to financial decisions due to distance-decay, thus inhibiting the long-distance spatial spillover of financial agglomeration on green development [84]. As a result, the conclusion of "death of distance" is not valid in the relationship between financial agglomeration and green development [85]. Considering the frictional effect caused by geographical distances, further study should be made to investigate the boundary of the spatial spillover effect of financial agglomeration on green development.

6. Conclusions

How financial industry drives the green development of Chinese cities from the perspective of space has always been an important topic for the government and academic circles. By selecting 285 Chinese cities above prefectural level as research subjects, based on the scientific measurement of green development by using the DPSIR model, this paper employs a BLISA model and a GTWR model to analyze the spatial autocorrelation characteristics and the spatial heterogeneity of financial agglomeration on green development over different time periods and across spatial regions. The results show that there is a significant spatial autocorrelation between the associations of financial agglomeration and green development. L-L and L-H clusters are the main cluster types. This has revealed obvious spatial heterogeneity and showed a trend of gradual decline from the southeast coastal areas to the northwest inland areas of China.

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Appendix A

Table A1. VIF test and matrix of correlation between variables.

Variables	VIF	lnGD	lnFA	lnP	lnA	lnT	lnER	lnHC	lnOP	lnIS	lnQW	lnTEM
lnGD	–	1										
lnFA	3.250	0.664 *	1									
lnP	2.780	0.034 *	0.180 *	1								
lnA	2.560	0.645 *	0.635 *	−0.157 *	1							
lnT	1.960	0.057 *	-0.059 *	−0.354 *	−0.105 *	1						
lnER	1.950	0.452 *	0.240 *	0.103 *	0.294 *	−0.052 *	1					
lnHC	1.700	0.473 *	0.570 *	0.137 *	0.531 *	−0.063 *	0.232 *	1				
lnOP	1.360	0.637 *	0.694 *	0.348 *	0.587 *	−0.135 *	0.236 *	0.551 *	1			
lnIS	1.300	0.310 *	0.388 *	0.201 *	0.174 *	−0.064 *	0.071 *	0.398 *	0.377 *	1		
lnQW	1.230	-0.240 *	−0.288 *	−0.261 *	−0.372 *	0.196 *	−0.171 *	−0.106 *	−0.397 *	−0.212 *	1	
lnTEM	1.140	0.035 *	0.079 *	0.245 *	0.005	−0.146 *	0.094 *	−0.076 *	0.139 *	0.038 *	−0.422 *	1

Note: * $p < 0.1$.

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