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Spatial–Temporal Characteristics and Driving Factors of the Coupling Coordination between Population Health and Economic Development in China

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Abstract: Promoting the coordinated development of population health and the economy is an important part of building a "Healthy China" and promoting high-quality economic development. Based on the systematic construction of the population health and economic development evaluation index system, this paper uses the coupled coordination model, geodetector, and geographically weighted regression (GWR) to comprehensively measure the population health level and economic development level at the provincial scale in China in 2000 and 2015, and reveals the spatial and temporal evolution characteristics of the coupled coordination relationship between the population health level and economic development level at the provincial scale in China from 2000 to 2015 and its driving factors. The results show the following: (1) China's population health and economic development are in a high-level coupling stage, and the coupling level increases slightly with time; spatially, two types of running-in coupling and high-level coupling coexist; the coupling degree in the eastern and central regions tends to increase, while the coupling degree in the western region tends to weaken. (2) China's population health and economic development are in a good coupling coordination stage as a whole, and the coupling coordination degree has an increasing trend; spatially, the coupling coordination degree shows high spatial differentiation characteristics in the east and low in the west; the good and high-quality coupling coordination type area tends to expand to the west, while the moderate coupling coordination type area tends to shrink to the west; there is also positive spatial agglomeration of coupling coordination degree, and the spatial agglomeration is gradually enhanced. (3) The coupling coordination of China's population health and economic development is driven by multiple factors such as natural conditions, health resources, culture quality, and urbanization level; the interaction between factors is stronger than that of a single factor, and the driving effect of each factor also shows significant spatial heterogeneity. This study is intended to provide a scientific basis for promoting harmonious population health and economic development.

Keywords: population health; economic development; coupling coordination; driving factors; China

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1. Introduction

Population health is a human capital input required for economic development, which in turn promotes population health enhancement. Since the founding of New China, especially since the reform and opening up, the health status of the population has been continuously improving along with rapid economic development. As of 2019, life expectancy in China has increased to 77.3 years, while infant mortality rate (IMR) and maternal mortality ratios (MMR) have decreased to 5.6 per 100,000 and 17.8 per 100,000, respectively [1], which are generally better than the levels of the world's middle- and high-income countries. While economic development creates material conditions for the improvement of population health, a series of problems that arise in the process of economic development, such as climate change, environmental pollution, and lifestyle changes, also bring new challenges

to the further improvement of population health. For a country with a large population such as China, failure to continuously improve the health of the population during the process of economic development may turn the advantage of human resources into a demographic burden, hiding a significant issue for future high-quality economic development. Population health and economic development are interlinked and interact with each other to promote economic and social progress. The "Healthy China 2030" Planning Outline clearly points out that the coordination between population health development and economic development should be enhanced, and promoting the coordinated development of population health and the economy is of great practical significance for building a "Healthy China", and thus promoting high-quality economic development.

In terms of the impact of economic development on population health, economic development provides the necessary food, nutritional healthcare, and other material conditions for population health promotion. Studies have concluded that economic development has a positive effect on population health improvement [2–6], and when economic development reaches a certain level, the rate of population health improvement tends to diminish, showing a slightly decreasing effect [7,8]. The effect of economic development on population health may not be immediately apparent, and some other studies have found that its cumulative time-lagged effects on population health are stronger than its current effects [9]. In addition, while income levels are increasing with economic development, income inequality has become increasingly prominent and an important constraint to further improvements in population health [10,11]. In terms of the impact of population health on economic development, human capital theory suggests that health, as an important human capital input, is one of the sources of economic growth [12–14]. An increase in the health of the population means an increase in effective labor time and productivity, which in turn affects economic development. Related studies have shown that healthy human capital can directly contribute to economic growth as an input factor in the production of final goods [15–17], but too much healthy human capital may also crowd out physical capital accumulation, which in turn is detrimental to economic growth [18–20]. As research progresses, it is also believed that healthy human capital indirectly contributes to economic growth through mediating factors such as labor supply, labor productivity, and savings rate [21,22]. Due to the improvement of population health, the health consumption demand for health care will also gradually increase, driving the development of the health service industry, so the improvement of population health also helps to promote the optimization and upgrading of economic structure [23]. All of the above studies are one-way analyses of the relationship between population health and economic development, while some studies also confirmed the bidirectional nature of the relationship between population health and economic development in terms of the interaction between the two [24–26]. Grasping the coupled and coordinated relationship between population health and economic development is conducive to a more accurate understanding of the relationship between population health and economic development, but to date, relevant studies only include Li Changda et al., who explored the coupled and coordinated relationship between the construction of "Healthy China" and economic and social development at a provincial scale in 2015 [27], and lacked the examination of the dynamic changes and driving factors of the coupled and coordinated relationship; thus, the research needs to be deepened.

Based on the above evaluation, based on the system coupling theory, this paper uses the coupling coordination degree model, entropy method, geodetector, and GWR to dissect the spatial and temporal characteristics and driving factors of the coupling coordination between population health and economic development at the provincial scale in China from 2000–2015 on the basis of constructing an evaluation index system of population health and economic development, and makes the following research hypotheses: (1) The coupling and coordination between the level of population health and the level of economic development at the provincial scale in China will tend to increase from 2000 to 2015 and show significant spatial differences. (2) The coupled coordination of population health

and economic development in China will be driven by multiple factors such as natural conditions, health resources, culture quality, and urbanization level.

The applied innovations and contributions of this paper are as follows: (1) It further enriches the international research on the interaction between population health and economic development and provides a Chinese case study, which is helpful in providing a reference for better handling the relationship between population health and economic development in the development process at the same stage of development, especially in developing countries. (2) The spatio-temporal evolution characteristics of the coupled coordination relationship between population health level and economic development level at the provincial scale in China from 2000 to 2015 were analyzed, and the interaction of its influencing factors was revealed using a geodetector, and the spatial differences in the effects of its influencing factors were revealed using GWR, which provided a more valuable scientific basis for accurate and locally appropriate coordination of population health and economic development.

