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Dynamic Evolution and the Mechanism behind the Coupling Coordination Relationship between Industrial Integration and Urban Land-Use Efficiency: A Case Study of the Yangtze River Economic Zone in China

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Abstract: It is of great significance to explore the dynamic coupling relationship between industrial integration and urban land-use efficiency (ULUE) in order to promote high-quality urban development. This paper presents a system for evaluating industrial integration and ULUE which combines the internal theoretical relationships between the two. Based on this system, this paper analyzes the evolution process and the mechanism behind the coupling coordination relationship between industrial integration and ULUE with the help of the coupling coordination model, nonparametric kernel density estimation, and the geographical detector method. The results indicate the following: (1) The coupling coordination relationship between industrial integration and ULUE in the Yangtze River Economic Zone experienced an overall steady increase during the investigation period. However, there were great spatial differences in the coupling coordination relationship among cities. (2) The lag of the industrial integration level was the key area of resistance to the improvement of the coupling coordination level. (3) The interaction between industrial integration and ULUE in the Yangtze River Economic Zone was very significant. In particular, the impact of industrial agglomeration and factor flow on the ULUE and the impact of land on industrial integration in terms of ecological environment were prominent. In addition, the interaction of different detection factors was mainly manifested as a double factor enhancement effect and nonlinear enhancement effect.

Keywords: industrial development; integration; urban land-use efficiency; coupling relation; geographic detector

1. Introduction

As the path to realize regional integration [1], industrial integration has gradually become an important link between each region, producing an agglomeration effect, maximizing the overall benefit, and improving the quality of economic growth [2–4]. A typical characteristic of the industrial integration development process is the continuous improvement of urban land-use intensity. However, the current conditions and reality in China reflect the fact that there are more people than the land can support, land resources are scarce, utilization efficiency is low, and land use causes serious damage to the environment [5–7]. Therefore, the traditional extensive mode of development of industrial land can no longer meet the requirements for improving the quality and efficiency of social and

economic development [8–11]. The report of the 18th National Congress of the Communist Party of China pointed out that land resources should be saved and used intensively. Furthermore, it stated that it was necessary to change the way land resources are used, strengthen the process of management, greatly reduce the intensity of land consumption, and improve land use efficiency. In China, urban land represents the practice of comprehensively deepening the reform of the economic system. As the strategic position of industrial integration becomes increasingly prominent, urban land use must move away from producing high levels of pollution and carbon emissions in the process of factor production input. It is necessary to gradually shift to the intensive utilization and efficient allocation of urban land required by the new era [12,13]. Therefore, coupling coordination between the levels of industrial integration and urban land-use efficiency (ULUE) needs to be accurately quantified and the coupling mechanism between them clarified. It is necessary to optimize the layout of industrial land, solve the constraints of land re-sources and the environment, and realize the coordinated development of industrial integration and ULUE.

The correlation between industrial integration and ULUE originates from Weber's industrial location theory [14]. Since the popularization of the theory, more and more scholars have utilized it to reveal the logical relationship between industrial development and ULUE by introducing agglomeration and spillover effects [15–17]. Ellison and Glaeser argue that income-increasing technologies and spillover effects exist in industrial agglomeration zones in theory [18]. These effects can lead to economic externalities by transforming industrial structures into specialized ones or diversifying others in order to improve the urban land-use efficiency [19]. Xin Gao constructs a framework for regional economic integration that influences ULUE through industrial layout and urban input–output structure. He explains that the industrial spatial layout can influence ULUE through the spillover effect [20]. Ma Tao believes that the flow of production factors and the distribution of economic activities determine the evolution of the spatial structure. Moreover, the spatial structure produces industrial clustering and gradient and promotes regional integration through agglomeration and radiation effects [21]. In turn, this affects ULUE [22]. It can be observed that the theoretical connotation of industrial integration has shifted from a spatial layout to factor flow. This means that production factors such as technology, capital, and labor are the key to changing ULUE [23]. The free inflow and outflow of this high-quality development element in a specific land space driven by profit enable land economic activities to achieve a Pareto improvement in overall efficiency. However, previous studies have ignored this point when evaluating industrial integration, only focusing on the location advantages of the industrial spatial layout.

Based on measuring the level of industrial development and ULUE, some scholars use econometric methods to empirically test the correlation between the two [24–27]. Jingming Liu combined the STIRPAT model and the spatial Durbin model (SDM) to analyze the impact of industrial structure optimization on ULUE. He found that the relationship exhibited a U-shaped curve [19]. Furthermore, Haojun He used the PVAR model to verify the long-term dynamic interaction between industrial structure change and ULUE. He found that the improvement of ULUE produced an inverted effect on the rationalization and upgrading of industrial structure [25]. Some scholars prefer to use the coordination model in order to quantify the coupling level of industrial development and ULUE. Similarly, they use it to analyze the spatial and temporal characteristics of that level [28–31]. These studies aimed to uncover the coupling level between industrial development and ULUE and clarify the principle by which the coupling coordination relationship changes. For example, Qunxi Gong used panel data from 2004 to 2018 to measure the level of coupling coordination between industrial agglomeration and intensive land use in eight cities of the Chengdu metropolitan area. He found that low–high–low spatial characteristics first appeared in the southwest and then in the northeast, while the general level of coupling coordination increased [29].

Overall, the existing studies have had a positive effect on promoting the level of industrial development and improving ULUE. However, they have a few shortcomings.

Firstly, many scholars have paid attention to the dialectical relationship between industrial development and urban land use and use mathematical models to verify it in their research. One drawback of these studies is that they do not specify the internal structure and elements of industrial development and ULUE systems. Furthermore, the geographical detector method has often been used to explore the interaction between industrial development and ULUE in a geographical space. Secondly, research on the industrial integration index mainly involves industrial agglomeration, structure change, and layout, but does not involve talent, capital, information, or technology flow in the evaluation system. The essence of industrial integration is factor flow. Based on regional spatial layout and factor flow, this paper constructs a comprehensive evaluation system of industrial integration by examining key factors that affect the development of integration. In addition, the evaluation index of ULUE is developed from a single economic benefit index [32,33] to a multi-benefit index that creates both social and environmental advantages [34]. Under high-quality urban development, ULUE not only emphasizes the maximization of economic, social, and environmental benefits, but also requires the minimization of resource consumption and emissions [35]. However, existing studies lack a unified understanding of the process of selecting specific indicators of energy input and non-expected output. Likewise, they have not managed to find a means of incorporating them into a measurement system. Considering that energy conservation is an inherent requirement of the sustainable development of urban land, this paper introduces it into an input index analysis framework and constructs the ULUE index system as follows: input + expected output + unexpected output.

Based on the aforementioned ideas, this paper includes 107 cities at prefecture level and above in the Yangtze River Economic Zone as its research subjects, re-examines the level of industrial integration and ULUE of each city in the region, and uses the coupling coordination degree model and nonparametric kernel density estimation method to analyze the current situation and dynamic evolution of the coupling coordination relationship between the two. Furthermore, the geographical detector method is introduced in order to thoroughly analyze the coupling coordination mechanism between industrial integration and ULUE. The research results aim to uncover the exact coupling coordination level of industrial integration and ULUE in the Yangtze River Economic Zone. Finally, the results also hope to provide empirical support and policy enlightenment for the coordinated development of industrial integration and ULUE.

