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Article

Spatio-Temporal Evolution and Drivers of High-Quality Utilization of Urban Land in Chinese Cities

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Abstract: This study constructs an evaluation system of high-quality utilization of urban land (HUUL) and comprehensively adopts the entropy method, the kernel density estimation, and the geodetector model to analyze the spatio-temporal evolution and driving factors of the HUUL levels of 284 Chinese cities from 2006 to 2020. The measurement results show that during 2006-2020, the HUUL level showed an obvious upward trend, and the eastern region > the central region > the overall region > the western region > the northeastern region. According to the kernel density map, except for the region of the west, there is a trend of different degrees of enlargement of the difference in the main peak position of the HUUL level among cities in the other three regions, and there are individual cities in the eastern and western regions with much higher HUUL levels than the others; According to the results of factor detection, it can be seen that innovative utilization and open utilization are the endogenous dominant factors that promote the improvement of HUUL level, and the level of economic development is the exogenous dominant factor that supports the improvement of high-quality utilization of urban land.

Keywords: urban land use; high-quality development; spatio-temporal evolution; driving factors

1. Introduction

According to the report of the 19th National Congress of the Communist Party of China (CPC), the main conflict in Chinese society has shifted, and the country's economy has moved from rapid growth to high-quality development. General Secretary Xi Jinping further emphasized in the report of the 20th Party Congress that "high-quality development is the primary task of building a modern socialist country in an all-round way" and that achieving high-quality development has become a new proposition for China's economic and social development at present and in the considerable period to come. As an important carrier of economic development, improving the quality of urban land use is crucial to promoting economic transformation and achieving high-quality development. Accompanied by the increasing tightening of environmental resources, urban land is facing the fourfold pressure of low land use efficiency, slow land resource flow, mismatch between land use and industrial structure, and uncoordinated land use and ecological environmental protection, and cracking the urban land use problems to improve the quality of urban land use, improve the structure of urban land use, and enhance the ability of coordinated development of land, which has become an important direction for the development of the future urban and regional development.

Urban land use shows different connotations in different stages of development, and land intensive and economic use [1,2], sustainable use [3], and green use [4] are the products of the land system adapted to various stages of socio-economic construction [5,6]. With China's economy shifting from the stage of high-speed growth to the stage of high-quality development, the traditional way of land use has gradually lagged behind social production [7,8]; scholars have begun to try to explore the effects of regional integration [9,10], innovative use [11,12], and land policy, etc.[13,14], on urban

land use, and the focus of the study has gradually shifted from the traditional intensive and economical use of urban land to the use of urban land under the guidance of high-quality development and the relationship between urban land use and high-quality development has been gradually revealed. Zhang et al. [15] examined the impacts of globalization, marketization, and decentralization factors on urban land use under the perspective of economic transformation, pointing out that urban land use in the Yangtze River Delta is characterized by obvious stage and time scale dependence. Ding et al. [16] pointed out that the coupling degree of "land use - economic quality development" is relatively higher in economically developed areas by constructing a coupling coordination evaluation index system. Wu et al. [17] even pointed out directly that the efficient use of land resources is the proper meaning of high-quality development and that obtaining the maximum economic, social, and ecological benefits with the minimum land investment is the important connotation of regional high-quality development. Although the existing literature has conducted relatively extensive research on the relationship between high-quality development and urban land use, most of the studies tend to focus on the level of explaining the relationship between high-quality development and urban land use [18,19] rather than constructing and measuring high-quality urban land use from the connotation of high-quality development.

Therefore, this paper constructs the HUUL measurement index system under the guidance of high-quality development and combines it with the new development concept. With reference to the analytical ideas and results of existing studies, this paper further analyses the spatio-temporal evolution characteristics and driving factors of the HUUL levels of 284 Chinese cities so as to provide an important theoretical foundation and methodological support for promoting the healthy, coordinated, and sustainable development of Chinese cities. Firstly, this paper adopts the new development concept in line with the high-quality development of the economy and constructs a system of measurement indexes from the five dimensions of innovation, coordination, openness, greenness, and sharing to measure the 284 HUUL levels in China from 2006 to 2020, and calculates the average of the HUUL levels in the four major regions for the spatio-temporal pattern display. Secondly, we employ the 3D Kernel Density Map to portray the dynamic evolutionary trends of the overall and sub-regional HUUL levels, revealing the evolution and differentiation of HUUL levels in the whole and the four major regions. Finally, we employ the geodetector model to explore the explanatory power of each driver on the HUUL level at both the internal and external levels, and the changes in the explanatory power of each driver in the four regions from 2006 to 2020 are reported.