2. Data and Methods

2.1. Selection of Indicators

The health level of the population was evaluated by three indicators: Life expectancy, IMR, and MMR, which are the core evaluation indicators of the health level in the national "Healthy China 2030" plan and are also the most important and commonly used indicators in academic research to evaluate the health level of the population [28–31]. Life expectancy reflects the health status of the population in terms of longevity, and it has been widely recognized as the indicator that best reflects the health status of the population [32–34]. IMR and MMR, on the other hand, reflect the health status of the population from the perspective of death, and because of their vulnerability to the external environment, infant and maternal mortality rates can more sensitively reflect the health status of the population in a region influenced by economic development, health care, culture quality [35,36], and have unique advantages in evaluating the health status of the population. Economic development not only refers to the growth of economic scale but also includes qualitative changes, i.e., optimization of economic structure and improvement of economic efficiency. The economic development level draws on the existing authoritative research results [37,38], follows the principles of scientificity, representativeness, and accessibility, and selects 11 indicators from the three dimensions of the economic scale, economic structure, and economic efficiency for comprehensive evaluation. The results of the selection of evaluation indicators for the level of population health and the level of economic development are shown in Table 1.

2.2. Data Sources

The data on population health level evaluation indicators were obtained from the China Statistical Yearbook [39] and the provincial statistical yearbooks. The data on the amount of investment in fixed assets of the whole society in the evaluation index of economic development level were from the China Statistical Abstract [40]. The data on the average wage of employees on duty were from the China Labor Statistical Yearbook [41], and the data on the remaining indexes were from the China Statistical Yearbook [39]; the data are on an annual basis. The study period of this paper is determined as 2000–2015, and limited to the availability of data, the two nodal years of 2000 and 2015 are mainly examined. The spatial scope of this paper was 31 provinces, autonomous regions, and municipalities directly under the central government in mainland China. Hong Kong, Macao, and Taiwan were not included in the study for the time being due to the lack of data, the spatial unit of study is the provincial administrative district. The map data used for the analysis were produced based on the standard map with the review number GS (2020) 4632 from the standard map service website of the Ministry of Natural Resources, and the base map was not modified.

Table 1. Evaluation index system of China's population health and economic development.

Target Layer	System Layer	Indicator Layer	Unit	Indicator Direction	Weights
Population Health Level	Lifespan Status	Life expectancy	Age	+	0.4705
	Death Status	Infant mortality rate (IMR)	‰	−	0.3584
		Maternal mortality ratios (MMR)	1/100,000	−	0.1711
Economic Development Level	Economic Scale	GDP	Hundred million (CNY)	+	0.0904
		Total social fixed asset investment	Hundred million (CNY)	+	0.0782
		Total retail sales of social consumer goods	Hundred million (CNY)	+	0.0911
		Local fiscal general budget revenue	Hundred million (CNY)	+	0.0922
		Urban and rural residents savings deposit balance	Hundred million (CNY)	+	0.0833
	Economic Structure	Share of secondary industry output in GDP	%	+	0.0221
		The proportion of tertiary industry output in GDP	%	+	0.0925
	Economic Benefits	GDP per capita	CNY	+	0.1069
		Per capita disposable income of urban residents	CNY	+	0.1209
		Net income per capita of rural residents	CNY	+	0.0973
		Average wage of employees in employment	CNY	+	0.1250

Note: "+" indicates the positive indicators, "−" indicates the negative indicators.

2.3. Research Methodology

2.3.1. Entropy Value Method

The entropy value method was used to calculate and determine the weights of each evaluation index of population health level and economic development level, and then synthesized the population health level, and economic development level by weighted summation and the calculation steps were as follows:

Data standardization processing: When considering the differences in the order of magnitude and positive and negative directions of each indicator, the raw data were first processed using the polar difference standardization method.

Positive indicators:

$$X_{ik} = \frac{x_{ik} - x_{k\min}}{x_{k\max} - x_{k\min}} \tag{1}$$

Negative indicators:

$$X_{ik} = \frac{x_{k\max} - x_{ik}}{x_{k\max} - x_{k\min}} \tag{2}$$

The weight of the value of indicator k in the i-th provincial unit:

$$Y_{ik} = \frac{X_{ik}}{\sum_{i=1}^{m} X_{ik}} \tag{3}$$

Calculation of the entropy value of the indicator:

$$E_k = -\frac{\sum_{i=1}^{m} (Y_{ik} \ln Y_{ik})}{\ln m} \tag{4}$$

Calculation of indicator weights:

$$W_k = \frac{1 - E_k}{\sum_{k=1}^{n} (1 - E_k)} \tag{5}$$

Weighted summation calculation of population health level and economic development level:

$$L_i = \sum_{k=1}^{n} X_{ik} W_k \tag{6}$$

where: x_{ik} is the value of the k indicator for the i provincial unit, $x_{k\min}$, $x_{k\max}$ are the minimum and maximum values of all provincial cells of the k-index, respectively. X_{ik} is the normalized value of the indicator k of the provincial unit i, m is the number of provincial cells, n is the number of indicators, E_k is the entropy value of the k-index, W_k is the weight of indicator k, L_i is the value of population health level and economic development level for provincial unit i. The results of the weights of each index calculated by the entropy value method are shown in Table 1.