2. The Coupling Coordination Mechanism of Industrial Integration and ULUE

2.1. The Effect of Industrial Integration on ULUE

Industrial integration is conditioned by market economy and adjacent cities in order to achieve an overall optimal level of integration and promote industry in the layout, division of labor, cooperation, and other aspects of extensive linkage (the final realization of elements within the region barrier-free circulation process) [36–38]. From the perspective of connotation, industrial integration includes two dimensions: the industrial spatial layout and factor flow. The industrial layout represents the physical spatial basis of land development and its utilization across regions, while factor flow indicates the direct driving force that improves ULUE. Therefore, this paper constructs a theoretical analysis framework for the effect that industrial integration has on ULUE based on the mentioned dimensions (Figure 1).
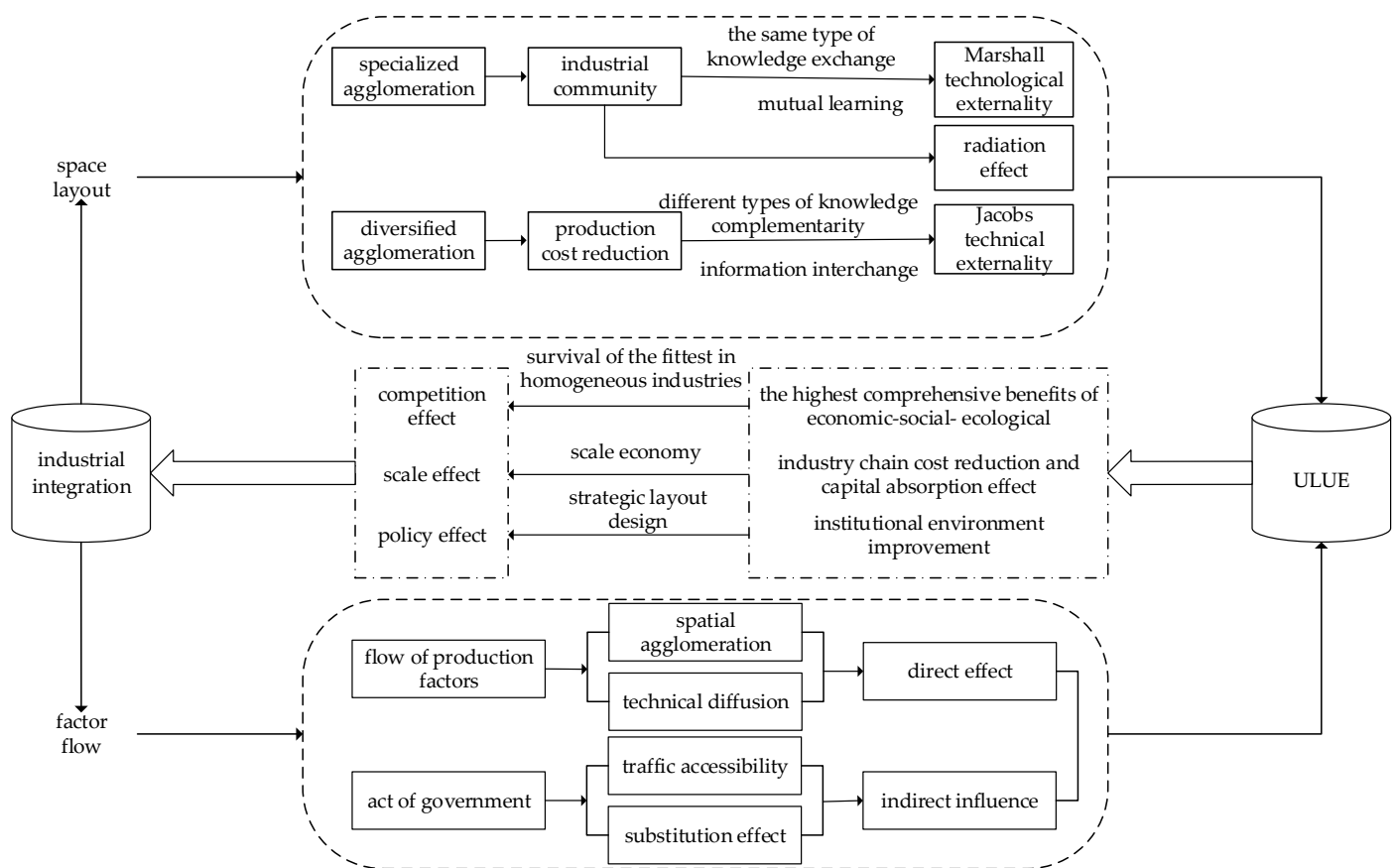
Figure 1. The coupling coordination mechanism between industrial integration and ULUE.

At the industrial layout level, industrial integration mainly changes the mode of cooperation of different enterprises between or within industries through two layout structures that specialize or diversify agglomerations. Furthermore, it relies on the technical externalities generated by knowledge spillover and information sharing that affect ULUE [17,39]. At the factor flow level, factor flow mainly affects ULUE through factor flow and government behavior. The industrial layout level is further explained and exemplified in Sections 2.1.1 and 2.1.2, while the description of the factor flow level can be found in Sections 2.1.3 and 2.1.4.

2.1.1. Industrial Specialization Agglomeration

To meet the needs of large-scale, specialized, and cooperative production in the process of industrial integration and produce comprehensive functions and a diversified supply of products, various industrial subjects establish extensive links in terms of layout, the division of labor, and collaboration so as to build an industrial community [1]. Enterprises in the industrial community go through a very interactive process of innovation, which can establish an information-sharing platform through knowledge exchange and mutual learning. This process is favorable for the realization of professional advantages, industrial cooperation, innovation [20], and the formation of Marshall technology externalities [40]. It can also improve the economic benefits of a land unit, thus promoting ULUE. When the industrial community reaches a certain scale, land-use efficiency in the central city will exhibit a spatial radiation effect on adjacent areas [19]. Combined with the technology spillover of the industry itself, the cross-integration of the two effects will jointly improve ULUE in adjacent areas [41]. At the same time, this effect is fueled by the spatial layout of land use in central cities, thereby forming a cumulative cycle that increases the efficiency mechanism [42].

2.1.2. Industrial Diversified Agglomeration

With the advancement of industrial integration, industries with interrelated knowledge gradually form industrial diversification agglomerations. Due to its characteristics, industrial diversification can incorporate more types of intermediate and final products into new production links. Therefore, transportation and land-use costs are reduced, which ultimately improves the ULUE [39]. Industrial diversification agglomeration also produces Jacobs technological externalities through knowledge complementarity and information exchange, as well [43]. In turn, the Jacobs technological externality improves the industrial structure by rationalizing and advancing it. Thereby, the overall productivity of regional labor and land-use efficiency is improved.

2.1.3. Factors of Flow Production

Firstly, the process of industrial integration can facilitate spatial agglomeration and optimize various factors by increasing the allocation of capital, labor, and information. This ultimately affects the efficiency of resource allocation and ULUE [1,44]. Secondly, production factors have spatial relevance as bridges of regional economic ties. A region's technological progress will be transmitted to other regions through the cross-regional flow of elements. In turn, technology diffusion will be formed and urban land-use efficiency is improved in other regions [45].

2.1.4. Government Behaviour

Local government behavior can influence the process of factor integration, indirectly impacting ULUE. On one hand, urban economic growth strategies on different spatial scales are transformed from mutual competition to horizontal cooperation in the context of integration [41]. This shift enables the government to provide strong financial support for the improvement of urban infrastructure. Furthermore, urban infrastructure, especially transport infrastructure in urban fringe areas, will be notably improved. Additionally, traffic accessibility can significantly reduce the commuting cost in cities and improve the output efficiency of urban land use by enhancing labor productivity [46]. On the other hand, the inelastic nature of land supply and the need for food security and environmental protection hinder the limitless expansion of industrial land. Inevitably, the government will require enterprises to substitute capital, manpower, and technology for land resources. Thereby, land-use intensity will be improved [19,42].

2.2. The Influence of ULUE on Industrial Integration

Urban land and its development products, as the spatial constraints and resource carriers of industrial structure layout and factor environment, contain the developmental elements for the high mobility of manpower, capital, information, and technology [34]. Not only does ULUE reflect the economic benefits of industrial development, it also directly relates to the scale and degree of industrial integration development.

The impact of ULUE on industrial integration is characterized by competition, scale, and policy effects.

If undesirable output is taken into consideration, the improvement of ULUE inevitably requires land suppliers to observe industries using in terms of the market competition effect due to the constraints of urban land supply. To maximize the social, economic, and ecological benefits, land suppliers tend to choose industries with a low input and high output [42]. Consequently, the best homogeneous industries might survive and replace enterprises with a high pollution and low efficiency [19].

In terms of scale effect, the improvement of ULUE is favorable for reducing the cost of the industrial chain, which highlights the industrial scale of the economy [17] and accelerates the rise of industrial clusters. Moreover, the improvement of ULUE can lead to the flow of people, logistics, and information being absorbed by adjusting the economic supply of land. Thus, the direction, structure, and layout of industrial development changes and ultimately affects the scale and speed of industrial integration development.

When it comes to policy effects, means of macro-control, such as land-use control and planning, are important policy tools that promote the process of industrial integration [1], which can effectively curb the blind expansion and extensive use of industrial land. Therefore, local governments can often create a good institutional environment through strategic layout design. The improvement of the institutional environment is favorable to the industry, enhances the scientific and technological innovation ability, enriches the format, and strengthens the cooperation and exchange between industries. Likewise, this kind of industry promotes the optimization of industrial structure and the rationalization of the layout.

