Spatiotemporal Characteristics of the Pollution Reduction Effect of Differentiated Coordinated Development in the Yangtze River Economic Belt, China

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Spatiotemporal characteristics of the pollution reduction effect of differentiated coordinated development in the Yangtze River Economic Belt, China

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Abstract

The pollution reduction effect of regional development could be analyzed more comprehensively from the perspectives of coordinated development and differentiated development. Based on the theory of regional coordinated development, this paper used panel data for cities in the Yangtze River Economic Belt from 2008 to 2017, adopted the spatial autocorrelation method and spatial econometric model to analyze the spatial and temporal distribution pattern of environmental pollution emission, regional coordination and differentiated development degree in the Yangtze River Economic Belt, analyzed the impact of regional differentiated coordinated development on pollution emission reduction in local and surrounding cities, and discussed the spatial spillover effect of regional differentiated coordinated development on pollution emission and its boundary test. The results showed that (1) at the overall level of the Yangtze River Economic Belt, coordinated regional development and differentiated regional development have significantly reduced pollution emissions and present complementary effects on pollution emission reductions; (2) an obvious spatial spillover effect was observed for the impact of regional coordinated and differential development on pollution reduction, a negative spatial spillover coefficient was observed for different urban economic circles, and an obvious inverted U-shaped trend occurred in the impact degree with increasing distance, with a 500 km range of urban economic circles considered a turning point; and (3) a heterogeneity test used the three major regions and sub-cities of the Yangtze River Economic Belt to verify and analyze the impacts of regional coordinated and differential development on pollution emissions, which showed that there was obvious spatial heterogeneity at different levels. Based on the above results, policy suggestions for decreasing pollution emissions in the process of differentiated coordinated development of the Yangtze River Economic Belt were proposed.

Keywords Yangtze River Economic Belt • Regional coordinated development • Regional differentiation development • Pollution reduction • Heterogeneity

Introduction

In recent years, the National Development Plan proposed that the Yangtze River Economic Belt should be "jointly protected rather than developed" to not only achieve high-quality economic development but also to strengthen ecological and environmental protection to realize the coordinated development of the social economy, resources and environment in the Yangtze River Basin. With the acceleration of industrialization and urbanization, the problems of environmental pollution and resource consumption in the Yangtze River Economic Belt have become increasingly serious, which seriously restricts social and economic development. As a golden waterway with the largest traffic volume in the world (LU 2018), the Yangtze River crosses the eastern, central and western regions of China, and the regional

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energy utilization methods, industrial structures and pollutant emission characteristics exhibit significant differences (Liu Yang and Chen 2016). Such unbalanced development may trigger vicious competition, hinder the free flow of market elements, and intensify pollution emissions. According to differences in the development of resource endowment among the Yangtze River Economic Belt cities, orderly and healthy competition in the market to promote industrial convergence and realize complementary advantages can provide new possibilities for energy conservation and emissions reduction.

Literature Review

At present, energy conservation and emission reduction under the concept of sustainable development have attracted extensive attention from scholars (Wagner and Timmins 2009; Sueyoshi and Yuan 2017; Azizalrahman and Hasyimi 2019; Brown et al. 2020). Based on the new economic geography theory, this paper analyzes the effect of regional pollution emission reduction from the perspective of economic factor agglomeration. Lu et al. (2014) found that economic activity agglomeration is beneficial for reducing the intensity of industrial pollution emissions, and Zhang and Wang (2014) built a theoretical model to analyze the two-way interaction mechanism between economic agglomeration and environmental pollution. Economic aggregates can improve environmental pollution, and there were significant spatial spillover effects. Other studies also found that economic element agglomeration had a nonlinear effect on environmental pollution (Zhu et al. 2019; Giannadaki et al. 2018; Dauda et al. 2019) in different regions because of spatiotemporal heterogeneity. For example, Xu et al. (2012) found that the concentration of Foreign Direct Investment (FDIs) in China can reduce pollution emissions and the degree of influence is significantly different based on different sources. Yang (2015) found that industrial agglomeration of pollution discharge has inverted U-shaped nonlinear effects, namely, industrial agglomeration at a low level will increase environmental pollution and industrial agglomeration that exceeds a threshold will improve environmental pollution. Shao et al. (2019) found that the energy-saving and emission-reduction effects of economic agglomeration may have a significant "inverted N-type" curve relationship and an obvious spatiotemporal dependence. The relationship between economic factor agglomeration and environmental pollution emissions has not yet been determined. Moreover, differences also occur in the environmental spillover effects of economic factor agglomeration on pollution emissions in different regions. Previous studies have focused on analyzing the spatial spillover effects of regional agglomeration on pollution emissions from the overall level; however, the spatial spillover effects of regional agglomeration on pollution emissions within the scope of different urban agglomerations still need to be further explored.

Scholars have also studied environmental pollution emissions and their mechanisms from the perspective of regional integration. As market segmentation increases, the gap between regional pollution emissions and energy efficiency has widened (Li and Lin 2017; Hasanbeigi and Price 2015) When the degree of market segmentation exceeds a certain limit, regional trade barriers will form and regional development will be inhibited (Lu and Chen 2009; Ramanathan and Feng 2009; Li et al. 2017). The spatial difference in the regional economic development level indirectly affects the effect of pollution reduction. He et al.（2016）, Shen et al.（2017） and Zhang（2018） found that regional integration can promote the intensity of pollution reduction caused by convergence and improve environmental pollution. Based on the "Environmental Kuznets Curve Theory" in the environmental pollution of scale, structure and technology effect, Sun and Cheng（2019） discussed the intermediate mechanism underlying the regional integration pollution emission effect. On this basis, scholars have further studied the transfer of pollution emissions within a region. Dou and Cui（2018） analyzed the interprovincial pollution transfer in China from a macro perspective, and Zhao（2019） and You and Chen（2019） considered the expansion of the Yangtze River Delta as the carrier of regional integration to test the pollution emission effect between the new cities in the Yangtze River Delta and older cities. A number of studies have found unbalanced regional pollution emissions: in the process of industrial transfer, factor flow and spatial allocation and integration, industrial pollution tends to move and spread from regions with high development levels to those with low development levels. Although scholars have reached a consensus on that regional integration promote the discharge of environmental pollution, few studies have investigated the pollution emission effect of regional differentiated development. Interregional urban integration is a process of "seeking common ground while maintaining differences". However, whether regional coordination and differentiated development can reduce pollution emissions is not clear and the mechanisms that lead to pollution emission reductions have not been identified. Therefore, it is of great significance to study the pollution emission effect from the perspective of regional coordination and differentiated development.

This article mainly performs research from three aspects: (1) based on the theory of regional coordinated development, PM2.5 emissions are selected as pollution indicators according to the regional coordination degree and differentiation to discuss the effect of pollution reduction in the development process of "seeking common ground while maintaining differences" among regional cities; (2) the spatial panel Durbin model is adopted to test the coordinated development of the regional differentiation spatial spillover effect on pollution emissions, inspect its spatial spillover boundary, and analyze the change trend of spatial spillover effects as with increased distance; and (3) a multiscale discussion is included on the degree of differentiation and the temporal and spatial differences of pollution emissions in the Yangtze River Economic Belt and the spatial heterogeneity of the impact of regional development on pollution emissions at different levels is verified. The visualization analysis of spatial distribution is carried out in combination with a spatial econometric model.