2.3.2. Coupled Coordination Model

1. Coupling degree model

The coupling degree indicates the degree of interaction and interconnection between two or more systems. In this paper, we introduce a coupling degree model to evaluate the degree of interaction between population health and economic development, which was calculated as follows [42]:

$$C = 2\sqrt{\frac{H \times E}{(H+E)^2}} \tag{7}$$

where C is the coupling degree of population health and economic development, and the value range is [0, 1], H is the level of population health, and E is the level of economic development. The higher the value of C, the stronger the degree of interaction between population health and economic development. Drawing on relevant research results [43], the coupling degree of population health and economic development is classified into four types, namely low-level coupling ($0 < C \leq 0.3$), antagonistic coupling ($0.3 < C \leq 0.5$), running-in coupling ($0.5 < C \leq 0.8$) and high-level coupling ($0.8 < C \leq 1$).

2. Coupling coordination degree model

The coupling degree model can analyze the degree of interaction between population health and economic development, but it cannot reflect whether the two are mutually reinforcing at a high level of interaction or closely linked at a low level of interaction [44], i.e., it cannot reflect the level of coordinated development between the two. Therefore, the coupled coordination degree model was further introduced to evaluate the level of coordinated development between population health and economic development, which was calculated as follows [42]:

$$D = \sqrt{C \times T},\ T = \alpha H + \beta E \tag{8}$$

where D is the coupling coordination degree of population health and economic development, and the range of values is [0, 1], C is the coupling degree, and T is the comprehensive coordination index of population health and economic development. α and β are coefficients to be determined and $\alpha + \beta = 1$. This study was conducted to reveal the coupled and coordinated relationship between population health and economic development, treating both population health and economic development as equal without differentiating their importance, so $\alpha = \beta = 0.5$. Furthermore, drawing on relevant research results [43], the coordination degree of population health and economic development was classified into four types, namely low coordination ($0 < C \leq 0.3$), moderate coordination ($0.3 < C \leq 0.5$), good coordination ($0.5 < C \leq 0.8$), and high-quality coordination ($0.8 < C \leq 1$).

2.3.3. Spatial Autocorrelation

Spatial autocorrelation includes global spatial autocorrelation and local spatial autocorrelation. The global spatial autocorrelation was used to measure the degree of global

spatial correlation of the coupling coordination between population health and economic development, measured by Global Moran's I. Global Moran's I takes values in the range of [−1, 1], Global Moran's I > 0. The greater the value, the stronger the spatial agglomeration, and the smaller the value, the stronger the spatial dispersion. Local spatial autocorrelation was used to measure the degree of local spatial correlation between population health and economic development coupling and coordination, measured by Local Moran's I. Local Moran's I > 0 indicates that spatial units with similar attribute values tend to be clustered, and Local Moran's I < 0 indicates that spatial units with similar attribute values tend to be discrete. The formulas of global spatial autocorrelation and local spatial autocorrelation were in accordance with the study of Moran [45].

2.3.4. Geodetector

Geodetector can be used to detect the spatial heterogeneity of geographical things and reveal their drivers [46]. In this paper, we used factor detection and interaction detection in geodetector to analyze the driving factors of the coupled coordination of population health and economic development. Factor detection measures the driving force of each factor by a *q*-value, and interaction detection measures the magnitude of the interaction by calculating the *q*-value of multiple factors acting together and comparing it with the q-value of a single factor acting. The *q*-value is calculated as follows [47]:

$$q = 1 - \frac{\sum_{h=1}^{L} N_h \sigma_h^2}{N\sigma^2} \tag{9}$$

where h = 1, 2, ..., L is the number of categorical zones of the driver, and the number of categorical zones uses a five-class discrete scheme of natural breakpoints at a maximum value of q. N and N_h are the number of provincial cells for the country and sub-district h, respectively. σ^2 and σ_h^2 are the variances of the national and sub-region h, respectively. The value of q ranges from [0, 1], and the larger the value, the stronger the driving force of the factor.

2.3.5. Geographically Weighted Regression (GWR)

Unlike traditional regression models that assume data are not spatially correlated and are homogeneously distributed, GWR incorporates the spatial attributes of the data in the model to reveal spatial differences in the relationships of variables and is calculated as follows [48]:

$$y_i = \beta_0(u_i, v_i) + \sum_k \beta_k(u_i, v_i) x_{ik} + \varepsilon_i \tag{10}$$

where y_i is the dependent variable (coupling coordination) of the provincial cell i, (u_i, v_i) is the spatial coordinate of provincial cell i, $\beta_0(u_i, v_i)$ is the intercept term of provincial cell i, x_{ik} is the kth independent variable (driver) of the i provincial cell, $\beta_k(u_i, v_i)$ is the regression coefficient of the k independent variable of the i provincial cell and ε_i is the random error term. In the paper, the model analysis was executed with the help of ArcGis 10.3 software (ESRI, Redlands, CA, USA), setting the kernel type as Adaptive Gaussian and the bandwidth method as AICc.

3. Results and Analysis

3.1. Spatial and Temporal Evolution of the Coupling Degree between Population Health and Economic Development

Overall, the mean value of coupling between population health and economic development in Chinese provinces rose slightly from 0.8665 in 2000 to 0.8722 in 2015, at a high level of coupling. In other words, overall, there was a strong interaction between population health and economic development in China from 2000–2015, with the strength of the effect increasing slightly over time.