3. Overview of the Study Area and Data Sources

The Yangtze River Economic Zone spans across China's east, central, and west regions and runs through nine provinces and two municipalities, including Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Hubei, Hunan Chongqing, Sichuan, Yunnan, and Guizhou. It includes the Yangtze River Delta urban agglomeration, the urban agglomeration in the middle reaches of the Yangtze River, and the Chengdu–Chongqing urban agglomeration. As strategic core areas of economic growth in the Yangtze River Economic Zone, the three agglomerations contain about 30% of the country's population and possessed about 8% of its land area, contributing to about 40% of the GDP in 2019. They also contain essential population, resources, and industrial agglomeration areas in China [47].

For the purposes of this research, municipal areas of prefecture-level cities in the Yangtze River Economic Zone are studied in order to investigate the spatial and temporal characteristics of coupling coordination between industrial integration and ULUE. Zhoushan, an island in Zhejiang Province, is not included in this study. In addition, the original Chaohu City was dissolved in 2011 and assigned as part of Hefei. In the end, this paper focuses on 107 cities at the prefecture level and above in the Yangtze River Economic Zone as areas of interest (Figure 2). The socio-economic data sources were taken from the China City Statistical Yearbook for the years 2006 through 2020 and the provincial statistical yearbooks. This paper supplements a small number of the missing values with linear interpolation.
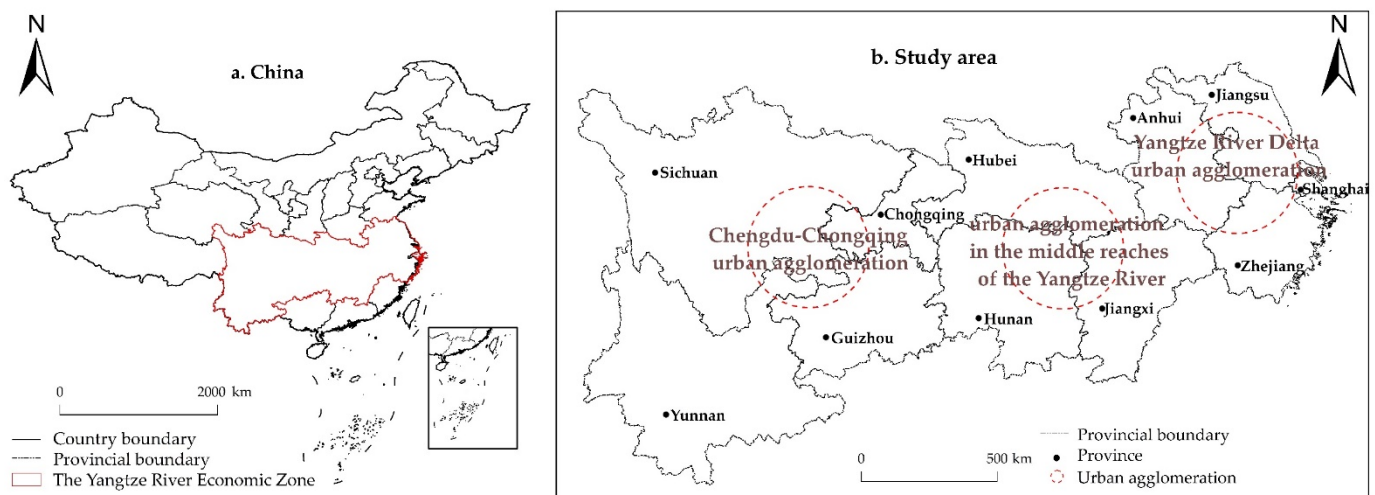

Figure 2. *Cont.*
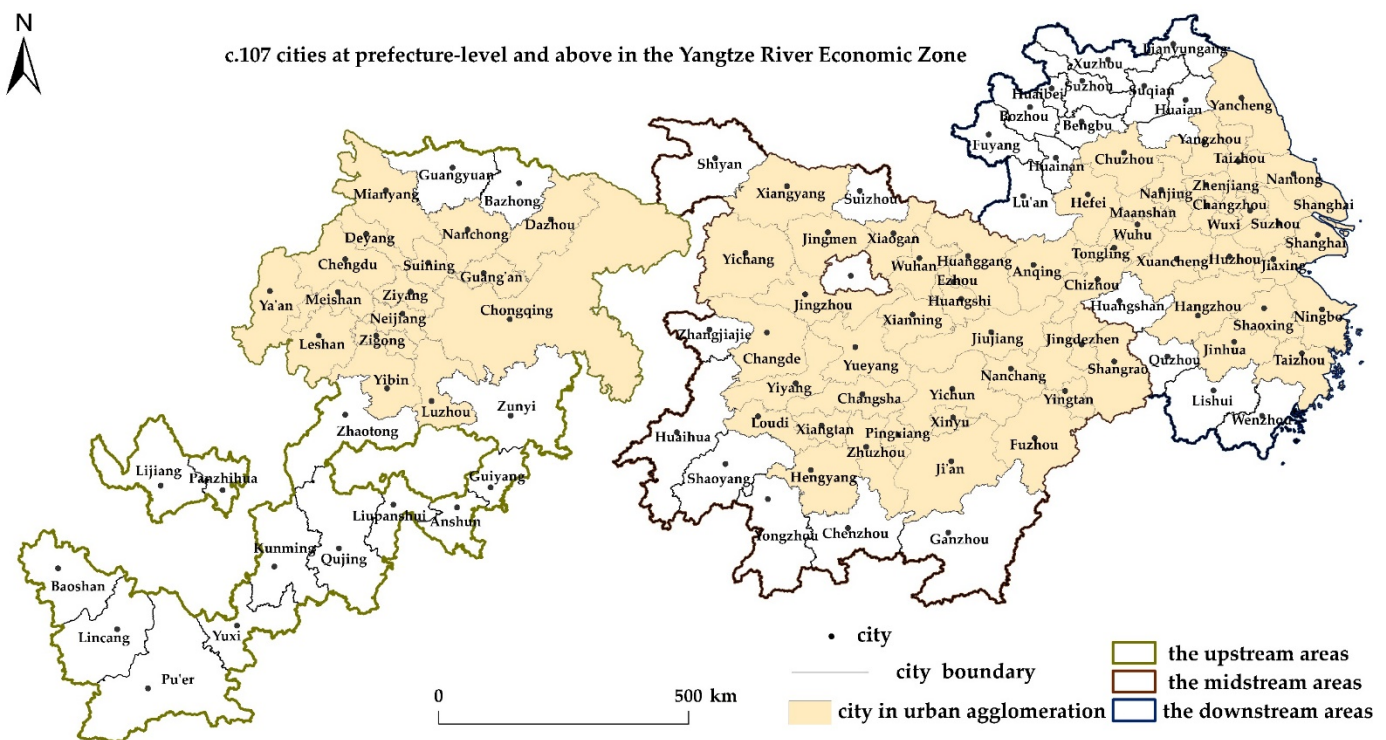
Figure 2. The spatial scope of the Yangtze River Economic Zone in China. (**a**) China; (**b**) the Yangtze River Economic Zone; (**c**) 107 cities at prefecture-level and above in the Yangtze River Economic Zone.

4. Research Design

4.1. Construction of the Index System

4.1.1. The Industry Integration Index System

According to the above theoretical analysis, this study regards industrial integration as a vertical development process from superficial integration to deep integration, that is, from the integration of industrial layout characterized by spatial physical linkages between regions to the integration of industrial factors flow with this interaction as the carrier within the region [48]. Based on the above understanding of the connotation of industrial integration, this paper combines the development status of industrial integration in the Yangtze River Economic Zone and relevant research results obtained at home and abroad [1,48], and constructs a system for the evaluation of industrial integration from the two dimensions of spatial layout and factor flow (Table 1). Among these, the obvious characteristics of spatial layout are industrial expansion, industrial cluster, industrial division of labor, and industrial upgrading, which mainly reflect the physical connection in the process of industrial development, including economies of scale, the spatial agglomeration effect, the division of labor and cooperation, and structural function upgrading. Moreover, labor, capital, information, and technology are significantly mobile and influential within and between industries. The differences in the flow speed, direction, and scope of each mentioned element lead to differences in regional industrial development patterns and forms, which affects the development of industrial integration.

Table 1. Industry integration index system.