Theoretical Mechanism

According to the "Haken synergy theory", despite differences in the characteristics of each city, there are interactional relationships between cities, including coordination, cooperation and competition, and mutual interference between restricting elements（Haken 1983）. Regional development is a process from the integration of independent economic entities into the whole economy, and it emphasizes the organic combination of regional synergy and regional differentiation (Li and Qi 2019; Liu et al. 2019). Regional economic factors influence environmental pollution reduction based on the regional synergy among cities as well as regional differentiation. The development mechanism is shown in Figure 1.

First, the efficiency of regional factors must be coordinated to promote energy conservation and emission reduction under regionally coordinated development. Along with the construction of intercity transportation networks, the development of information technology and the optimization of regional spatial structures, capital flows, logistics, people flows and information flows move at a high speed, thereby reducing the cost waste caused by information asymmetry (Shi et al. 2018; Lanzi et al. 2018). The sharing of infrastructure and public resources can accelerate industrial agglomeration to reduce the common production operation costs of enterprises in the region and realize the effective allocation of resources to reduce pollution emissions (Liu and Wu 2017; Yao et al. 2019). Second, the standardization of regional environmental regulation should be promoted. By formulating new environmental laws and regulations, local governments have proposed new requirements in terms of emission standards, product standards and product specifications. With the intensified competition caused by homogenization among enterprises, the rising cost of pollution control forces enterprises to gradually turn to clean energy, accelerate scientific and technological research and innovation and reduce pollution emissions (Zhang et al. 2020). Moreover, the process of the transferring regional labor factors, the environmental protection concept of immigrants transferred to areas with stricter environmental supervision is increasingly strengthened, which promotes cross-regional dissemination and cultivation of green environment concepts. Third, interregional cooperation and complementarity of resource elements should be promoted. Market segmentation will intensify tax competition among cities, and fiscal decentralization and promotion and assessment by local officials will lead to a "race to the bottom" phenomenon, in which foreign investment will be introduced at the expense of the ecological environment and regions with low economic development will become a "pollution paradise"(Baghdadi et al. 2013), which will have a negative impact on the overall ecological environment. By promoting environmental performance as an important indicator for performance appraisals, regions have focused more attention on overall interests. Local governments will abandon "local protectionism" in favor of resource complementarity, mutual assistance, benefit sharing, and coordinated relationships between economic and environmental development. Moreover, regional cooperation and exchanges accelerate the transfer of economic factors, and cross-regional employment of the population reflects the spillover effect of knowledge and improves the efficiency of production factors.

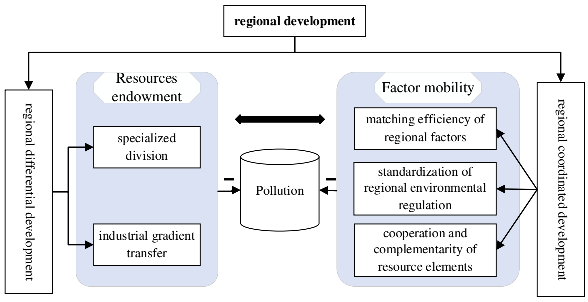

Fig 1 Regional differentiation and coordinated development of pollution emission reduction mechanisms

Energy conservation and emission reductions under regionally differentiated development benefit from the specialized division of labor between regions, with different regions relying on their own resource factor endowment, which generates different comparative advantages, develops characteristic industries, builds local brands, and accelerates product upgrades to improve their scientific and technological innovation ability. Regionally dominant industries attract the transfer of production factors from surrounding areas, gradually break market segmentation and "local protectionism", promote cross-regional resource integration, save energy and reduce pollution. Moreover, these industries benefit from industrial gradient transfer because new technologies tend to spread gradually from high-gradient regions to low-gradient regions. In addition, the upstream and downstream industries of the Yangtze River Economic Belt have heterogeneity due to regional development differences, which is conducive to industrial gradient transfer and docking. According to their own advantages, local governments should rationally distribute industry to prevent overcapacity caused by industrial structure convergence, maximize benefits, and promote industrial structure optimization and upgrades to reduce pollution emissions.

Econometric model setting

Establishment of spatial econometric model

The STIRPAT model is widely used in environmental economics, and the original IPAT model can extend the random variable (Dietz and Rosa 1994). In this study, explanatory variables, such as the degree of regional coordinated development and the degree of regional differentiated development, are added, and they are expressed are as follows:

$$lnpollu_{it} = \alpha_0 + \alpha_1 lnec_{it} + \alpha_2 lnec_{it} * lndv_{it} + \alpha_3 lndv_{it} + \alpha_4 X_{it} + \varepsilon_{it} \quad (1)$$

where $lnpollu_{it}$ represents the amount of pollution emitted by each city; $lnec_{it}$ is the regional synergetic degree of each city and other cities in the Yangtze River Economic Belt; $lndv_{it}$ is the degree of regional differentiation between each city and other cities in the Yangtze River Economic Belt; $lnec_{it} * lndv_{it}$ is the interaction term of regional cooperation degree and regional differentiation degree; X_{it} is the control variable; and ε_{it} is the random error term.

According to the above model, a further judgment is made as follows: according to the criteria of the spatial measurement model, the Hausman test, LR test, WALD test and LM test should be used to further determine the model. The verification results are shown in Table 1. In the Hausmann test results, chi_2 is negative. The null hypothesis is accepted, and a random effect is selected. The LM test results showed that all four tests were significant at the 1% level, indicating that the spatial Durbin model (SDM) had a better fitting effect. To further validate the conclusions, the corresponding Wald spatial lag after inspection and spatial error analysis, and LR space lag inspection and space error analysis are under the level of 1% by significance test, showing that the spatial lag model (SAR) and spatial error model (SEM) are appropriate. In conclusion, the spatial Durbin model (SDM) combining the two spatial models should be used to analyze the regional synergy differentiation development impact on pollution reduction.

In summary, the expression of the model is as follows:

$$lnpollu_{it} = \beta_0 + \rho \sum_{j=1}^{N} W_{it}\, lnpollu_{it} + \beta_1 lnec_{it} + \beta_2 lnec_{it} * lndv_{it} + \beta_3 lndv_{it} + \gamma_1 \sum_{j=1}^{N} W_{it}\, lnec_{it} + \gamma_2 \sum_{j=1}^{N} W_{it}\, lnec_{it} * lndv_{it} + \gamma_3 \sum_{j=1}^{N} W_{it}\, lndv_{it} + \beta_4 X_{it} + \gamma_4 \sum_{j=1}^{N} W_{it}\, X_{it} + \varepsilon_{it} \quad (2)$$

where W_{it} is the space weight; ρ represents the spatial autoregression coefficient; and γ represents the space overflow coefficient.

Data processing

Based on data availability, this paper selects the data of 105 cities above the prefecture level in the Yangtze River

Economic Belt from 2008 to 2017 and replaces some missing values with a linear interpolation or the average growth rate method. Descriptive statistics of the main variables are shown in Table 2.