The map visual representation of the coupling degree of population health and economic development was used to form a map of the spatial and temporal evolution of the coupling degree of population health and economic development from 2000 to 2015 (Figure 1). From Figure 1, it can be found that from 2000 to 2015, there were spatial heterogeneity characteristics in the coupling degree of population health and economic development, and two types of coupling, running-in coupling and high-level coupling, coexist, but the high-level coupling provinces predominate. In 2000, the total number of running-in coupling provinces was eight, accounting for 25.81%, except for the eastern region (the eastern region includes Liaoning, Beijing, Tianjin, Hebei, Shanghai, Shandong, Jiangsu, Zhejiang, Fujian, Guangdong, and Hainan; the central region includes for Shanxi, Anhui, Jiangxi, Henan, Hubei, Hunan, Jilin and Heilongjiang; the western region includes Inner Mongolia, Shaanxi, Gansu, Ningxia, Chongqing, Sichuan Guizhou, Yunnan, Guangxi, Xinjiang, Qinghai, and Tibet). In addition to Hainan, the others were mainly distributed in the central and western regions, specifically showing the spatial characteristics of clustering and distribution in two major areas, including the Gansu–Ningxia–Neimenggu–Shanxi–Jilin contiguous distribution area and the Guizhou–Guangxi contiguous distribution area. A total of 23 high-level coupled provinces, accounting for 74.19%, were widely distributed in the eastern, central, and western regions, specifically showing the spatial characteristics of contiguous distribution in other provinces except for Heilongjiang. In 2015, the number of running-in coupling provinces increased by one and the number of high-level coupling provinces decreased by one, and the spatial distribution of abrasive coupling provinces showed an obvious trend of westward shift. Running-in coupling provinces, except Hainan in the east, were located in the western region, which still exhibits the spatial characteristics of clustered distribution in two major areas, including the Qinghai–Gansu–Ningxia contiguous distribution area and the Yunnan–Guizhou–Guangxi contiguous distribution area. The high-level coupled provinces were still widely distributed in the east, central and western regions. From 2000 to 2015, the westward shift in the spatial distribution of Chinese population health and economic development running in coupling provinces reflected that the interaction between population health and economic development tended to increase in the east and central regions, while the interaction between population health and economic development tended to weaken in the west. Further calculation of the average of the coupling degree of each province in the three major regions reveals that the coupling degrees of the eastern, central, and western regions were 0.9316, 0.8303, and 0.8457, respectively, in 2000, while the coupling degrees of the eastern, central and western provinces shifted to 0.9353, 0.8461 and 0.8171, respectively, in 2015, which well confirms this changing trend.

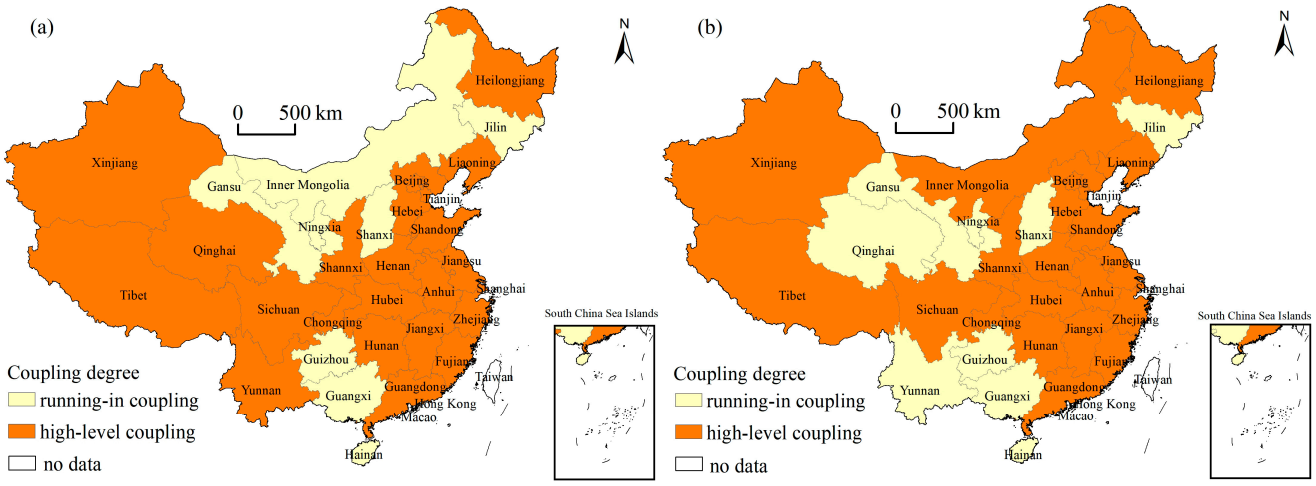

Figure 1. Spatial–temporal evolution of the coupling degree between population health and economic development in China: (**a**) 2000; (**b**) 2015.

3.2. Spatial and Temporal Evolution of the Coordination between Population Health and Economic Development

Overall, the mean value of the coupling coordination between population health and economic development in all provinces of China increased from 0.5999 in 2000 to 0.6624 in 2015, an increase of 10.42% in 15 years, reflecting that China's population health and economic development were in a good coordination stage at this stage, i.e., population health and economic development promoted each other with a higher level of interaction degree, and with this mutual promotion effect, the tendency was to increase.

The coupled coordination degree of population health and economic development in 2000 and 2015 were expressed visually in maps to form the spatial and temporal evolution of the coupled coordination degree (Figure 2a,b). As can be seen from Figure 2a,b, the coupling coordination degree of population health and economic development showed the spatial divergence characteristics of high in the east and low in the west, and there were three coupling coordination types: medium, good, and high quality in space. The area of good and high-quality coupling coordination types tended to expand to the west, while the area of medium coupling coordination types tended to contract to the west. Specifically, the type of quality coupling coordination in 2000 was distributed only in the three eastern provinces of Beijing, Shanghai, and Guangdong, accounting for 9.68%. Good coupling coordination type was widely distributed in the east, central and western regions, including 20 provinces, accounting for 64.52%. The moderate coupling coordination type was all distributed in the western region, covering eight provinces, accounting for 25.80%. Quality coupling coordination type provinces increased to seven in 2015, accounting for 22.58%, all distributed along the eastern seaboard. Good coupling coordination type provinces increased to 21, accounting for 67.74%, still widely distributed in the eastern, central, and western regions, but the distribution range expanded significantly to the west. Moderate coupling coordination type of provinces decreased to three, accounting for 9.68%, with a distribution of further westward contraction, including only the western region of Xinjiang, Qinghai, and Tibet.