Criterion Layer	Indicator Layer	Calculation Basis
space layout	industrial expansion	number of industrial enterprises above designated size
	industrial cluster	$Gini = \sum_i (s_i - x_i)^2$
	industrial division	$S_{ij} = \frac{\sum (x_{ik} \times x_k)}{\sqrt{(\sum x_{ik}^2 \times \sum x_k^2)}}$
	industrial upgrading	$IQ = SV/TV$
factor flow	labor flow	passenger traffic/total population
	capital flow	amount of foreign capital utilized
	Information flow	the total volume of post and telecommunications business
	technology flow	number of science and technology service personnel

In the formula for the calculation of industrial clusters, the Gini coefficient represents the degree of industrial agglomeration, s_i is the proportion of employment in industry i within the total employment capacity of the industry in a region, x_i is the proportion of employment within the total employment capacity of the province where it is located, and i can be 2 or 3. In the calculation formula for the industrial division of labor, S_{ij} represents the similarity of industrial structure; x_{ik} and x_{jk} represent the output value of the industry k of the region i and the province in which the region is located, respectively; and k can be 2 or 3. In the calculation formula for industrial upgrading, IQ represents the upgrading of the industrial structure, while SV and TV represent the output value of the tertiary and secondary industry in a particular region, respectively.

4.1.2. The Urban Land-Use Efficiency (ULUE) Index System

ULUE is an essential indicator when measuring the intensity of land-use input and output adaptation under multiple objectives, such as resource utilization; scale optimization; environmental pressure minimization; and the coordinated promotion of social, economic, and ecological output [49]. Specifically, this paper constructs an index system for measuring ULUE in reference to the ideas of Liutao Liang [49], Deqi Wang [50], Xinhai Lu [51], and other scholars (Table 2). The input indicators include land, capital, labor, and energy, which are characterized by the built-up area, fixed asset investment per land, number of tertiary industry employees in the area, and power consumption per unit of GDP. Moreover, the expected indicators mainly consider the economic, social, and environmental benefits of urban land use. To a certain extent, the total GDP can characterize the economic land output level. This paper uses the regional GDP index to convert nominal GDP to real GDP at comparable prices based on the initial year in order to approximate the data. Furthermore, the social development index can reflect the level of regional social development and the improvement of people's livelihoods. Therefore, the entropy weight method is used to calculate social development indicators by selecting the rate of population growth, the proportion of people with college or higher education among the total population, and the number of hospital beds per 10,000 people. Furthermore, an eco-friendly way to use urban land is to expand green areas within built-up ones. The green area coverage rate of the built-up areas is selected as the ecological quality index of urban land use. For the specific selection of undesirable indicators, this paper uses the entropy weight method to synthesize three types of waste—i.e., industrial wastewater discharge, solid waste emissions, and industrial SO_2 emissions—into the pollutant emission index. If the negative environmental effect of CO_2 emission on urban land use is taken into consideration, the unexpected output increases the energy carbon emission index. This includes the carbon emissions generated by the consumption of raw coal, coke, gasoline, kerosene, diesel oil, fuel oil, liquefied petroleum gas, natural gas, clean coal, other coal washing, and coke oven gas. Finally, this

paper refers to the IPCC accounting framework in order to calculate the energy carbon emission index [52].

Table 2. ULUE index system.

Goal Layer	Criterion Layer	Indicators
Inputs	land	built-up area
	capital	fixed asset investment per unit of land
	labor force	tertiary industry employees per unit of land
	energy	power consumption per unit of GDP
Expected outputs	economic benefit	total GDP
	social benefit	social development index
	environmental benefit	green area coverage of the built-up area
Undesired outputs	emission-reduction	emission of three types of wastes
	low carbon	CO_2 emission

4.2. Selection of Research Methods

4.2.1. Support Vector Regression for Measuring Industrial Integration

Support vector regression can avoid the problem of index dimension defects and weight subjectivity and reduce structural risk, making it especially suitable for time series data mining. It has a good generalization performance in comparison to the neural network and multi-factor comprehensive evaluation methods [1,53]. Therefore, this paper uses the support vector regression method to measure the level of industrial integration. The operating software used is MATLAB R2018b and the specific steps are as follows: (1) Standardized processing of the evaluation index data. Based on the open-source code provided by Chen Li [53], this paper first carries out SVR regression simulation training to determine the optimal classification function of indicators. (2) With the optimal classification function, this paper sets the internal parameters as σ, ε, C. The prediction accuracy of the SVM model is greatly influenced by hidden parameters such as kernel function σ, insensitive loss function coefficient ε, and penalty factor C. Among these, the parameter σ affects the radial range of the function, the parameter ε controls the insensitive region, and the parameter C determines the error tolerance. (3) Determine the complex correspondence between the predicted value a_i and the target value y. After repeated iterations, we obtain the most reasonable weight value of each index w_i and the correlation function f. (4) Use the $y = \sum\limits_{i=1}^{n} a_i w_i + \frac{f(a_i)}{\sqrt{C}}$ formula to measure the level of industrial integration.

4.2.2. The Use of the Super-Efficiency SBM Model for Measuring ULUE

The super-efficiency slack-based model (SBM) is a data envelopment analysis method proposed by Tone with slack variables and undesirable outputs [49]. This model can solve the problem of input-output slack. As a consequence, it is used to measure efficiency in this paper. Likewise, the super-efficiency SBM mode is also used to measure ULUE. The basic model is represented by the following equations [54,55]:

$$\min \rho = \frac{\frac{1}{m}\sum\limits_{i=1}^{m}\left(\overline{x}/x_{ik}\right)}{\frac{1}{r_1+r_2}(\sum\limits_{s=1}^{r_1}\overline{y^d}/y_{sk}^d + \sum\limits_{q=1}^{r_2}\overline{y^u}/y_{qk}^u}$$

(1)

$$
\left\{
\begin{array}{ll}
\overline{x} \geq \sum\limits_{j=1,\neq k}^{n} x_{ij}\lambda_j & i = 1,2\cdots,m \\[2mm]
y^d \leq \sum\limits_{j=1,\neq k}^{n} y_{sj}^d\lambda_j & s = 1,2\cdots,r_1 \\[2mm]
y^d \geq \sum\limits_{j=1,\neq k}^{n} y_{qj}^u\lambda_j & q = 1,2\cdots,r_2 \\[2mm]
\lambda_j \geq 0 & j = 1,2\cdots n \\[1mm]
\overline{x} \geq x_k & k = 1,2\cdots m \\[1mm]
y^d \leq y_d^k & q = 1,2\cdots,r_1 \\[1mm]
y^u \geq y_k^u & u = 1,2\cdots,r_2
\end{array}
\right\}
\tag{2}
$$

In Equations (1) and (2), n represents the number of decision-making units; m, r_1, and r_2 represent the input, expected outputs, and undesired outputs, respectively; x, y^d, and y^u represent the number of elements in the corresponding input, expected, and undesired matrices, respectively; and ρ is the ULUE.

4.2.3. The Coupling Coordination Degree Model for Evaluating the Coupling Coordination Level of Industrial Integration and ULUE

As ULUE objectively reflects the coupling level between the input structure of production factors and the output structure of urban land use [41], it can be regarded as a system. The development of industrial integration depends on the interaction of regional factors such as capital, talent, information, and technology in a region [48]. Consequently, industrial integration can also be regarded as a system. From a systematic perspective, industrial integration and ULUE are the most significant components of the urban system. The system's key means for restoring order is the synergy between internal order parameters. The coupling degree, its physical concept, depicts this effect [56]. Therefore, this paper constructs the following model to evaluate the relationship between industrial integration and ULUE [57].

$$
C = \left[\frac{U_1 U_2}{(U_1 + U_2)^2} \right]^K
\tag{3}
$$

In Equation (3), C represents the coupling degree, while U_1 and U_2 are the level of industrial integration and ULUE, respectively. For the adjustment factor, K takes a value of 0.5. In reference to the study of Xuesong Kong [58], this paper divides the coupling degree into a low-level coupling stage (0, 0.3), antagonistic stage (0.3, 0.5), running-in stage (0.5, 0.8), and high-level coupling stage (0.8, 1.0).

Coupling degree is of great importance when judging the role of industrial integration and ULUE systems. However, it is difficult to express the synergistic effect of system components. Therefore, this paper introduces the coupling coordination model [59]:

$$
\begin{array}{c}
D = \sqrt{C \times T} \\
T = aU_1 + bU_2
\end{array}
\tag{4}
$$

In Equation (4), D is the coupling coordination degree, T is the comprehensive coordination index, and a and b are both undetermined coefficients. Since the contributions of the two systems are consistent, $a = b = 0.5$. In reference to Lijun Liu's research [31], this paper uses the uniform distribution function to classify the coupling coordination degree (Table 3). In addition, it introduces the synchronous development model [60] to divide the synchronous relationship between industrial integration and ULUE into industrial integration lag ($H < -0.1$), relative synchronization ($|H| \leq 0.1$), and ULUE lag types ($H > 0.1$), where $H = U_1 - U_2$.

Table 3. Coupling coordination degree level.