Table 1 Space metrology test

Test		Results	P-value
Hausman test		-21.7	-
Wald test	Test for SAR	44.16	0.000
	Test for SEM	36.37	0.000
LR test	Test for SAR	49.5	0.000
	Test for SEM	143.93	0.000
LM test	LMerr	858.732	0.000
	LMlag	136.459	0.000
	R-LMerr	815.627	0.000
	R-LMlag	93.354	0.000

Table 2 Descriptive statistical analysis

Variable	N	Mean	Std. Dev.	Min	Max
pollu	1050	47.15	13.91	10.88	75.62
ec	1050	68695.37	90908.92	965.95	896677.9
dv	1050	322.14	18.42	281.6	397.44
Fdis	1050	329221	2.4 E+06	3	3.45E+07
Gov	1050	0.22	0.18	0.02	2.03
Dens	1050	0.83	10.26	0.01	143.42
Tc	1050	655.85	1 809.74	1	20 567
Struct	1050	0.92	0.49	0.24	4.92
Mp	1050	2540.41	4285.01	98.89	48309.4

Core variables

Regional synergy (*ec*). The higher the intercity connection, the higher the degree of regional cooperative development; and the greater the geographical distance between cities, the lower the degree of collaborative development between cities (Li and Zeng 2016). The modified gravity model was used to calculate the degree of regional collaborative development between cities and 104 other cities in the Yangtze River Economic Belt:

$$ec_{it} = \sum_{j=1}^{104} X_{ijt} * \sqrt{R_{it} * GDP_{it}} * \sqrt{R_{jt} * GDP_{jt}} / D_{ij}^2 \qquad (3)$$

$$X_{it} = \frac{GDP_{it}}{(GDP_{it} + GDP_{jt})} \qquad (4)$$

where i represents the city, j represents other cities in the Yangtze River Economic belt except the city, t represents the year, R_t is the population of the city at the end of t, GDP_t is the GDP in year t, and D_{ij} represents the geographical distance between city i and city j.

Regional differentiation *(dv)*. The degree of difference between city i and 104 other cities in the Yangtze River Economic Belt in year t was determined by using the method of Liu and Wu (2017). The specific calculation formula is as follows:

$$dv_{it} = \sum_{j=1}^{104} \sum_{x=1}^{11} abs\left(D_{it}^x / D_{it} - D_{jt}^x / D_{jt}\right) \qquad (5)$$

where D_t^x represents the employed population of the city in x industry in year t (the number of employees in 11 industries selected to calculate regional differentiation because the number of employees in different industries is frequently missing from statistical yearbooks); and D_{it} and D_{jt} represent the total number of employees of 11 industries in i and j cities in year t.

Pollution degree *(pollu)* is an index of the serious effect of air pollution on environmental quality, which has attracted wide attention from all walks of life in recent years. Moreover, air pollutants have strong mobility in the region, and the effect of spatial spillover effects is better. Therefore, the annual average PM2.5 concentration is selected as a pollution indicator to measure the degree of regional pollution.

Control variables

Foreign direct investment (FDIs). The environmental protection technology of foreign enterprises is more advanced, and the associated environmental protection awareness is strong. The introduction of foreign enterprises is conducive to reducing pollution emissions, and urban foreign direct investment is considered a measure of FDIs (Xu and Deng 2012). Government intervention *(gov)* is considered an index of local governments' rational allocation of resources according to local information and the emission intensity level of pollution in the current year to reduce pollution emissions. The level of government intervention is calculated by dividing government fiscal expenditure by GDP (Sun and Cheng 2019). Energy efficiency *(eng)* is an index of how improved energy efficiency can reduce pollution emissions (Zhang et al. 2013), and it is measured by the ratio of GDP to local electricity consumption. Infrastructure *(inf)* is an index indicating that more complete infrastructure corresponds to lower costs and less pollution emissions, and it is measured by per capita urban road area (Zhao 2019). Population density *(dens)* is an important factor that affects regional pollution benefits, and it is measured using the local area of the city divided by its population, namely, the number of people per square kilometer (Shao et al. 2019). Market size *(mp)* is an index indicating that the expansion of the market has a "scale effect"(Sun and Cheng 2019), with regional economic agglomeration reducing cost and energy consumption, and it is measured by dividing the city's GDP by the city's area. Technological progress *(tc)* is an index of the number of invention technologies acquired by the city in that year, and it is used to measure the technological development and innovation level of the region. A greater number of patented technologies corresponds to a higher technological innovation level of the city. Industrial inspection *(struct)* is an index of the proportion of the output of tertiary industry in the output of the secondary industry in each prefecture-level city. A larger proportion indicates that the industrial structure transformation and upgrading are fast and that the degree of optimized allocation of factors is high.

Spatial-temporal characteristics of pollution emissions

This article analyzes the temporal and spatial differences in regional coordinated development, differentiated development and pollution emissions in the Yangtze River Economic Belt and obtains the temporal and spatial distribution characteristics of each element in the Yangtze River Economic Belt. Global Moran's I analyzes the spatial correlation of global pollution in the Yangtze River Economic Belt; the local spatial correlation index Getis-Ord G* judges the local distribution of high-value pollution agglomeration areas and low-level pollution agglomeration areas in the Yangtze River Economic Belt. The spatial correlation index is divided into four points according to the self-breaking point. The method is divided into hot spot areas, sub-hot spot areas, sub-cold spot areas and cold spot areas.

Pollution global spatial correlation

Moran's I index of pollutant emissions in the Yangtze River Economic Belt from 2008 to 2017 was between 0.35 and 0.49; thus, both years passed the significance test at the 1% level and were positive, indicating that there is a positive spatial correlation of pollution emissions in the Yangtze River Economic Belt. That is, areas with high (low) pollution levels are adjacent to areas with high (low) pollution levels. The data is shown in Table 3. Moran's I index of pollution indicators varies greatly from 2008 to 2013, indicating that the regional pollution concentration changes greatly. Moran's I index remained stable from 2013 to 2017, indicating that pollution emissions have little spatial variation.

Table 3 Global Moran's I Index of pollution emissions in the Yangtze River Economic Belt from 2008 to 2017

Year	Moran's I	Variance	Z-value	P-value
2008	0.391	0.032	12.507	0.001
2009	0.401	0.032	12.758	0.001
2010	0.366	0.030	12.457	0.001
2011	0.351	0.032	11.272	0.001
2012	0.386	0.032	12.303	0.001
2013	0.367	0.032	12.325	0.001
2014	0.459	0.032	14.503	0.001
2015	0.462	0.032	14.568	0.001
2016	0.442	0.032	24.227	0.001
2017	0.495	0.031	16.327	0.001

Local temporal and spatial distribution differences

From 2008 to 2012, the "clustering" of pollution emissions in the Yangtze River Economic Belt became more obvious, thus showing a spatial pattern of "high in the center and low in the surrounding area". As shown in Figure 2 and Figure 3, agglomeration "hot spots" mainly occur in the northern region of the lower reaches of the Yangtze River and agglomeration "cold spots" mainly occur in the southwestern region of the upper reaches of the Yangtze River. Highly polluted areas are mainly concentrated in the Sichuan-Chongqing urban agglomeration, Wuhan City cycle, Changsha-Zhuzhou-Xiangtan urban agglomeration area, northern Anhui, and northern Jiangsu. The pollution levels in the middle reaches of the Yangtze River and the Sichuan-Chongqing urban agglomeration have increased significantly. The area of moderately polluted areas has shrunk, thus forming small areas in Hunan, Sichuan, Anhui, and Jiangsu. The low-pollution areas are mainly concentrated in the southern areas of the middle and lower reaches of the Yangtze River Economic Belt, and the pollution scope has experienced little change. The southwest region centered around Kunming maintains a low pollution state, while the spatial distribution pattern of pollution has undergone significant changes from 2012 to 2017. The overall ecological environment of the Yangtze River Economic Belt has been greatly improved, and the degree of pollution in the region has shown an increasing trend from north to south. High-pollution and higher-pollution areas are distributed in the northern part of the lower reaches, such as the Sichuan-Chongqing urban agglomeration, the Yangtze River Delta, and the Yangtze River middle-reach urban agglomeration, indicating that the regional integration of urban agglomerations strengthens the degree of intercity regional connections. The degree of coordination between the north and south in the upper, middle, and lower reaches of the Yangtze River Economic Belt has also been continuously strengthened. For example, the collaboration degree of the middle reaches of the Changsha-Zhuzhou-Xiangtan urban agglomeration and the Wuhan City cycle, the upstream area Sichuan-Chongqing urban agglomeration and Guizhou Province is gradually becoming denser.