The introduction of spatial autocorrelation analysis can further identify the spatial correlation status of the coupling coordination between population health and economic development. The global spatial autocorrelation analysis showed that the Global Moran's I in 2000 and 2015 were 0.2780 ($p < 0.01$) and 0.3089 ($p < 0.01$), respectively, indicating that overall, there was a positive spatial correlation between the coupling coordination of population health and economic development, i.e., there was a spatial clustering between provinces with high values of coupling coordination or between provinces with low values of coupling coordination The spatial distribution tended to be clustered between provinces with high values of coupling coordination or provinces with low values, and this spatial clustering was increasing. As shown in Figure 2c,d, the local spatial autocorrelation visualizes the local spatial correlation status of the coupled coordination degree of population health and economic development in 2000 and 2015. As can be seen from the figure, the high–high concentration areas of the coupling coordination between population health and economic development from 2000 to 2015 were stably distributed in the four eastern provinces of Shandong, Jiangsu, Shanghai, and Zhejiang, while the low–low concentration areas showed an expansion trend. The low–low agglomeration area in 2000 was only distributed in two provinces of Qinghai and Tibet, and in 2015 it was further increased to the two provinces of Xinjiang and Gansu. The high–high clusters remained stable, while the gradual expansion of low–low clusters indicated that the overall spatial clustering of population health and economic development coupling coordination tended to increase, mainly driven by the spatial clustering among provinces with lower coupling coordination.

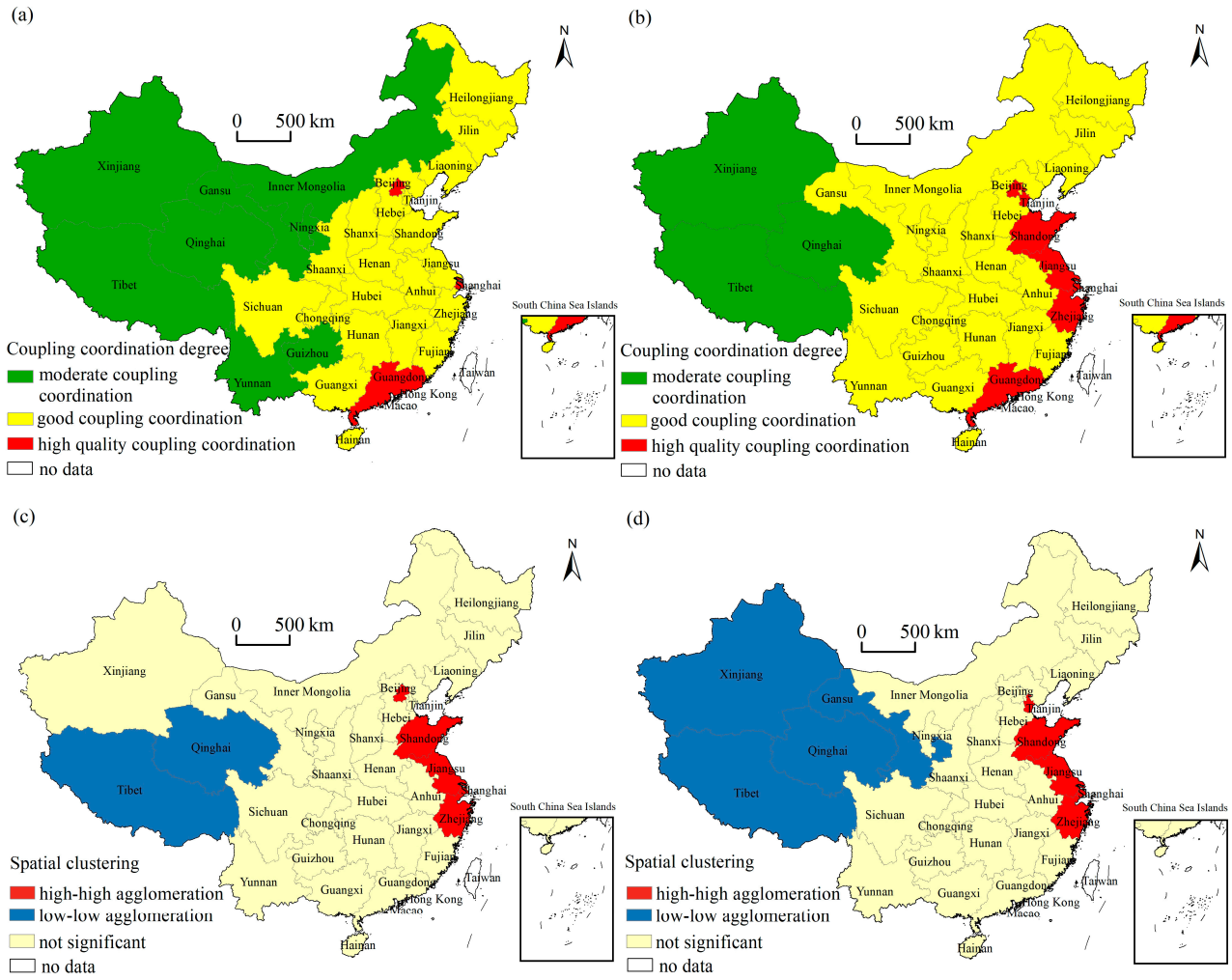

Figure 2. Spatio–temporal evolution of coupling coordination degree and spatial clustering between population health and economic development in China: (**a**) Coupling coordination degree in 2000; (**b**) Coupling coordination degree in 2015; (**c**) Spatial clustering of coupling coordination degree in 2000; (**d**) Spatial clustering of coupling coordination degree in 2015.