Level	Extreme Disorder Recession	Severe Disorder Recession	Moderate Disorder Recession	Mild Disorder Recession	Endangered Disorder Recession
interval	(0, 0.1]	(0.1, 0.2]	(0.2, 0.3]	(0.3, 0.4]	(0.4, 0.5]
level	reluctantly coordinated integration	primary coordinated development	intermediate coordinated development	good coordinated development	high-quality coordinated development
interval	(0.5, 0.6]	(0.6, 0.7]	(0.7, 0.8]	(0.8, 0.9]	(0.9, 1.0]

4.2.4. The Nonparametric Kernel Density Estimation for Reflecting Dynamic Evolution Characteristics of the Coupling Coordination Degree

Kernel density estimation is a nonparametric method used for estimating the probability density function of random variables. It can describe the distribution, shape, and extensibility of random variables using density curves [54]. The formula for it is:

$$f(x) = \frac{1}{N_h} \sum_{i=1}^{N} K(\frac{X_i - x}{h}) \tag{5}$$

In Equation (5), N is the sample number; h is the window width; and $K(\bullet)$ is a random function that includes the Gaussian, triangular, quadrilateral, and Epanechnikov kernel functions. This paper uses the MATLAB R2018a software to estimate the kernel density with the Gaussian kernel function and determines that $h = 0.02$ after repeated experiments. Likewise, it uses the kernel density estimation curve to show the dynamic evolution characteristics of the coupling coordination degree between industrial integration and ULUE in the Yangtze River Economic Zone.

4.2.5. The Geographical Detector for Identifying Coupling Coordination Mechanism

This paper uses the geodetectors model to detect spatial differentiation between geographical objects, and then reveal their action mechanism [50]. It has been widely applied in the fields of land use, ecology [61], and regional economy [62]. Furthermore, this paper applies the model to identify the interaction of the coupling factors between industrial integration and ULUE. The specific formula is as follows:

$$q = 1 - \frac{\sum\limits_{h=1}^{L} N_h \sigma_h^2}{N \sigma^2} \tag{6}$$

In Equation (6), q is the explanatory power of influencing the spatial differentiation of dependent variables; L is the number of variable layers; N_h and N are the number of samples for the layer h and the region, respectively; and σ_h^2 and σ^2 are the sample variances for the layer h and the whole area, respectively.

5. Empirical Analysis

5.1. Spatial and Temporal Characteristics of Industrial Integration and ULUE

This paper applies the ArcGIS 10.2 natural discontinuity method to present industrial integration and ULUE. Figure 3 shows that the overall ULUE of 107 cities at the prefecture level and above in the Yangtze River Economic Zone exhibited a steady upward trend from 2005 to 2019, but the efficiency level of ULUE indicated obvious regional differences. From a regional perspective, in 2019, high-value cities were mostly distributed in economically developed regions of the Yangtze River Delta, regional economic centers, and areas with ecological tourism resource endowments. Among these, typical representative cities include Hangzhou, Shaoxing, Jinhua, Quzhou, and Taizhou. These cities gradually formed local high-value agglomeration areas by virtue of their geographical proximity and may have

experienced accelerated development under the economies of scale effect and multiplier effects. Low and very low-value cities are mainly distributed in underdeveloped areas in the middle and lower reaches of the Yangtze River. With the advantages of their natural background, some cities in this region showed a relatively high level of development at the beginning. However, later, because of their slow growth rate, they come to lag behind other regions. This is mainly because the geographical locations of these cities are poor, with few available resources that could be used in the process of economic development, resulting in insufficient endogenous impetus for their development. Therefore, these differences are closely related to the economic foundation, industrial level, and technological innovation capabilities of different cities.
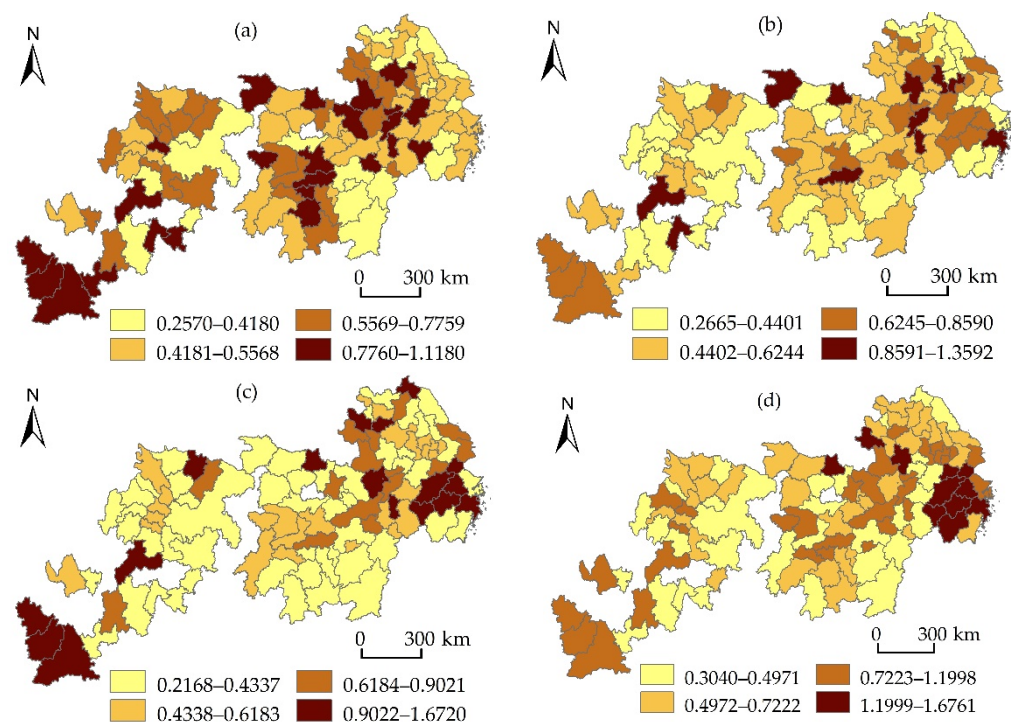

Figure 3. Spatial differentiation of the ULUE. (**a**) The ULUE in 2005; (**b**) the ULUE in 2009; (**c**) the ULUE in 2014; (**d**) the ULUE in 2019.

The level of industrial integration also exhibits the same regional differences. Figure 4 shows that the industrial integration level of 107 cities at the prefecture level and above in the Yangtze River Economic Zone significantly improved during the study period. In particular, the urban agglomeration in the middle reaches of the Yangtze River improved. The Yangtze River Delta urban agglomeration also significantly improved. However, the industrial integration level of the Chengdu–Chongqing urban agglomeration is always at a low level, and the potential space for improvement remains large.

During the study period, the analysis of spatial and temporal characteristics showed that a certain degree of coupling is observable between the industrial integration level of the Yangtze River Economic Zone and ULUE is observable. To further verify the existence of the coupling relationship, this paper uses the coupling coordination degree model and nonparametric kernel density estimation to analyze the temporal evolution characteristics of industrial integration and ULUE coupling coordination in the Yangtze River Economic Zone.
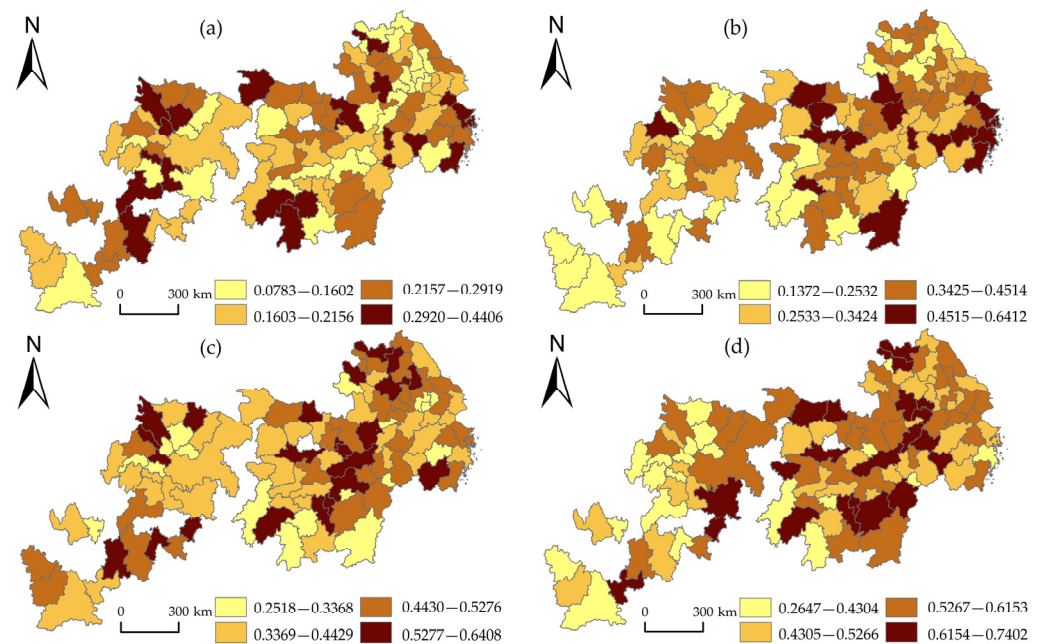
Figure 4. Spatial differentiation of the industrial integration. (**a**) The industrial integration in 2005; (**b**) the industrial integration in 2009; (**c**) the industrial integration in 2014; (**d**) the industrial integration in 2019.