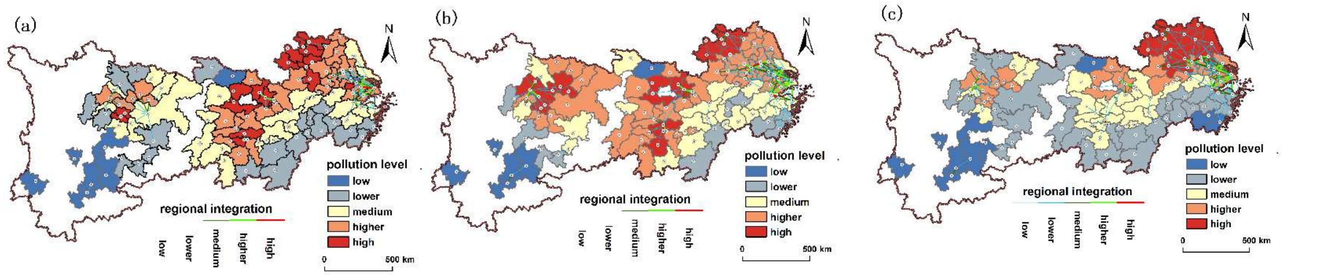

Fig 2 Spatial and temporal differentiation of pollution emissions in the coordinated development of the Yangtze Economic Belt (a: in 2008; b: in 2012; c: in 2017)

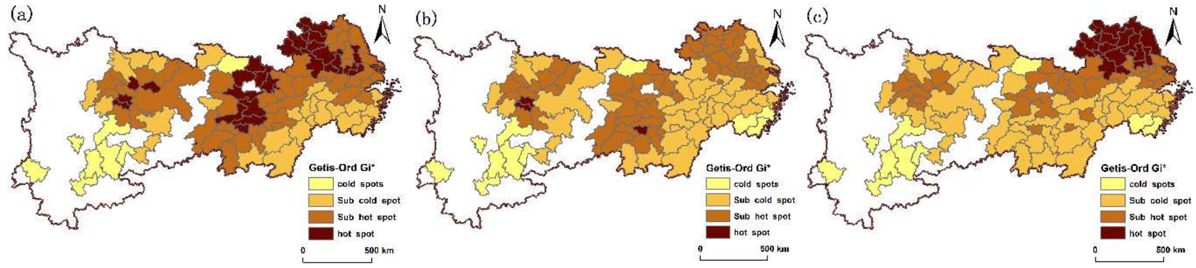

Fig 3 Spatial and temporal differentiation map of pollution concentration hotspots and cold spots cities in the Yangtze River Economic Belt is different (a: in 2008; b: in 2012; c: in 2017)

This article further analyzed the degree of regional differentiation development. As shown in Figure 4, the overall degree of regional differentiation in the Yangtze River Economic Belt from 2008 to 2017 showed a significant downward trend. Compared with regions in the middle and upper reaches of the Yangtze River, the lower reaches of the Yangtze River have a higher degree of differentiation. At the same time, the degree of regional coordination between cities in the lower reaches of the Yangtze River is also high, which further shows that the coordinated development and differentiated development of the region are not in conflict and jointly promote regional development. The provinces in the upper reaches of the Yangtze River are less differentiated, and Hubei Province in the middle reaches of the Yangtze River has a high degree of regional differentiation.

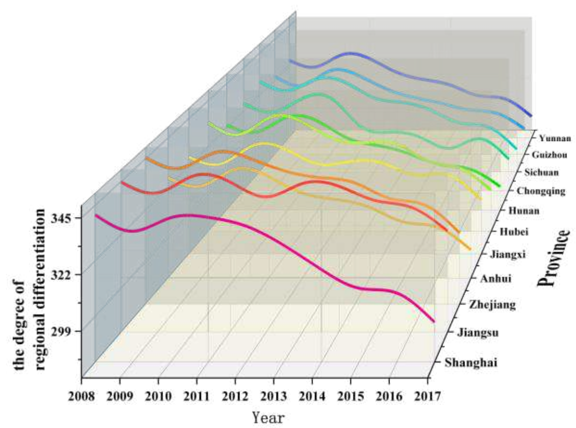

Fig 4 Development degree of different provinces and cities in the Yangtze River Economic Belt is different

Pollution reduction effect test of regional coordinated and differential development

Benchmark regression analysis

To ensure the robustness of the estimation results of various variables, this paper adopts the regression analysis of four types of spatial measurement models. The regression results are shown in Table 4. The coefficient signs of the spatial measurement models are completely consistent, and the regression coefficients of the core variables on local pollution emissions pass the 5% significance level test, indicating that the regression results are relatively robust. The spatial autoregressive coefficients of pollution emissions are positive, and all passed the 1% significance test, indicating that the aggravation of pollution emissions from surrounding cities will increase local urban pollution emissions. In other words, pollution emissions in the region have an agglomeration effect, which is consistent with the conclusion drawn above. The coefficient of regional coordinated development on pollution emissions in the region is negative and passes the significance test of at least 5%, indicating that the coordinated development of regional cities has a significant inhibitory effect on pollution emissions; the coefficient of regional differential development on pollution emissions in the region is negative and passes the 5% significance test, indicating that regional differential development has a significant inhibitory effect on pollution emissions; the coefficient of the interaction term between regional coordinated and regional differential development is positive, and both pass the 5% significance test. These findings show that regional coordinated development and regional differentiated development complement jointly promote pollution emission reduction, which has a significant effect on pollution reduction. The regression coefficient of the spatial lag variable is negative, indicating that the coordinated development and differentiated development of the local city have a negative impact on neighboring pollution reduction.

Spatial effect trend of different urban economic circles

A previous article analyzed the significant pollution reduction effects of regionally differentiated and coordinated development and then used the indirect effects of the random effect spatial Durbin model for further analysis (Bai et al. 2017). The "Circular Cumulative Causation Theory" states that regional development is not uniformly diffused. Usually, the "central zone" begins to accumulate advantages first and gradually spreads outward through different channels (Krugman, 1991). The Yangtze River Economic Belt spans a wide range, and the impact of regional factor flow on environmental pollution has spatial spillover effects. Drawing lessons from the methods of Yuan et al. (2019) and Dong and Wang (2019), different thresholds were set and a spatial weight matrix was established to discuss the spatial spillover effects of regional coordinated and differentiated development on pollution emissions within the distance of different urban agglomerations.

The spatial spillover coefficient passed the 10% significance test within the range of the urban economic groups of 100 to 525 kilometers and became no longer significant after exceeding a range of 525 kilometers. The results are shown in Figure 5.