3.3. Analysis of the Drivers of Coupled and Coordinated Population Health and Economic Development

The coupled coordination of population health and economic development was driven by multiple factors. Based on a review of existing studies and taking into account the availability of data, we analyzed four aspects of their driving roles: natural conditions, health resources, cultural quality, and urbanization level. Natural conditions are the material basis for population health and economic development, while altitude is a fundamental element of natural conditions and directly influences physical geographic elements such as climate, which is closely related to population health [49–52] and is a key natural endowment on which economic development depends [53–55], and therefore characterizes natural conditions by mean altitude. Health resources are an important guarantee of population health, and under the current health resource allocation system, financial health expenditure largely determines the supply and functional realization of health resources. This not only directly affects economic development [56–58] but also promotes economic development through the human capital effect, consumer demand effect, and production efficiency effect [59]. Thus, the health resource status was characterized by per capita financial health expenditure. Cultural education shapes people's health perceptions and changes lifestyles and behaviors, thereby influencing population health [60,61], and it is also a human capital

element needed for economic development, characterized by the share of the population aged 6 years and older with a university degree and above. Urbanization brings changes in the lifestyle and health literacy of the population, which affects the health status of the population [62–64] and acts on economic development through the agglomeration effect of physical and human capital production factors [65–67]. Thus, the level of urbanization was characterized by the proportion of the urban population to the total population.

By using a geodetector, the *q*-value of each driven factor on the coupled coordination of population health and economic development was calculated using data from 2000 and 2015 and ranked according to the q value (Table 2). Both study time points indicate that the drivers are ranked in order of influence: urbanization level > natural conditions > cultural quality > health resources. The results of interaction factor detection (Table 3) showed that the interactions among the influencing factors were enhanced in both study time points, indicating that the synergistic role of multiple factors in driving the coupled coordination of population health and economic development was stronger than the role of a single factor, which also reflects the complexity of the driving role. In 2000, the interaction between natural conditions and health resources and the level of urbanization and health resources ranked in the top two of all six pairs of two-factor interactions, reflecting the key influence of health resource allocation on the coupling and coordination of population health and economic development in China at the beginning of this century in a context where the health care allocation system was still inadequate [68]. In 2015, the interactions between urbanization level and health resources, and natural conditions and cultural quality ranked in the top two among all six pairs of two-factor interactions, while the one-factor influence of urbanization level and natural conditions also ranked in second place according to the previous analysis, reflecting the fundamental driving role of urbanization level and natural conditions on the degree of coupling and coordination between population health and economic development.

Table 2. The detection results of driven factors for the coupling coordination degree of population health and economic development from 2000–2015.

2000		2015	
Factor Ranking	***q*-Value**	**Factor Ranking**	***q*-Value**
Urbanization level (x4)	0.599	Urbanization level (x4)	0.715
Natural Conditions (x1)	0.477	Natural Conditions (x1)	0.536
Cultural quality (x3)	0.407	Cultural quality (x3)	0.442
Health Resources (x2)	0.172	Health Resources (x2)	0.122

Table 3. The interaction detection results of driven factors for the coupling coordination degree of population health and economic development from 2000–2015.

2000		2015	
Interaction Factor	***q*-Value**	**Interaction Factor**	***q*-Value**
x1∩x2	0.905	x1∩x2	0.717
x1∩x3	0.739	x1∩x3	0.895
x1∩x4	0.789	x1∩x4	0.833
x2∩x3	0.582	x2∩x3	0.723
x2∩x4	0.876	x2∩x4	0.913
x3∩x4	0.715	x3∩x4	0.826

Note: See Table 2 for factor explanations.

The analysis based on geodetector revealed the overall influence status of each factor but could not reveal the spatial differences in the effects of each factor. A geographically weighted regression model was further introduced to dissect the status of spatial variation in the role of factors on the coordination of population health and economic development coupling. In order to eliminate the effects of order-of-magnitude differences of each factor,

the mean data of two years were first standardized for extreme differences, and then a geographically weighted regression model was established with the degree of coupled coordination between population health and economic development as the dependent variable and natural conditions, health resources, cultural quality, and urbanization level as the independent variables. The statistics of the regression results are shown in Table 4. The results show that the model R^2 reached 0.860, and the Moran's I of the residuals was 0.016 (p = 0.524), indicating that the residuals were randomly distributed in space, and the model fit better. From the mean values of regression coefficients of independent variables, under the condition of considering the spatial heterogeneity of variable relationships, overall, natural conditions and health resources were negatively correlated with coupling coordination, while cultural quality and urbanization level were positively correlated with coupling coordination, and the intensity of influence of urbanization level remains the largest.

Table 4. Statistics of GWR analysis results of driving factors for the coupling coordination degree of population health and economic development coordination.