2. Indicator Construction and Research Methodology

2.1. Indicator Construction

Since the reform and opening up, Chinese cities have experienced serious waste of land resources, deterioration of the ecological environment, and tripartite conflicts between population, economic growth, and resource supply [14,20,21], and have gradually developed different concepts such as conservation and intensive use, sustainable development, and green use for guiding the urban land use in different periods. Excellent achievements have been made in the stage of rapid urbanization of population, but with the change of the main contradiction in society [22], problems such as the prominent contradiction between supply and demand of urban land, uncoordinated spatial structure of land allocation, differentiated quality of land use, and imbalance of intensity and efficiency of land use have gradually begun to appear [14,20,21]. In November 2015, General Secretary Xi Jinping introduced the new development concept during his visit to Shaanxi province. He further emphasized the high-quality development of the economy at the Nineteenth CPC National Congress and the Central Economic Work Conference in 2017. The conference explicitly advocated for high-quality economic development [24], and these two macro perspectives indicate the path for China's future economic growth and urban land utilization. This paper holds that high-quality utilization of urban land is under the guidance of high-quality development, emphasizes the five development concepts of innovation, coordination, green, openness, and sharing, and solves the deep-rooted problems existing in the process of urban land utilization by optimizing the land

utilization structure, promoting technological innovation, deepening international cooperation, strengthening ecological, environmental protection, promoting fair distribution and improving the policy system, so as to achieve high-quality, high-efficiency and sustainable utilization of land resources.

Accordingly, based on the basic principles of scientific, accessibility, and objectivity in the selection of indicators for the evaluation system, and concerning the relevant research results of previous researchers [25,26], this paper constructs a comprehensive evaluation indicator system for HUUL under the perspective of high-quality development from five dimensions: innovation, coordination, openness, greenness, and sharing. Compared with the previous evaluation index system of land use, this study, in the process of index selection, starts from the new development concept, combines the characteristics of urban land use in China at the current stage, pays attention to the balanced development of the economy, society, and the environment, as well as the sustainability, inclusiveness, and innovativeness of land use, which is more in line with the requirements of the high-quality development of the economy in the new period. The system of measurement indicators is shown in Table 1:

Table 1. HUUL level Evaluation Index System.

Guideline Layer	Index Layer	Index Meaning	Weight
innovation Utilization	Innovation	Education expenditure per square kilometer	0.1023
	Input	R & D internal expenditure per square kilometer	0.1299
	Innovation	Patent authorization per square kilometer	0.1354
	Output		
	Innovation	Number of college students per 10,000 people	0.0586
Coordinated utilization	Environment		
	Industry	Rationalization of industrial structure	0.0005
	Coordination	Upgrading of industrial structure	0.0044
	Employment	The number of registered urban unemployed per ten thousand people at the end of the year	0.0214
	Coordination		
Green Utilization	Green Life	Per capita green area	0.0565
		Green coverage rate of built-up area	0.0036
		Industrial wastewater discharge per square kilometer	0.0004
	Green		
	Governance	Industrial waste gas emissions per square kilometer	0.0009
Open Utilization		Harmless treatment rate of domestic waste	0.0080
	Open Network	Number of Internet users per ten thousand people	0.0230
	Market	The import and export volume of goods per square kilometer	0.2141
	Opening		
	Open Financing	The actual amount of foreign capital used per square kilometer in the year	0.0733
Shared Utilization	Medical	Number of beds in hospitals and health centres per ten thousand population	0.0395
	Sharing		
	Transport	Road area per capita	0.0272
	Sharing		

Cultural Sharing	Public library collections per ten thousand people	0.1007
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Note: The upgrading of industrial structure is the ratio of the value added by the tertiary industry to that of the secondary industry; the rationalization of industrial structure is measured based on the data of the three industrial structures using the Thiel index.