Table 4 Space panel measurement results

Variable	SEM		SAR		SAC		SDM	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	lnpollu	lnpollu	lnpollu	lnpollu	lnpollu	lnpollu	lnpollu	lnpollu
Local								
lnec	0.732**	0.701**	0.992***	0.887***	0.892***	0.703***	0.809**	-0.955**
	(0.276)	(0.275)	(0.2450)	(0.248)	(0.166)	(0.199)	(0.289)	(0.292)
lndv	1.229**	1.220**	1.697***	1.517**	1.699***	1.256***	1.416**	1.787***

	(0.519)	(0.517)	(0.445)	(0.463)	(0.302)	(0.370)	(0.545)	(0.554)
Lnec*lndv	0.130**	0.126**	0.172***	0.155***	0.160***	0.130***	0.148**	0.174***
	(0.048)	(0.048)	(0.042)	(0.043)	(0.029)	(0.035)	(0.050)	(0.050)
Neighborhood								
lnec							0.094	0.140
							(0.396)	(0.412)
lndv							0.142	0.446
							(0.712)	(0.734)
lnec*lndv							0.007	0.025
							(0.069)	(0.072)
rho	0.831***	0.836***	0.899***	0.896***	1.106***	0.925***	0.895***	0.882***
	(0.024)	(0.023)	(0.016)	(0.016)	(0.011)	(0.017)	(0.016)	(0.018)
Control variables	N	Y	N	Y	N	Y	N	Y
N	1 050	1 050	1 050	1 050	1 050	1 050	1 050	1 050
LOG L	1 603.32	1 611.14	1 276.78	1 282.98	1 639.9	1 623.76	1 284.61	1 307.73

Note: 1) ***, **, and * passed the significance level test at 1%, 5%, and 10%, respectively. 2) The value of *t* is in brackets.

Regional coordinated development and regional differentiated development have exactly the same impact on pollution emissions. As the scope of urban agglomerations expands, differentiated coordinated development has always had a negative impact on pollution emissions from surrounding cities, which further shows that regional coordinated development and differential development complement each other, thereby promoting pollution emissions from surrounding cities. The pollution reduction effect of regionally differentiated and coordinated development shows an inverted U shaped trend. That is, within a certain geographic distance, the spillover and emission reduction of regionally coordinated pollution will first increase and then decrease. Specifically, in the range of 100-300 kilometers, regional coordinated differential development has relatively little impact on the pollution emissions of surrounding cities, indicating that the efficiency of pollution reduction in the area of 100-300 kilometers is relatively low. When the spatial distance range exceeds 300 kilometers, as the distance range expands, the impact of regionally differentiated development on the pollution reduction effect of surrounding cities is greatly strengthened because the expansion of the spatial range of urban agglomerations is more conducive to local labor cooperation to promote technology spillovers and the upgrade and transfer of industry. A peak is reached within 500 kilometers, and the pollution reduction effect continues to weaken after 500 kilometers until the spatial spillover effect is no longer significant. In summary, the verification shows that within different distances, regional coordinated and differentiated development has different spatial spillover effects on pollution reduction.

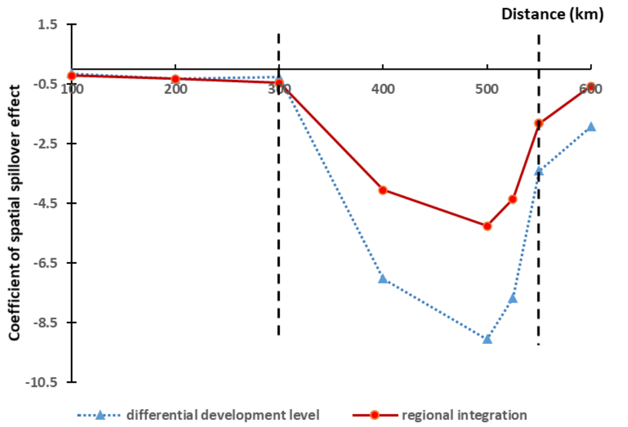

Fig 5 Spillover coefficient of differentiated coordinated development space in different urban areas

Analysis of the heterogeneity of the three major regions of the Yangtze River Economic Belt

The regression results at the overall level of the Yangtze River Economic Belt indicate that the differential and coordinated development of the Yangtze River Economic Belt has promoted the reduction of pollution and further indicate the impact of regional differentiated coordinated development on pollution emissions in the lower, middle and upper reaches of the Yangtze River Economic Belt. The regression results are shown in Table 5. The coefficient of regional coordinated development and differential development in the lower reaches of the Yangtze River is positive, and the coefficient of the interaction term of the two is negative and passes the 10% significance test. The sign of the spatial lag coefficient is the opposite. It promotes the reduction of pollution emissions in the surrounding areas. The coefficients of regional coordinated development and differentiated development in the upper and middle reaches of the Yangtze River are both negative and pass the 10% significance test, and the coefficient of the interaction term is positive and passes the 10% significance test, indicating that the upper and middle reaches of the two major regions of the Yangtze River Economic Belt promote pollution reduction in the process of differentiated and coordinated development. The pollution reduction effect of the upper and middle reaches of the Yangtze River is consistent with the overall level of the Yangtze River Economic Belt, and the intensity of the reduction effect of coordinated and differential development in the upper reaches of the Yangtze River is significantly greater than that of the middle reaches of the Yangtze River.

Table 5 Regression results of the spatial econometric model in different regions of the Yangtze River Economic Belt

city	Whole	Upper	Middle	Lower
Local				
lnec	0.955**	1.119*	0.651*	1.066**
	(0.292)	(0.600)	(0.355)	(0.380)
lndv	1.787**	1.571*	1.157*	1.953**
	(0.554)	(0.951)	(0.672)	(0.745)
lnec*lndv	0.174***	0.191*	0.114*	0.175**
	(0.050)	(0.105)	(0.061)	(0.065)
Neighborhood				
lnec	0.140	0.322	0.322***	1.791**
	(0.412)	(0.212)	(0.098)	(0.618)
lndv	0.446	0.345***	0.604***	3.324**
	(0.734)	(0.064)	(0.044)	(1.210)
lnec*lndv	0.025	0.069*	0.054**	0.303**
	(0.072)	(0.035)	(0.017)	(0.106)
rho	0.882***	0.724***	0.880***	0.916***
	(0.018)	(0.039)	(0.021)	(0.014)
Control variables	Y	Y	Y	Y
N	1 050	280	360	410

Heterogeneity analysis of cities of different sizes

To further test the spatial heterogeneity of the impact of the differential and coordinated development of the Yangtze River Economic Belt on pollution emissions at the level of different cities, referring to the methods of Yu and Jin (2014), Feng and Wang (2019), the belt cities are divided into four categories for the regression analysis. The results are shown in Table 6.

Table 6 Regression results of the scale spatial econometric model

City	Mega-city	Large sized	Medium sized	Small sized
Local				
lnec	2.269*	1.728**	2.072**	0.163
	(1.233)	(0.723)	(0.670)	(0.705)
lndv	5.032**	3.139**	4.013**	0.504
	(2.516)	(1.371)	(1.282)	(1.146)
lnec*lndv	0.400*	0.299**	0.377**	0.012
	(0.214)	(0.125)	(0.116)	(0.121)
Neighborhood				
lnec	34.032***	1.679*	2.480**	0.900
	(6.106)	(1.008)	(0.970)	(1.124)
lndv	61.984***	3.475*	5.487**	1.227
	(11.573)	(1.929)	(1.850)	(1.568)
lnec*lndv	5.899***	0.291*	0.441**	0.116
	(1.068)	(0.175)	(0.170)	(0.192)
rho	0.219*	0.764***	0.616***	0.410***
	(0.131)	(0.028)	(0.040)	(0.073)
Control variables	Y	Y	Y	Y
N	270	340	310	130

The signs of the coefficients of the coordinated development of mega cities on the pollution of the city and surrounding cities are all negative, with both passing the 10% significance level test, and the coefficients of the two interaction terms are both positive. This finding shows that the coordinated and differential development of mega cities not only promotes the reduction of pollution emissions in the local city but also has spatial spillover effects to reduce pollution emissions from surrounding cities, thus exerting the "scale effect" of mega cities, saving resources and reducing pollution emissions. The results of the coefficients for large and medium sized cities are similar. The impact of regional coordinated development and regionally differentiated development on local pollution emissions passes the 10% significance level test, and the coefficient sign is negative; however, the coefficients of the two on the pollution emissions of the surrounding cities are positive and passed the 10% significance test. This finding shows that the coordinated development of large and medium sized cities has promoted the reduction of pollution emissions in local cities. The coefficients of regional coordinated development and regional differential development in small cities have failed the 10% significance level test, which may be due to the limited spatial scope and low interregional collaboration efficiency. Thus, the differential and coordinated development of small cities has a negative impact on pollution reduction.