Constants, Independent Variables	Average Value	Maximum Value	Minimum Value	Upper Quartile Value	Median Value	Lower Quartile Value	AICc	R^2
Constants	0.467	0.570	0.273	0.324	0.475	0.523		
Natural Conditions	−0.092	0.183	−0.464	−0.282	−0.089	0.068		
Health Resources	−0.121	0.029	−0.396	−0.205	−0.107	−0.036	−70.993	0.860
Cultural Quality	0.018	0.276	−0.272	−0.058	0.028	0.106		
Urbanization Level	0.465	0.764	0.105	0.275	0.477	0.632		

A map visual representation of the regression coefficients of the factors can reveal the spatial differences in their effects on the degree of coordination of population health and economic development coupling, and the results are shown in Figure 3. There was significant spatial heterogeneity in the driving effects of the factors. The role of natural conditions, i.e., altitude, was not all negative spatially; southwest, south China and the central Hunan and Jiangxi region were relatively better at overcoming the adverse effect of altitude on the coupling and coordination of population health and economic development, thus showing a positive association, while the rest of the region showed a negative association. Health resources were negatively associated with coupling coordination in the majority of provinces nationwide, indicating that the positive effect of health resources on the coupling and coordination of population health and economic development in these provinces was still not effectively played, while Xinjiang, Heilongjiang, and Jilin had relatively sufficient health resources allocated by the population due to their vast areas and sparse populations, which strongly contributed to the coupling and coordination of population health and economic development. Cultural quality was positively associated with coupling coordination mainly in the central and eastern regions, reflecting the strong influence of higher levels of cultural quality on promoting the coupled and coordinated development of population health and economy, while the western regions showed a negative association due to the relatively backward level of Cultural quality, which to some extent limited the coupled and coordinated development of population health and economy. The driving effect of urbanization level on coupling coordination was positively correlated across the country, and the correlation strength had the spatial characteristics of decreasing from south to north.

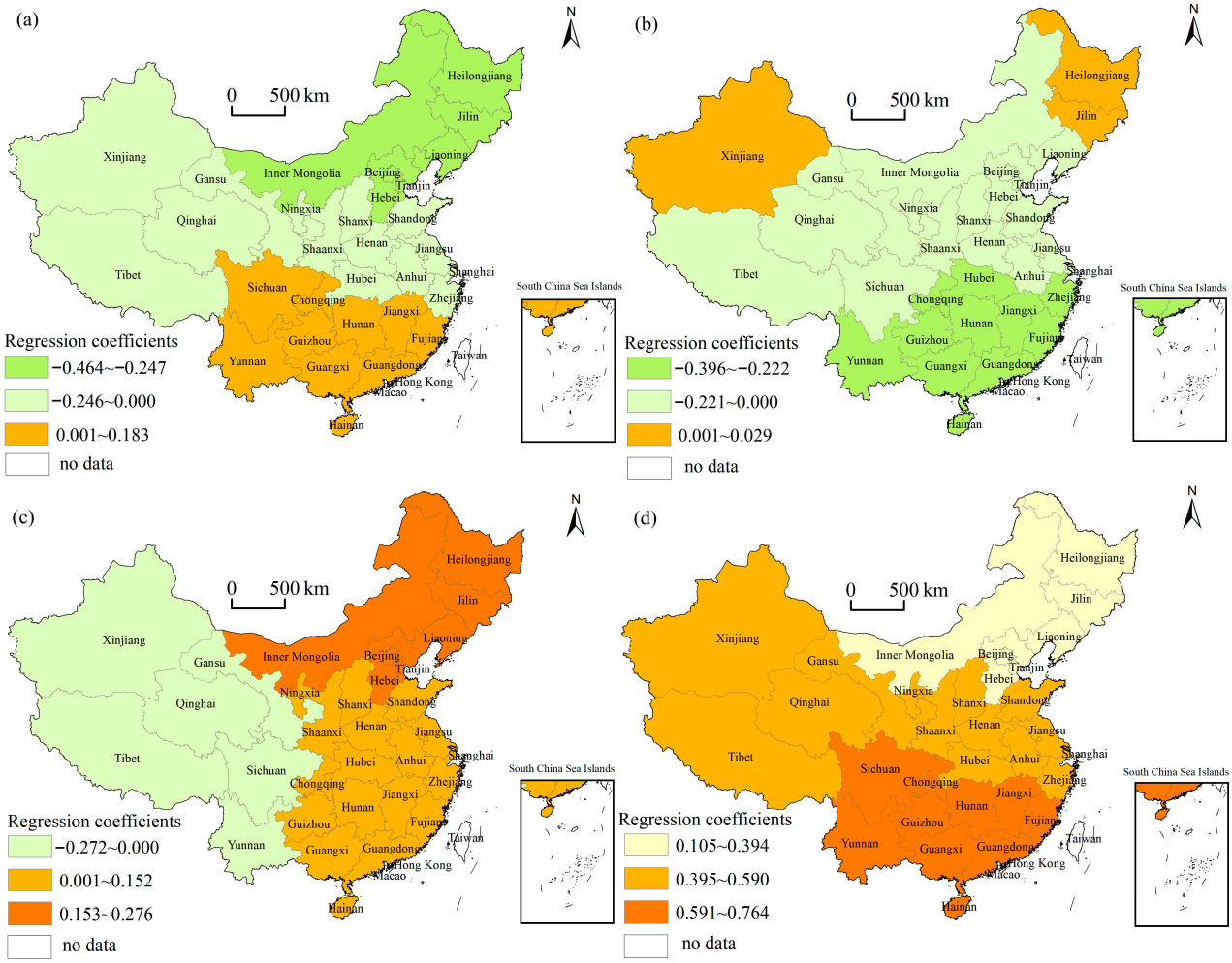

Figure 3. Spatial differences of GWR coefficients of driving factors for the coupling coordination degree of population health and economic growth: (**a**) Natural condition; (**b**) Health resources; (**c**) Cultural quality; (**d**) Urbanization level.