2.2. Methods

2.2.1. Subsubsection Entropy Method

As an objective assignment method, the entropy method is more suitable for dealing with multi-indicator data and uncertainty information than subjective evaluation methods. It is widely used in quantitative analysis [27,28]. In this paper, the discrete degree of data is used to objectively measure the weights of indicators so as to obtain more accurate and reasonable evaluation results of high-quality utilization of urban land. The specific process of the entropy method refers to the research of Zhao et al. [28].

2.2.2. Kernel Density Estimation

As a nonparametric method, Kernel density estimation is mainly used to study the spatio-temporal dynamic evolution [29–31]. The frequently employed kernel density functions include the triangular kernel, quadrangular kernel, Gaussian kernel, and Epanechnikov kernel. This paper focuses on studying the distributional dynamics of the HUUL level in China [32] using the Gaussian kernel function, which is widely recognized and commonly used in the theoretical community. The formulas are as follows:

$$f(x) = \frac{1}{nh} \sum_{i=1}^n K\left(\frac{\bar{X} - X_i}{h}\right)$$
 (1)

$$K(x) = \frac{1}{\sqrt{2\pi}} e^{\left(-\frac{x^2}{2}\right)}$$
 (2)

In the formulas, $K(x)$ denotes the Gaussian kernel density function, $X_1, X_2, \dots, X_n$ is the HUUL value of each city, $\bar{X}$ is the mean value, n is the number of sample cities, and h is the window width [33].

2.2.3. Geodetector

Wang et al. pointed out that geodetector is a Spatial analysis model used to study the relationship between a certain geographic attribute and its explanatory factors, to detect the spatial differentiation of the research object, and to reveal its driving force [34,35]. The method is widely used in studying driving mechanisms of natural economic and social phenomena [36–38]. Compared to other methods, geodetector have a clear advantage in dealing with mixed types of data and can still be useful when constrained by fewer prerequisites. In this paper, we use the factor detection probe module of the geodetector to investigate the magnitude of the degree of explanation of each driving factor and the changes in the evolution of the HUUL level. The q statistic is calculated as shown in equation (3):

$$q = 1 - \frac{SSW}{SST}$$
 (3)

$$SSW = \sum_{i=1}^m n_i \sigma_i^2, SST = n \sigma^2$$
 (4)

In the formulas, $i = 1, 2, \dots, m$ denotes the classification, partitioning, or stratification of factor Y or variable X, and m denotes the number of classifications. n_i and n represent the number of cells in the i-th stratum and the whole region, respectively, and σ^2 are the variance of the X-values in the i-th stratum and the entire region, respectively. SSW denotes the sum of the variances within all the strata, and SST is the total variance of the whole area. q-value ranges between [0,1], and in the case of factor X, for example, q-value denotes the factor explanation power of factor X on the factor explanatory power of HUUL, with a larger q implying a greater explanatory power of the factor [38]. In the extreme case, when the q value of factor X is 1, it means that factor X can fully explain HUUL, while 0 means that factor X is irrelevant to HUUL.

2.3. Data Sources

The data is sourced from the China City Statistical Yearbook, the China Urban and Rural Construction Statistical Yearbook, the China Environmental Statistical Yearbook, as well as provincial and municipal statistical yearbooks and national economic and social development plans over the period 2007–2021. The data interval of the study is 2006–2020, and when the statistical calibre of the data is not uniform, the data released by the statistical agency at the higher level shall prevail. The missing data of individual years and cities are made up by interpolation. In order to avoid the problem of multicollinearity, this study tested the covariance of the indicators with the help of inflated factor analysis. The results showed that the VIF values of all variables were less than 10, and the results obtained met the requirements. Meanwhile, to ensure the chi-square of variable data and the validity of empirical results, some cities with more missing data are excluded. Finally, 284 cities are identified as the research unit (excluding Tibet, Hong Kong, Macao, and Taiwan data).