Conclusion

Based on the theory of regional coordinated development, this paper uses panel data of prefecture level cities in the Yangtze River Economic Belt from 2008 to 2017 to analyze the degree of regional coordinated development, the degree of differentiated development, and the temporal and spatial distribution pattern of pollution emissions in the Yangtze River Economic Belt. Based on the Durbin model, this paper used the STIRPAT model to analyze the impact of regional differentiation and coordinated development on pollution emissions and its spatial spillover effects. The analysis results show the following.

At the overall level of the Yangtze River Economic Belt, regional differential and coordinated development promoted pollution reduction and improved the ecological environment of the Yangtze River Economic Belt. The effects of regional coordinated development and differential development on pollution emissions are complementary. Regional coordinated and differential development also has a spatial spillover effect on pollution reduction. This effect shows an obvious inverted U shaped trend, with 500 kilometers representing the turning point, and the distance range will reduce pollution in the surrounding area before reaching the turning point. The impact continues to rise, although after reaching the turning point, the impact continues to decline and its effect is no longer significant. The heterogeneity test shows that the differential and coordinated development of the middle reaches of the Yangtze River at the three major regional levels of the Yangtze River Economic Belt promotes pollution reduction in local and surrounding cities. At the city level, the differentiated and coordinated development of mega cities promotes the development of the city and the surrounding cities. The coordinated development of large and medium sized urban areas promotes the reduction of local urban pollution emissions and aggravates the pollution emissions of surrounding cities. The differential and coordinated development of small cities does not have a significant impact on pollution emissions.

Based on the above conclusions, in the process of differentiated and coordinated development of the Yangtze River Economic Belt, the following policy recommendations are proposed to suppress pollution emissions.

First, the government should acknowledge the synergy among regional cities and strengthen cooperation in regional pollution control. Environmental pollution emissions among urban agglomerations need to be jointly managed, accelerate the process of regional integration, break "local segregation", reduce the mismatch of resource elements caused by market segmentation, establish a pollution emission trading market, and make all regions pay more attention to the overall benefits of the region. Formulate unified environmental governance standards and mutual supervision of the implementation of environmental laws and regulations between governments.

Second, the government should focus on regional advantages to promote differentiated division of labor within the region and develop characteristic industries based on local conditions. The government actively guides healthy competition in the market, promotes the appropriate development of industries in various regions of the Yangtze River Economic Belt, and improves overall resource utilization efficiency to achieve emission reduction. The regional industrial gradient transfer should be improved and the upper, middle, and lower reaches of the Yangtze River Economic Belt should be optimized to save the public cost of products and reduce the waste of resources. Products from various regions have achieved complementary advantages via mutual competition and accelerated the upgrading of the industrial structure. The leading role of the regional center should be acknowledged and the transformation of the regional industrial structure to a clean and green industry should be promoted.

Finally, the government should fully exploit the role of technological innovation, industrial structure optimization and economic agglomeration in the coordinated and differential development of the Yangtze River Basin. Moreover, low energy consumption and clean industries should be encouraged and promoted to form linkages in different provinces and cities and realize the effect of economic agglomeration to promote cross regional technical cooperation.

Author contributions This article was planned and designed by Li-Xin Xiong; the research data and the model was constructed and analyzed by Jia-Jun Ning; the paper was constructed by Yun-He Dong and Meng-Meng Dai.

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Ethical Approval Not applicable

Consent to Participate Not applicable

Consent to Publish Not applicable

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References

Azizalrahman H, Hasyimi V (2019) A Model for Urban Sector Drivers of Carbon Emissions. Sustainable Cities and Society 44:46–55

Baghdadi L, Martinez Zarzoso I, Zitouna H (2013) Are RTA agreements with environmental provisions reducing emissions? Journal of International Economics 90(2): 378–390

Bai JH, Wang Y, Jiang FX, Li J (2009) R&D Element Flow, Spatial Knowledge Spillovers and Economic Growth. Economic Research Journal 44(3):42–52

Brown WM, Dar - Brodeur A, Tweedle J (2020) Firm networks, borders, and regional economic integration. J Regional Sci 60:374 - 395

Dauda L, Long X, Mensah CN, Salman M (2019) The effects of economic growth and innovation on CO2 emissions in different regions. Environ Sci Pollut Res 26:15028–15038

Dietz T, Rosa E A (1994) Rethinking the Environmental Impacts of Population， Affluence and Technology Human Ecology Review 2(1): 277–300

Dong ZQ, Wang H (2019) Local Neighborhood Effect of Green Technology of Environmental Regulation. China Industrial Economics (01): 100–118

Dou JM, Cui SH (2018) Does domestic market integration promote the transfer of polluted industries? Industrial Economics Research (4): 76–87

Giannadaki D, Giannakis E, Pozzer A, Lelieveld J (2018) Estimating health and economic benefits of reductions in air pollution from agriculture. Science of The Total Environment 622–623

Haken H (1983) Synergetics: An Introduction. New York: Springer —Verlag

Hasanbeigi A, Price L (2015) A technical review of emerging technologies for energy and water efficiency and pollution reduction in the textile industry. Journal of Cleaner Production 95:30–44

He XM, Lai YJ, Nie AY (2016) Regional integration and regional environmental pollution emission convergence—based on the natural experiment of the Yangtze River Delta regional integration. Soft Science 30(3):41–45

Krugman PR (1991) Increasing returns and economic geography. Journal of Political Economy 99(3): 483–499

Lanzi E, Dellink R, Chateau J (2018) The sectoral and regional economic consequences of outdoor air pollution to 2060. Energy Economics 71:89–113

Li B, Wu S (2017) Effects of local and civil environmental regulation on green total factor productivity in China: A spatial Durbin econometric analysis. Journal of Cleaner Production 153: 342–353

Li J, Lin B (2017) Does energy and CO2 emissions performance of China benefit from regional integration? Energy Policy 101: 366–378

Li L, Zeng W (2016) A Study on the Mechanism of the Impact of

Geographical Proximity and Cognitive Proximity on the Coordinated Development of the Interprovincial Boundary Regional Economies An Empirical Analysis of the Central Delta and the Yangtze River Delta. East China Economic Management 30(05): 1 8+193

Li XS, Qi XX (2019) Analysis of Differentiated and Cooperative Development of Urban Agglomeration in the Middle Reaches of Yangtze River. Journal of Industrial Technological Economics 38(12): 75–83

Li XS, Zhang YQ Sun BW (2017) Does regional integration promote the efficiency of economic growth? an empirical analysis of the Yangtze River Economic Belt China Population. Resources and Environment 27(01): 10–19

Liu G, Yang Z, Chen B (2016) Prevention and control policy analysis for energy related regional pollution management in China. Applied Energy 166: 292–300

Liu NQ, Wu Y (2017) Can the enlargement in Yangtze River Delta boost regional economic common growth. China Industrial Economics (6):79–97

Liu XY, Yang XF, Li YX, et al (2019) Variations in dissolved inorganic carbon species in effluents from large-scale municipal wastewater treatment plants (Qingdao, China) and their potential impacts on coastal acidification. Environ Sci Pollut Res 26:15019–15027