4. Discussion

4.1. From the Coupling Coordination Degree

Compared with existing studies, this paper finds that the coupling coordination between population health and economic development in China tends to increase over time and was influenced by multiple factors, and the influence of each factor was also characterized by interaction and spatial differences, which effectively remedied the deficiency of the current study in analyzing the coupled and coordinated status of population health and economic development in China only from a static perspective, and improved the understanding of the interrelationship between population health and economic development. Specifically, This paper shows that the coupling coordination degree of population health and economic development at the provincial scale in China in 2015 was 0.6667, which is very close to the coupling coordination degree of "Healthy China" construction and economic and social development of 0.668 calculated by Changda Li et al. [27], and although there were differences in the measurement indicators of health and economic development, both confirm that the population health and economic development at the provincial scale in China in 2015 were at the stage of good coupling and coordination. In addition, this study adds the analysis of the coupling coordination degree in 2000, which can better grasp the dynamic changes of the coupling coordination relationship and dissect the driving factors of the coupling coordination degree and its spatial differences, thus

providing a more valuable scientific basis for accurate and localized coordination of the relationship between population health and economic development.

4.2. From the Driving Factors

The analysis of the drivers of coupled and coordinated population health and economic development in China revealed that the driving influences of urbanization level, natural conditions, cultural quality, and health resources were in descending order of strength, while urbanization level and natural conditions played the main driving roles, and the synergistic driving effects of multiple factors were all greater than the single factor driving. The GWR results show that natural conditions, i.e., average altitude, were significantly negatively correlated with coupling coordination, but this effect was not absolute, and relative to higher latitudes, a few lower latitudes show a positive correlation due to their better ability to overcome the negative effects of higher altitude. Health resources, i.e., per capita financial health expenditure, were significantly negatively correlated with coupling coordination in the vast majority of provinces nationwide, suggesting that, as opposed to simply increasing the investment in health resources, optimizing the allocation of health resources is the effective measure to improve the coupling coordination between population health and economic development, especially the population allocation of health resources, which could be corroborated in the area of Inner Mongolia and Heilongjiang, which showed a positive correlation. Cultural quality was significantly and positively correlated with coupling coherence but showed opposite results in the western region. It indicates that at the national level, especially in the western region where culture and education are more backward, we should deepen the reform of the culture and education system and improve the level of culture quality of the population so as to promote the coupling of population health and economic development. The driving effect of urbanization level on coupling coordination was significantly and positively correlated across the country, and the driving effect increased gradually from north to south. It showed that increasing the level of urbanization was beneficial to the coordination of population health and economic development, which was more evident in the southern region than in the north.

4.3. Policy Suggestions

Based on the above analysis, it could be found that population health and economic development were not mutually separated and contradictory, economic development can improve health, and good health could also promote economic development, and the two were interrelated and unified. Various countries, especially developing countries, need to change the past tendency to focus on economic growth while neglecting the huge health costs caused by environmental pollution and ecological degradation and form a positive interaction between population health and economic development in order to finally achieve sustainable and high-quality development of health and economy. Meanwhile, the following policy recommendations are made to further promote the harmonious development of China's population health and the economy: First, since the coupling and coordination of population health and economic development are influenced by multiple factors, it is important to consider all the driving factors at the national level in an integrated manner and to integrate health into all policies, strengthen the top-level design and institutional safeguards based on the existing constraints of natural conditions, in terms of optimizing the allocation of health resources, deepening the reform of the culture and education system, and improving the quality of urbanization development. Second, since the factors influencing the coupling and coordination of population health and economic development have spatial differences, it is necessary to promote the coordinated development of population health and economic development at the regional level according to local conditions, especially in the western regions where coordinated development is lagging behind, and should focus on optimizing the allocation of health resources and improving population culture while trying to overcome the adverse effects of natural conditions. Third, promote the participation of multi-dimensional subjects, insist on the combination

of government-led and social and individual participation, and form a synergy to achieve coordinated development of population health and the economy.

4.4. Limitations and Future Research

The measurement of population health covers physiological, psychological, social adaptation, and other dimensions limited by the availability of data; this paper only measured the population health level from the physiological dimension, and in the future, the index system of population health level can be further improved to measure from physiological, psychological, social adaptation, and other dimensions. Furthermore, limited by the availability of data, this paper only carried out provincial-scale research, and in the future, the coupling relationship between population health and economic development can be refined and compared from provincial, municipal, and county scales, and at the same time, the scope of drivers needs to be further expanded in the future to make the research results more scientific value and policy guidance significance.

5. Conclusions

Due to the overlapping influence of multiple factors, population health has an impact on economic development, which in turn has an impact on population health, and this two-way effect is both positive and negative [24–26] and has both immediate and cumulative effects [9]. Therefore, the relationship between population health and economic development is an extremely complex proposition. From the perspective of the coupled and coordinated relationship between population health and economic development in China, this paper explores the dynamic changes and driving factors of the coupled and coordinated relationship, which is of great significance in sorting out the complex relationship between population health and economic development and promote the coordinated development between population health and economic growth. Based on the analysis of the spatial and temporal characteristics and drivers of the coupling and coordination of population health and economic development in China, the main findings include:

(1) China's population health and economic development as a whole are at a high level of coupling, and the level of coupling has slightly increased over time. Spatially, two types of coupling, running-in coupling and high-level coupling, coexist, and the coupling level tends to increase in the east and central regions, while the coupling level tends to weaken in the west.
(2) China's population health and economic development as a whole are in the stage of good coupling and coordination, and the degree of coupling and coordination has a tendency to increase. Spatially, the coupling coordination degree shows a spatial divergence characteristic of high in the east and low in the west, and the good and high-quality coupling coordination type areas tend to expand to the west, while the moderate coupling coordination type areas tend to contract to the west. There is a positive spatial clustering of population health and economic development coupling coordination, and the spatial clustering is gradually increasing.
(3) The coupled coordination of population health and economic development in China is driven by multiple factors such as natural conditions, health resources, culture quality, and urbanization level; the interaction between the drivers is stronger than the role of a single factor, and the drivers of each factor also show significant spatial heterogeneity.

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