3. Spatio-Temporal Patterns and Dynamic Evolution of the High-Quality Utilization of Urban Land Level in China

3.1. Spatio-Temporal Patterns of High-Quality Urban Land Utilization in China

This study calculates the mean values of the four main regions and the overall HUUL levels from 2006 to 2020 based on the measured HUUL levels, and the line graph is shown in Figure 1. During the sample period, the trend of changes in the mean value of HUUL for the country and the four major regions was relatively consistent, showing a fluctuating growth trend. The national HUUL level continued to climb, with an average annual growth rate of 2.19 percent. In terms of subregions, the HUUL level in the eastern region has always been higher than the national average. In 2006, relying on its geographical location, resource endowment, and policy background, the east region was already ahead of other regions in terms of HUUL level. The east region maintained an average annual growth rate of 1.85 percent between 2006 and 2020. From 2006 to 2020, the average yearly growth rate of the HUUL level in the central region was higher than that of the other three regions at 2.96 percent, and the central region’s HUUL level is in a period of rapid growth. The difference between the HUUL levels of the eastern region and the central region during the sample period has a clear tendency to narrow, indicating that, in the context of the policy of the rise of central China, the central region is actively exploring a high-quality development path that meets its characteristics; as can be seen in Figure 1, the average annual growth rates of the HUUL levels in the western and northeastern regions between 2006 and 2020 were 1.80 percent and 2.32 percent, respectively, which show a long-term upward trend. However, the western and northeastern regions have lower HUUL levels than the national average due to their geographic location differences, brain drain, and lack of effective planning and governance of existing land.

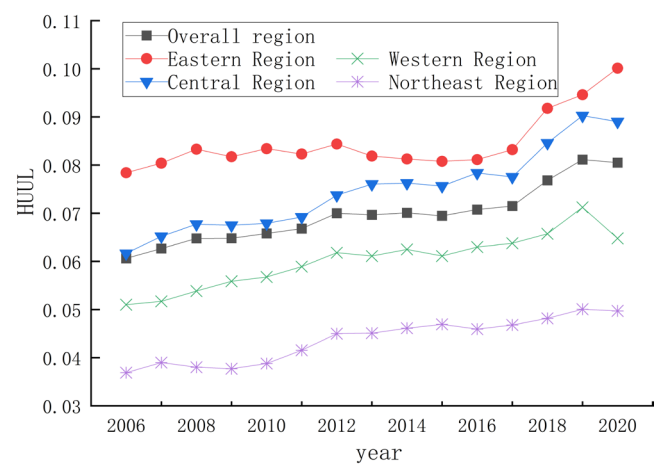


Figure 1. Calculation of HUUL for the whole and the four regions of China.

3.2. Dynamic Evolution of High-Quality Utilization of Urban Land Level in China

In order to show the HUUL level distribution status, distribution trend, distribution ductility, and polarisation trend more graphically and intuitively, this paper uses Matlab2021b software to draw the three-dimensional map of HUUL level Kernel density for the whole country and the four regions. The results are shown in Figures 2 and 3:

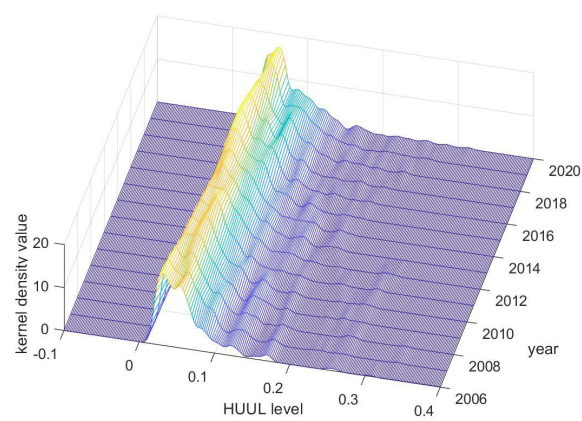
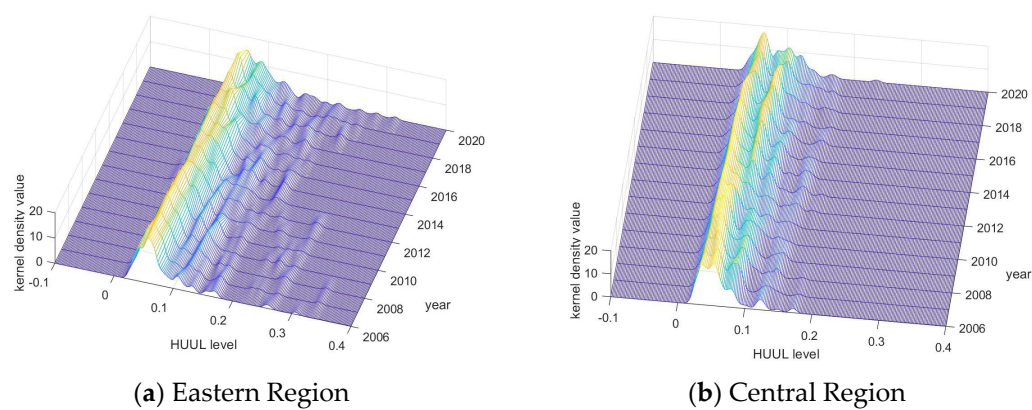


Figure 2. Three-dimensional kernel density estimation of HUUL in Chinese cities.