Lu DD (2018) Conservation of the Yangtza River and sustainable development of the Yangtze River Economic Belt: An understanding of General Secretary Xi Jinping's important instructions and suggestions for their implementation. Acta Geographica Sinica 73(10): 1829–1836

Lu M, Chen Z (2009) Fragmented growth: why economic opening may worsen domestic market segmentation? Economic Research Journal 44(03):42–52

Lu M, Feng H (2014) Agglomeration and emission reduction: an empirical study on the influence of city size gap on industrial pollution intensity. The Journal of World Economy 37(07):86–114

Ramanathan V, Feng Y (2009) Air pollution, greenhouse gases and climate change: Global and regional perspectives. Atmospheric Environment 43:37–50

Shao S, Zhang K, Dou JM (2019) Comparisons on the Income Measurements in Chinese Household Survey Data. Management World 35(01): 36 60+226

Shen J, Wei Y D, Yang Z (2017) The impact of environmental regulations on the location of pollution intensive industries in China. Journal of Cleaner Production 148: 785–794

Shi D Q, Ding H, Wei P, et al (2018) Can smart city construction reduce environmental pollution. China Industrial Economics (06):117–135

Sueyoshi T, Yuan Y (2017) Social sustainability measured by intermediate approach for DEA environmental assessment: Chinese regional planning for economic development and pollution prevention. Energy Economics 66:154–166

Sun BW, Cheng ZQ (2019) Research on industrial pollution discharge mechanism of market integration: Taking the Yangtze River Economic Belt as an example China. Environmental Science 39(02):868–878

Wagner UJ, Timmins CD (2009) Agglomeration Effects in Foreign Direct Investment and the Pollution Haven Hypothesis. Environ Resource Econ 43:231–256

Xu HL, Deng YL (2012) Does foreign direct investment cause environmental pollution in China? Spatial measurement based on Chinese provincial panel data. Management World (02):30–43

Yan CH, Wang XH (2019) How does Financial Agglomeration Affect Green Development Efficiency? Empirical Analysis of SPDM and PTR Models Considering Spatio temporal Double Fixation. Journal of Guizhou University of Finance and Economics (01): 25–36

Yang RF (2015) Whether Industrial Agglomeration Can Reduce Environmental Pollution or Not China Population. Resources and Environment 25(02): 23–29

Yao Z, Wang F, Wang C, et al (2019) Anaerobic ammonium oxidation coupled to ferric iron reduction in the sediment of a eutrophic lake. Environ Sci Pollut Res 26:15084–15094

You JH, Chen XQ (2019) Whether regional integration cooperation leads to pollution transfer: Evidence from the enlargement of the Yangtze River Delta urban cluster China Population. Resources and Environment 29(6): 118–129

Yu BB, J G (2019) Space spillovers of Chinese urban structure adjustment and pattern selection. China Industrial Economics (01): 100–118

Yuan HX, Liu YB, Feng DY (2019) Land finance，financial development and urban expansion. Journal of Guizhou University of Finance and Economics (01): 25–36

Zhang K (2018) Is Regional integration beneficial to emission reduction? Journal of Financial Research (1):67–83

Zhang K, Shao S, Fan S (2020) Market integration and environmental quality: Evidence from the Yangtze river delta region of China. Journal of Environmental Management 261: 110–208

Zhang K, Wang DF (2014) The interaction and spatial spillover between agglomeration and pollution. China Industrial Economics (06): 70–82

Zhang X, Wu L, Zhang R et al (2013) Evaluating the relationships among economic growth, energy consumption, air emissions and air environmental protection investment in China. Renewable and Sustainable Energy Reviews 18: 259–270

Zhao LD, Xu L (2019) Study on water pollution effects of regional integration based on the quasi-natural experiment of the enlargement in Yangtze River DeltaChina Population. Resources and Environment 29(03):50–61

Zhu Y, Xia Y (2019) Industrial agglomeration and environmental pollution: Evidence from China under New Urbanization. Energy & Environment 30(06): 1010–1026

Figures

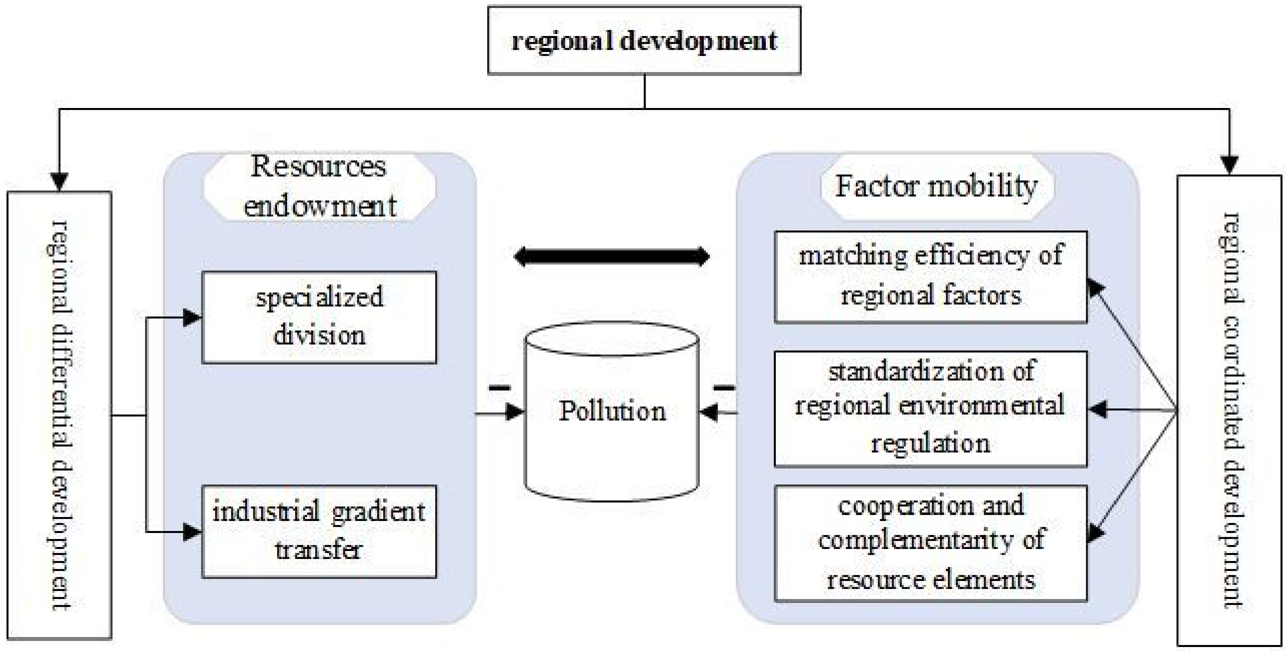

Figure 1

Regional differentiation and coordinated development of pollution emission reduction mechanisms