5.2. Analysis of the Temporal Evolution Characteristics of Coupling Coordination between Industrial Integration and ULUE

5.2.1. Analysis of the Temporal Trend Characteristics

Firstly, Table 4 shows that the average level of industrial integration in the Yangtze River Economic Zone increased from 0.2244 in 2005 to 0.5292 in 2019. The ULUE also rose from 0.6093 in 2005 to 0.7692 in 2019. Likewise, the average coupling coordination degree increased from 0.4201 in 2005 to 0.5521 in 2019. The level of industrial integration, ULUE, and the coupling coordination degree between the two indicate an overall steady and positive trend.

Table 4. Coupling coordination degree of "industrial integration–ULUE" system.

Year	Industrial Integration	ULUE	Coupling Degree	Coupling Coordination Degree
2005	0.2244	0.6090	0.4363	0.4201
2006	0.2436	0.6144	0.4421	0.4290
2007	0.2632	0.6162	0.4499	0.4389
2008	0.2921	0.5969	0.4588	0.4460
2009	0.3423	0.5605	0.4744	0.4578
2010	0.3703	0.5301	0.4826	0.4608
2011	0.3598	0.5632	0.4799	0.4651
2012	0.4156	0.5759	0.4843	0.4840
2013	0.4625	0.5847	0.4840	0.4978
2014	0.4461	0.5892	0.4837	0.4931
2015	0.4832	0.5980	0.4847	0.5047
2016	0.5061	0.6315	0.4824	0.5180
2017	0.4895	0.7227	0.4788	0.5307
2018	0.5078	0.7855	0.4790	0.5495
2019	0.5292	0.7692	0.4818	0.5521

Secondly, the table shows that the average coupling coordination degree of the Yangtze River Economic Zone is in the range of 0.4 and 0.6 based on the evolution of the coupling coordination relationship. It shifts from an endangered disordered recession to reluctantly

coordinated integration. Furthermore, a big gap can be observed in the level of high-quality coordinated development. One reason for the existence of such a gap is the fact that the coupling degree of industrial integration and ULUE is always in an antagonistic stage, while the interaction between them is constrained. From the perspective of the synchronous relationship between industrial integration and ULUE, it can be seen that the development of industrial integration has always lagged behind the ULUE, ultimately failing to meet the requirements for its improvement. In addition, the average value of ULUE wildly fluctuates, indicating that priority is given to volatility, while rising is complementary. Between 2007 and 2010, ULUE decreased from 0.6162 to 0.5301, showing negative growth. It can be seen that the effect on ULUE caused by industrial development becomes more and more apparent over time. The extensive development model of industrial land dramatically restricts the coordinated development of industry and land use at the expense of the environment. Until 2011, the "National Main Functional Area Planning" issued by the State Council required local governments to improve relevant planning regulations such as those relating to industry, land, and the environment, which gradually formed a level of coordination between industrial development and intensive urban land use. In short, the main reason why the coupling coordination effect of the industrial integration–ULUE system failed to yield results is the differences in the structure and factor allocation of each subsystem.

5.2.2. Analysis of the Temporal Evolution Characteristics

This paper applies the MATLAB R2018b software to show the kernel density estimation curve of the coupling coordination degree of industrial integration and ULUE in the Yangtze River Economic Zone.

Figure 5 shows that the coupling coordination curve characteristics of industrial integration and ULUE in the Yangtze River Economic Zone changed significantly during the study period.

Based on the distribution position of the gravity center of the nuclear density curve, the center of gravity of the curve shows an overall shift to the right. This means that the coupling coordination degree of the Yangtze River Economic Zone continues to rise, which is consistent with previous analyses of timing trends.

Based on the peak of the nuclear density curve, the trend exhibiting a shift in the low-value area from the left to the right was more potent than that of the high-value area shifting to the right between 2005 and 2014. Consequently, the increase in coupling coordination degree in the low-value area was higher than that in the high-value area during this period. Likewise, a trend to catch up with the high-value area is noticeable. Thus, the key to improving the overall coupling coordination degree of the Yangtze River Economic Zone lies in coordinating the interactive relationship between industrial integration and ULUE in low-value areas. From 2014 to 2019, the increase rate of high-value areas was more obvious. This implies that the rapid development of the coupling coordination degree of high-value areas led to the improvement of the overall development level of the Yangtze River Economic Zone. However, the gap between high-value and low-value areas was also exacerbated.

Based on the number of nuclear density peaks, the curve shape is characterized by a single peak–double peak. In reference to the peak, the coupling coordination degree of the Yangtze River Economic Zone shows convergence growth in the early stage of the study, while prominent dynamic polarization characteristics are present in the later stage.

Regionally, the urban agglomerations of the Yangtze River Delta and the middle reaches of the Yangtze River also show the same evolution trend, which is no longer redundant. The peak curve shape of nuclear density in Chengdu–Chongqing urban agglomeration is characterized by a pattern of bimodal–weak bimodal. This shows that the polarization effect of the coupling coordination degree of the urban agglomeration is weakened.
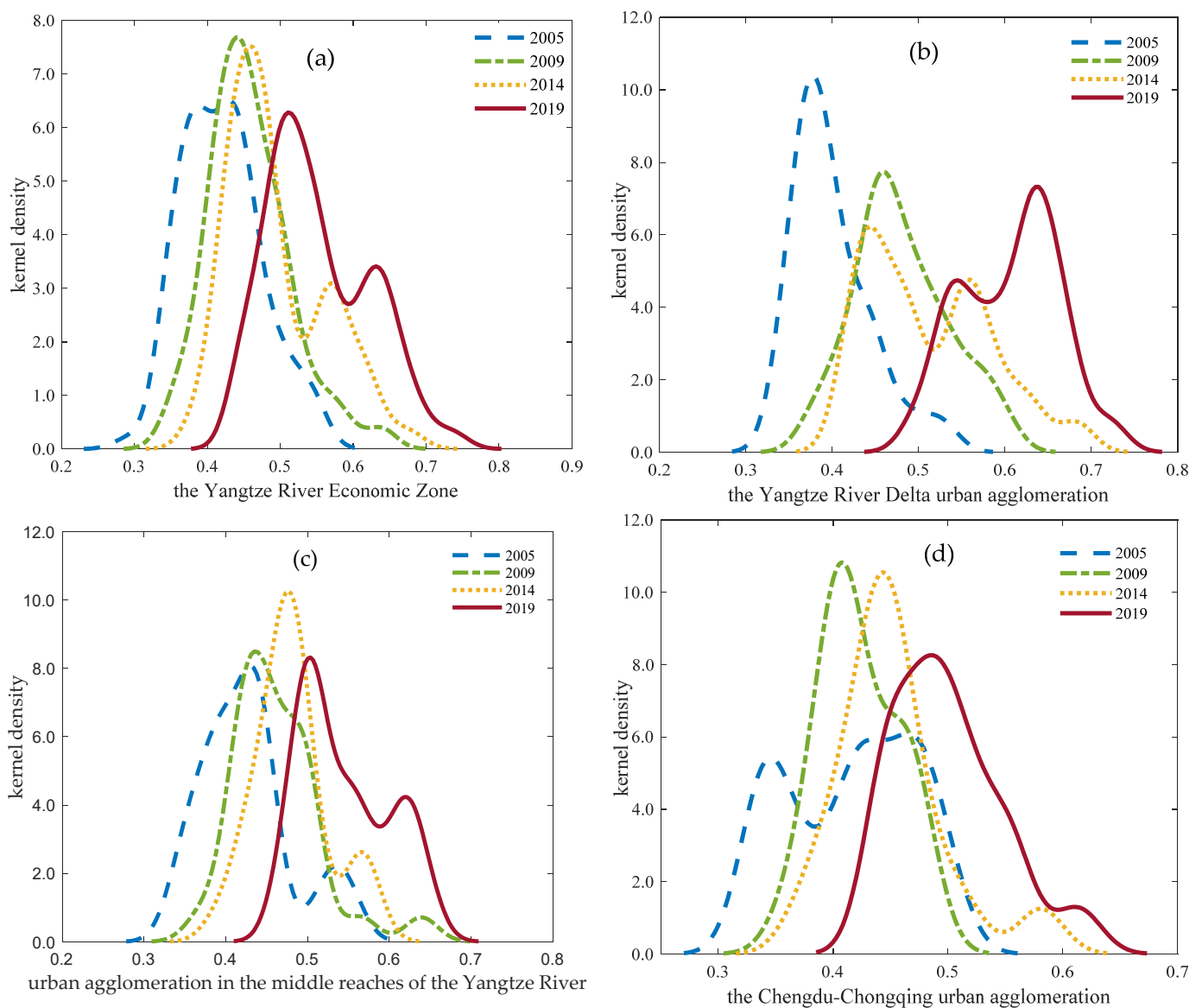
Figure 5. Temporal evolution of coupling coordination degree between industrial integration and ULUE. (**a**) The Yangtze River Economic Zone; (**b**) the Yangtze River Delta urban agglomeration; (**c**) urban agglomeration in the middle reaches of the Yangtze River; (**d**) the Chengdu–Chongqing urban agglomeration.