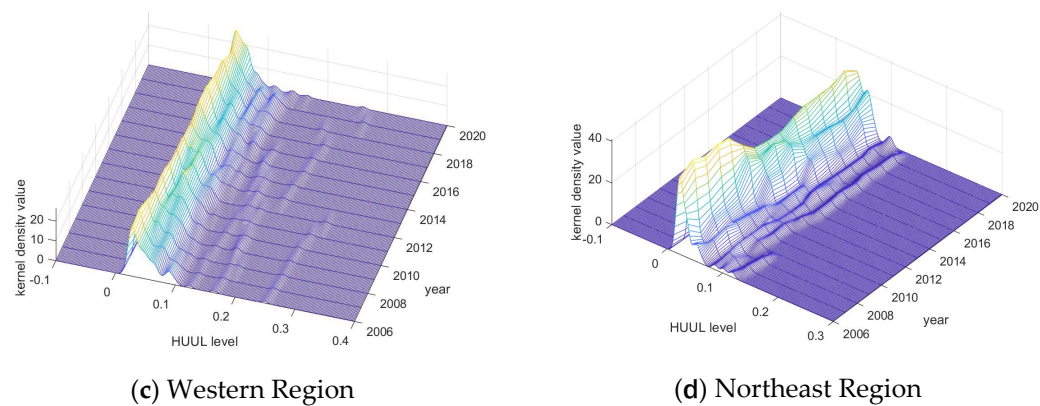


Figure 3. Three-dimensional kernel density estimation map of HUUL in four regions.

According to Figure 2, the distribution center of gravity of the national HUUL level from 2006 to 2020 has a trend of constantly moving to the right, the ductility is continually expanding, and the span of the wave peaks is gradually widening, with an obvious right trailing characteristic. It indicates that the HUUL levels of 284 cities in the country show a general upward trend, and the overall HUUL levels are constantly increasing, with individual cities having higher HUUL levels. There is a single peak - double peak transition, indicating a club trend in the HUUL level, and the HUUL level shows a polarisation trend.

From a subregional standpoint, China's HUUL levels exhibit the following notable characteristics:

Firstly, from the distribution position, the distribution center of gravity of the HUUL level in the four major regions shows a tendency to move to the right, and there is an expansion trend in ductility. This indicates that the HUUL levels of the four major regions show an increasing trend from 2006 to 2020, consistent with the results of the spatio-temporal pattern measurements in the previous section.

Secondly, from the distribution pattern, the HUUL kernel density map trend in the eastern and northeastern regions is more consistent. Since 2006, the distribution of HUUL levels in the eastern and northeastern regions has shown a trend from single-peak to double-peak, and the span of the peaks has gradually widened, indicating that HUUL levels in the eastern and northeastern regions have shown a trend of bipolarity, and that the gap between the two regions is widening; The distribution of HUUL levels in the central region shows a trend of transformation from single peak - double peak - multiple peaks, and the span of the wave peaks is gradually widening, indicating that there is a trend of multi-polarisation of HUUL levels in the central region. The gap in the HUUL level between cities is widening. The trend of multi-level differentiation is beginning to appear, and the "Matthew effect" of the HUUL level between cities is significant. The difference in the HUUL level between cities in the main peak of the central region is greater than that in the eastern and northeastern regions. In the western region, the HUUL level has always shown a single-peak pattern, and there is no obvious differentiation in the HUUL level among the main peak regions.

Finally, in terms of distributional extensibility, the kernel density images of the eastern and western regions have a clear right trailing feature, suggesting that there is a phenomenon that individual cities within these two regions have a much higher level of high-quality utilization of land than other cities. It is presumed that this is because individual coastal cities or cities with mineral resources can more easily increase the level of HUUL through the development of advantageous resources. The kernel density images of the central and northeastern regions, on the other hand, do not have obvious trailing features, indicating that the HUUL levels of cities in the central and northeastern regions are more concentrated and that there are no extremely high HUUL levels within the regions.