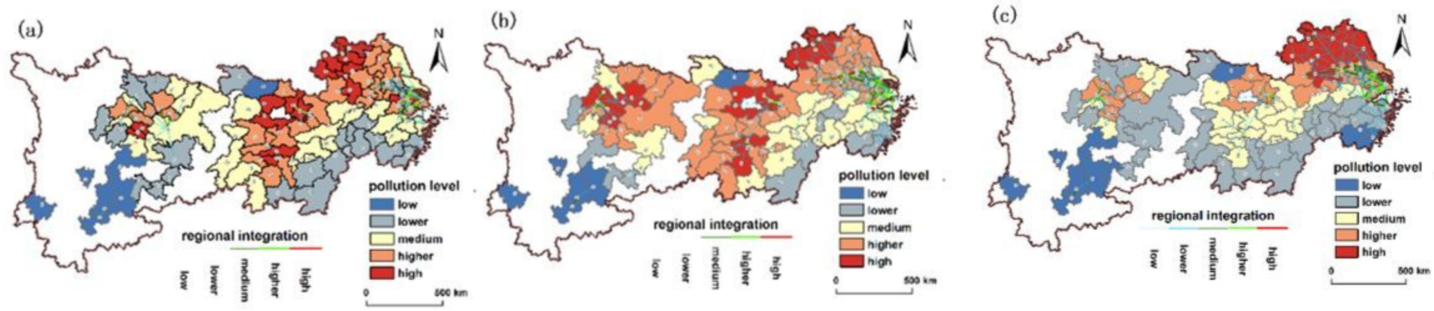

Figure 2

Spatial and temporal differentiation of pollution emissions in the coordinated development of the Yangtze Economic Belt (a: in 2008; b: in 2012; c: in 2017) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

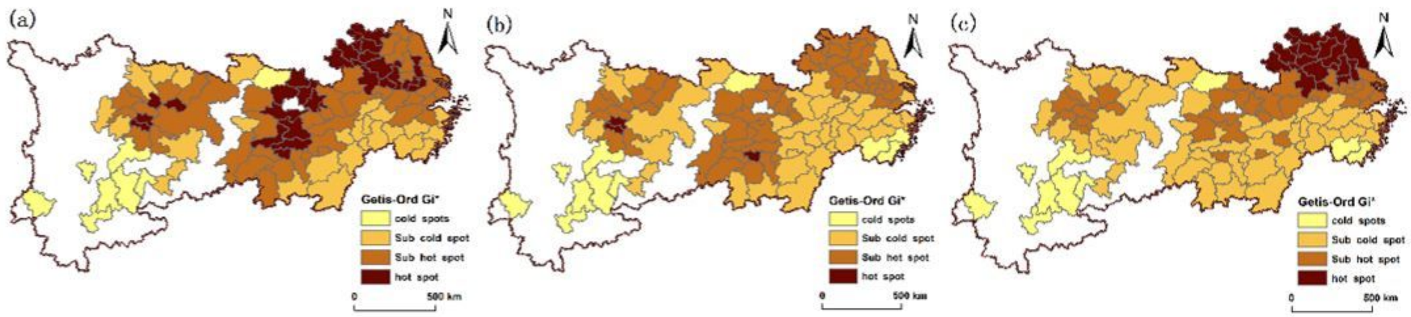

Figure 3

Spatial and temporal differentiation map of pollution concentration hotspots and cold spots cities in the Yangtze River Economic Belt is different (a: in 2008; b: in 2012; c: in 2017) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

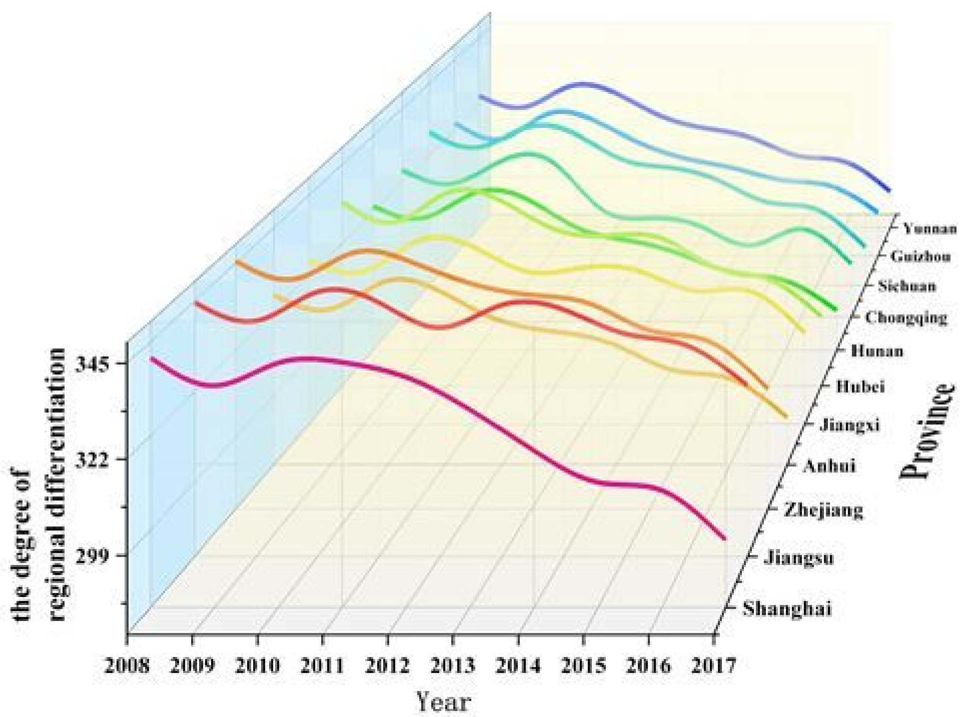

Figure 4

Development degree of different provinces and cities in the Yangtze River Economic Belt is different

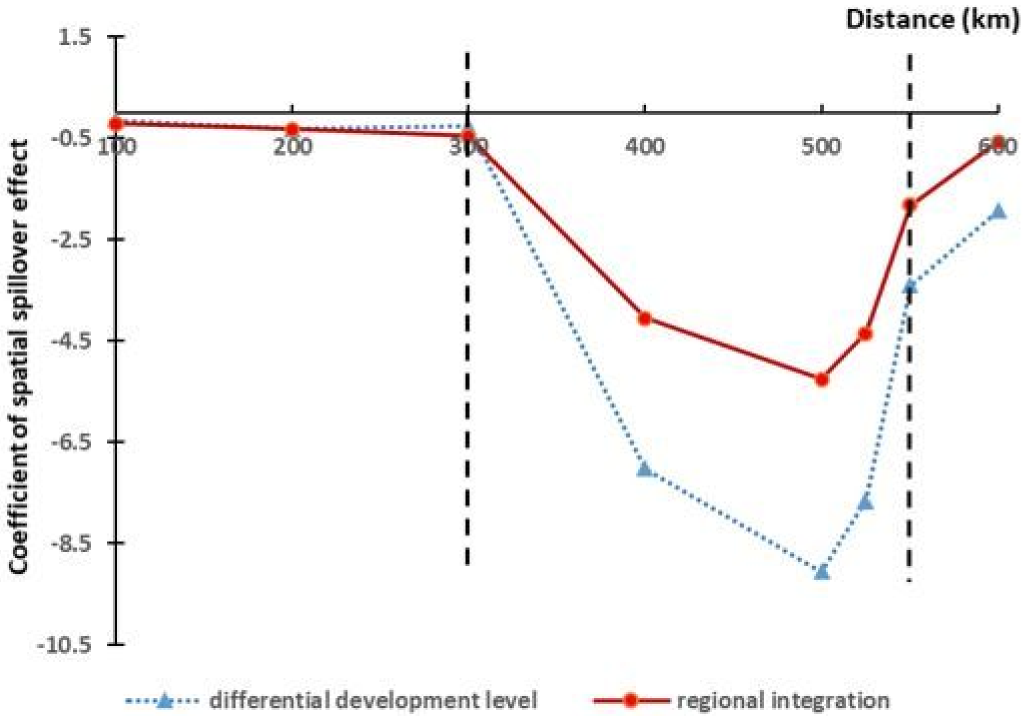

Figure 5

Spillover coefficient of differentiated coordinated development space in different urban areas