5.3. The Spatial Characteristics of Coupling Coordination between Industrial Integration and ULUE

This paper applies the ArcGIS 10.2 software to present the spatial characteristics of the coupling coordination between industrial integration and ULUE in the Yangtze River Economic Zone. Figure 6 shows that the high-value area of coupling coordination between industrial integration and ULUE presents the spatial differentiation characteristics of urban agglomeration stratification. The areas of high value prioritize the Yangtze River Delta urban agglomeration while also gradually penetrating to the urban agglomerations in the middle reaches of the Yangtze River and Chengdu–Chongqing.
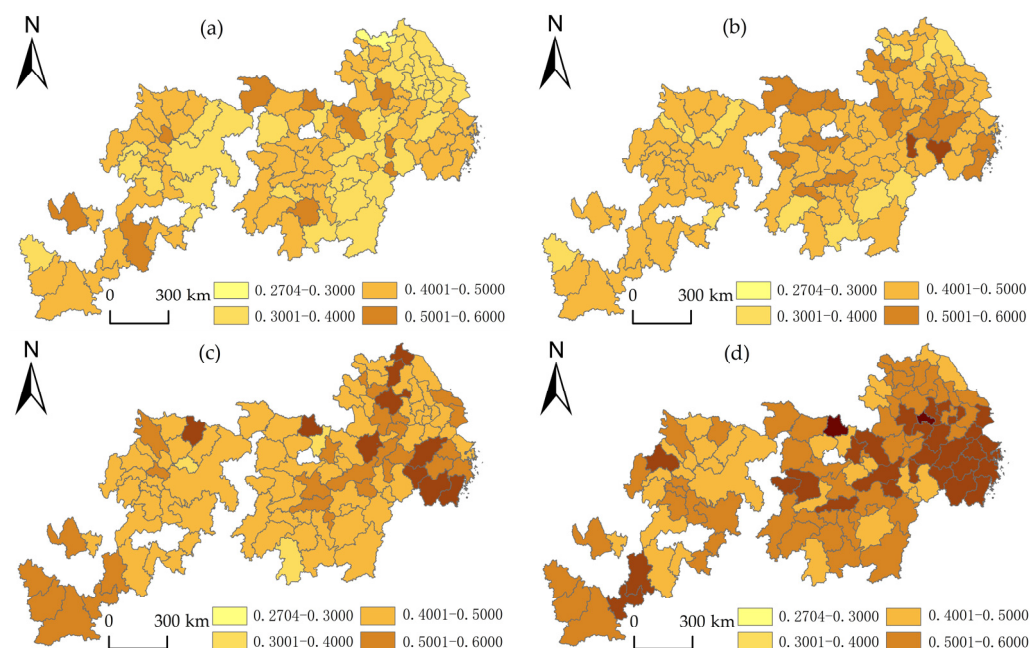
Figure 6. Spatial differentiation of coupling coordination between industrial integration and ULUE. (**a**) The coupling coordination degree in 2005; (**b**) the coupling coordination degree in 2009; (**c**) the coupling coordination degree in 2014; (**d**) the coupling coordination degree in 2019.

Specifically, the coupling coordination degree of the Yangtze River Delta urban agglomeration increased significantly during the study period. Moreover, it was the earliest to enter the primary coordinated development stage in 2019. Since the Hangzhou, Suzhou–Wuxi–Changzhou, and Ningbo Metropolitan Areas represent integral parts of the Yangtze River Delta's spatial structure and regional growth pole, they are seen as the strategic cores for promoting industrial transformation. Industrial land in these regions tends to be orientated towards green development. Capital- and technology-intensive industries account for a large proportion of the industrial structure. Furthermore, the cities in the Yangtze River Delta have stringent control over the emission of pollutants, which highlights the green economic effect of urban land in its development and utilization process. In addition, the integrated development strategy of the Yangtze River Delta urban agglomeration and a series of policies, such as the Yangtze River Delta urban agglomeration development plan (2016–2020), can enhance the impact of industrial integration on ULUE.

Generally, the industrial level, land-use structure, and economic strength of the central cities are better than those marginal areas. In the later stages of our analysis, the coupling coordination degree of Wuhan, Changsha, and Nanchang also gradually became prominent. These three central cities promote the coordinated development of the Wuhan metropolitan area, Changzhou–Zhuzhou–Xiangtan urban agglomeration, and Poyang Lake urban agglomeration with a three-pillar structure [63]. Cities such as Zhangjiajie and Jiujiang exhibit a high tourism value under their natural endowment conditions. As local governments attach great importance to the environmental protection of tourist cities, these areas can form a highly coordinated development pattern between industrial integration and the intensive use of urban land. Even though regions such as Huanggang, Suizhou, and Changde have rugged terrain, underdeveloped transportation infrastructures, and weak industrial foundations, they are good at absorbing the radiation effect of central cities. Furthermore, they constantly introduce capital, technology, and other factors to the industry with the support of the relevant industrial policies. External advantages weaken the constraints of natural conditions in remote areas. Therefore, the coupling coordination relationship between industrial integration and ULUE is naturally benign and interactive.

The growth rate of the coupling coordination degree of the Chengdu–Chongqing urban agglomeration is relatively slow. Only Chengdu, Kunming, and Yuxi achieved initial

coordinated development in 2019, with other cities remaining in a transitional stage where the coupling interaction between industrial integration and ULUE is not apparent. One reason for this is the fact that these cities have not completed the industrialization process yet, mainly because they tended to develop heavy industries such as coal, petroleum, metallurgy, energy, and steel. Consequently, these industries bear high environmental costs when developing industrial land. Even worse, insufficient investment in land pollution control and adverse environmental effects are more prominent due to the weakening economic strength of these cities. In turn, the improvement of ULUE with unexpected output is largely restricted.

5.4. The Coupling Interaction Process between Industrial Integration and ULUE

This paper uses the geographical detector to empirically analyze the interactive coupling process between industrial integration and ULUE in the Yangtze River Economic Zone. To do so, the natural discontinuity method of ArcGIS 10.2 is first used to distinguish between the influencing factors. Afterwards, this paper explores the explanatory power of the indicators in the evaluation system of industrial integration in relation to ULUE and vice versa.

Table 5 shows the results of the factor and interaction detection of ULUE with the indexes of the industrial integration subsystem. This paper ranks the explanatory power of each factor from largest to smallest. The top five factors are the ones that can improve ULUE—namely, industrial expansion (0.2256), capital flow (0.2010), technology flow (0.1804), labor flow (0.1308), and industrial cluster (0.1282). As shown in the theoretical analysis above, industrial expansion can improve urban land use efficiency by stimulating market potential to highlight the scale effect of urban land use. Cross-regional two-way flows of factors of production, such as capital, technology, and population, will broaden their allocation scope and improve their allocation efficiency, thereby increasing the ULUE. The impact of industrial agglomeration on ULUE is positive, indicating that there are spatial dependence and spatial spillover effects among different cities in the region. In contrast, industrial division (0.0941) and industrial upgrading (0.0997) exhibit a weak explanatory power for ULUE. A possible explanation for this is that some local governments in the Yangtze River Economic Zone are eager to respond to the country's policy requirements, which impose a transfer mode and structure adjustment. Without regional factor endowments, the blind pursuit of industrial upgrading in these regions has weakened the basis of industrial development [18], leading to a mismatch of resources and factors in land use. The interaction terms of different detection factors mainly produce two-factor enhancement (16 items) and nonlinear enhancement effects (12 items). This indicates a synergistic enhancement between the factors. In other words, the influence of any two factors on ULUE after the interaction is stronger than that of a single factor on ULUE.

Table 6 shows the results of the factor and interaction detection of the industrial integration level with all indexes of ULUE. Presented from largest to smallest, the explanatory power of each factor is 0.2197 for ecological output, 0.2113 for electricity consumption, 0.1182 for pollutant emission, 0.0568 for capital input, 0.0401 for labor input, 0.0393 for social output, 0.0387 for carbon emissions, 0.0350 for economic output, and 0.0300 for land input. The first three factors represent a reflection of the impact of ULUE on the ecological environment. In addition, it can be said that nature is the basis of industrial integration. Its vulnerability restricts the blind expansion of industry, which is, in turn, subject to strict requirements for industrial integration development. Furthermore, the interactive detection results show that the explanatory power of the interaction between different detection factors is dominated by the nonlinear enhancement effect (33 items) and supplemented by the two-factor enhancement effect (three items). After interacting with other factors, the explanatory power of capital and labor inputs—economic, social, and ecological outputs—and pollutant emission indicators is significantly greater than the sum of two factors characterized by nonlinear enhancement. This shows that the coordinated

development of the aforementioned five factors and other factors is better able to drive the process of industrial integration.

Table 5. Factor detection and interactive detection results of industrial integration for ULUE.

Detection Factor	Industrial Expansion	Industrial Cluster	Industrial Division	Industrial Upgrading	Labor Flow	Capital Flow	Information Flow	Technology Flow
industrial expansion	0.2256							
industrial cluster	**0.4508**	0.1282						
industrial division	0.2862	**0.4245**	0.0941					
industrial upgrading	0.3105	**0.3030**	**0.2441**	0.0997				
labor flow	0.2914	**0.3455**	**0.3073**	**0.2489**	0.1308			
capital flow	0.2876	**0.3889**	0.2587	0.2825	0.2864	0.2010		
information flow	0.2504	**0.2842**	**0.2231**	0.1536	**0.2216**	0.2149	0.0636	
technology flow	0.3016	0.3079	**0.2879**	0.2662	0.2789	0.2526	0.2377	0.1804

Note: The diagonal values are the value of single-factor detection, the bold values represent nonlinear enhancement, and the underscore values represent double-factor enhancement.

Table 6. Factor detection and interactive detection results for the effect of ULUE on industrial integration.

Detection Factor	Land Input	Capital Input	Labor Input	Electricity Consumption	Economic Output	Social Output	Ecological Output	Pollutant Emission	Carbon Emissions
land input	0.0300								
capital input	**0.1293**	0.0568							
labor input	**0.1168**	**0.2756**	0.0401						
electricity consumption	0.2200	**0.3690**	**0.3071**	0.2113					
economic output	**0.0839**	**0.2318**	**0.2524**	**0.3251**	0.0350				
social output	**0.1014**	**0.2439**	**0.2675**	**0.3843**	**0.2308**	0.0393			
ecological output	**0.3588**	**0.4351**	**0.3824**	**0.5297**	**0.3606**	**0.4526**	0.2197		
pollutant emission	**0.1555**	**0.2494**	**0.2992**	**0.3684**	**0.2087**	**0.3798**	**0.3527**	0.1182	
carbon emissions	0.0522	**0.1786**	**0.2094**	0.2331	**0.0868**	**0.2752**	**0.3406**	**0.1615**	0.0387

Note: The diagonal values are the value of a single factor detection, the bold values represent nonlinear enhancement, the underscore values represent a double factor enhancement.

6. Discussion and Conclusions

In comparison to the existing research, this paper may contribute to the exploration of the coupling and coordination mechanism between industrial integration and ULUE, as well as the construction of a comprehensive evaluation system for industrial integration and a green evaluation system for ULUE based on multi-objective constraints. Furthermore, this paper uses the coupling coordination degree model, the nonparametric kernel density estimation method, and the geographical detector to explore the dynamic evolution characteristics and mechanism of the coupling coordination relationship between industrial integration and ULUE in the Yangtze River Economic Zone for the period between 2005 and 2019.

The results show that the coupling coordination relationship between industrial integration and ULUE is steadily developing, so much so that both show an upward trend. Likewise, both have promoted the transformation of the coupling coordination relationship of the Yangtze River Economic Zone into the coordination type. However, we can state that

a significant gap exists in the level of coupling coordination among cities in the Yangtze River Economic Zone judging from the number of nuclear density peaks. Specifically, the curve shape is characterized by a single peak–double peak pattern. In the early stages of this study, the coupling coordination degree of the Yangtze River Economic Zone shows convergence growth, while pronounced dynamic polarization is present in the later stage. In terms of the spatial characteristics, the highly valued areas of coupling coordination between industrial integration and ULUE exhibit spatial differentiation characteristics of urban agglomeration stratification. The areas of high value prioritize the Yangtze River Delta urban agglomeration. Afterwards, they gradually penetrate towards the urban agglomerations in the middle reaches of the Yangtze River and Chengdu–Chongqing.

Moreover, the coupling coordination relationship between industrial integration and ULUE is far from high-quality coordinated development. There are three main reasons for this occurrence. Firstly, the coupling strength is always in the antagonistic stage and never high enough. Secondly, the level of industrial integration lags behind the level of ULUE. Additionally, the level of industrial integration represents the critical resistance in the process of improving the coupling coordination relationship between the two. Finally, ULUE showed negative growth from 2007 to 2010, which led to the failure of the coordination effect between industrial integration and urban land-use efficiency.

This paper uses the geographical detector to confirm the interaction between industrial integration and ULUE in the Yangtze River Economic Zone. On one hand, industrial division and industrial upgrading exhibit a weak explanatory power for ULUE. On the other, ecological output, electricity consumption, and pollutant emissions have strong explanatory power for industrial integration. Moreover, the driving force of any two elements after the interaction is more robust than that of a single factor.

Based on the aforementioned conclusions, this paper puts forward the following policy recommendations. The proposed policies are described in Sections 6.1–6.3.

6.1. Construct a Regional Coordinated Development Mechanism and Form the Linkage Development Pattern of Industrial Dislocation and Complementary Advantages among Cities

Firstly, local governments should establish a complete development concept for the Yangtze River Economic Zone. They can strengthen the cooperation and exchange between cities in regard to the industrial spatial layout, division of labor, collaboration, and land resource development and utilization by constructing regional coordination mechanisms for internal linking and external sharing. Secondly, the development strategy of urban agglomeration and metropolitan areas should be taken as an opportunity to connect different regions by constructing a system for the division of the industrial value chain. In turn, the division system will form a clear division and close connection of industries in the various areas. Finally, industrial integration should exhibit knowledge spillover, demonstration sharing, and radiation diffusion effects of developing and utilizing land resources between different regions, especially among core cities. These measures contribute to the balanced spatial development of the effective interaction between industrial integration and ULUE.

6.2. Actively Exploring a City–Industry Integration Mechanism to Speed up the Development of Industrial Integration

By promoting the integration of industry and city, the spatial organization of sharing information, learning to cooperate, and starting innovative interactions facilitates the spatial aggregation of talent, information, technology, capital, etc. In the end, it realizes the cumulative and cyclic effect of land benefits. Similarly, the construction of infrastructures, such as transportation, logistics, and information networks, should also be strongly promoted. The promotion can provide a physical spatial connection basis for industrial–urban integration and factor aggregation. Moreover, the construction of infrastructures reduces the spatial transaction cost inherent in the allocation of resources that help to accelerate the integration process and realize the effective coupling between industrial integration and urban land use.

6.3. Formulating Reasonable Industrial Development and Land-Use Control Strategies Based on the Coupling Coordination Performance of the Industrial Integration–ULUE System

In the context of industrial technology-driven transformation, Pareto optimization cannot be achieved solely by relying on the advantage of the traditional labor cost in the process of land use. Local governments and enterprises should guide the upgrading and transformation of traditional industries through technological change, talent introduction, and innovative research development based on the existing industrial foundation and comparative local advantages. Moreover, it is necessary to develop new strategic service industries and cultivate high-tech industrial communities using innovative technologies such as cloud computing, big data, and Internet+. Guided by land-use control and ecological environment protection policies, the model of urban land use should transform into stock optimization from incremental management. Therefore, a land supply reverse mechanism should be formed to promote the optimization and upgrading of the industrial structure.

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