4. Drivers of high-Quality Utilization of Urban Land Level in China

The HUUL level in the context of high-quality development comprises five essential components: innovative, coordinated, green, open, and shared urban land use. These components must be deployed clearly, orderly, and synergistically to maximise urban land's economic, social, and ecological benefits [17]. The five components of urban land innovation, coordination, greenness, openness, and shared utilization, are the HUUL's constituents and the dimensions that facilitate the high-quality development of urban land. Therefore, five components were selected as endogenous drivers to examine the drivers of HUUL levels. Meanwhile, based on the combination of related studies and the current situation of China's urban socio-economic development [39–41], this paper examines the exogenous drivers of the HUUL level by selecting the five aspects of urban development carrying level, population agglomeration level, economic development level, governmental support level, and energy consumption level. Given this, this paper will use geo-detectors to detect the key drivers of HUUL from both endogenous and exogenous perspectives. Among them, the ratio of construction land to urban area is used to denote the urban development carrying level, the number of population per unit of urban land is used to denote the population agglomeration level, the GDP output per unit of urban land is used as a proxy variable for the level of economic development, the government expenditure per unit of urban land is used as a proxy variable for the level of government support, and the electricity consumed per unit of urban land is used as a proxy variable for the level of energy consumption.

4.1. Endogenous Drivers of High-Quality Utilization of Urban Land Level

This paper uses the factor detector method to explore the endogenous driving factors of high-quality urban land development based on the structural perspective. It measures the q-value and significance level of the five components of innovative, coordinated, green, open, and shared utilization, as shown in Table 2. The factor detector helps explain the endogenous driving factors of high-quality urban land development from a structural perspective. All endogenous driving factors, except for green utilization in the western region, have passed the 1 percent significance level test. This indicates that these factors possess significant determining power for high-quality urban land utilization.

As shown in Figure 4(a), innovative and open utilization greatly impact Chinese cities and the four major regions more than other factors. These two factors are the main internal driving forces of HUUL. Firstly, innovative utilization has a direct impact on the HUUL level. It encompasses both technological innovation and institutional innovation. Technological innovation has the potential to enhance land use efficiency. Using new construction technology and materials can result in more space-efficient buildings, while implementing new agricultural technology can boost land productivity. Institutional innovation can enhance the efficiency of land allocation, boost the dynamism of land utilization, and optimize land utilization. Secondly, open utilization reflects the degree of influence of external resources on land use. Open utilization refers to the incorporation of external capital and the integration of external technology. Introducing external capital can enhance investment in land development and optimize land utilization. Introducing external technology can bring advanced land use technology and management expertise to enhance the HUUL and management levels. Furthermore, shared utilization is a secondary inherent factor that impacts HUUL, while coordinated utilization and green utilization also play a significant role in driving it.

In the eastern region, innovative and open utilisation are the main factors contributing to urban land's high-quality development. These factors have explanatory powers of 0.8613 and 0.7483, respectively. Among these factors, innovative utilization is the primary factor driving HUUL in the Eastern region. The eastern region's advantage of its geographic location for easy absorption of overseas investment makes its open utilization significantly higher in explanatory power than the other three regions. However, the explanatory power of coordinated, green, and shared utilization in the eastern region are smaller. The explanatory power of the factors for the five dimensions in the central region is higher than that of the eastern region, except for green and open utilization. The disparity in the use of open resources and green resources between the eastern and central regions is the primary factor contributing to the higher level of HUUL in the eastern region, and the difference

in open utilization is the dominant factor in this disparity; In the Western region, open utilization has a greater explanatory power than innovative utilization. Open utilization plays a crucial role in HUUL in the western region and is the main driving force behind the significantly higher HUUL in individual cities compared to others. Due to the high proportion of mountainous area in the western region and the aridity and low rainfall in most parts of the region, the impact of green utilization on HUUL is not significant; In the northeastern region, innovation utilization is higher than the explanatory power of the other four endogenous explanatory factors for the HUUL level. This suggests that innovative utilization is crucial in promoting technological innovation, upgrading industrial structure, and enhancing HUUL in the northeastern region. In the Northeast region, the explanatory power of coordinated utilization and shared utilization on HUUL is higher than that of the remaining three regions, which plays an important role in enhancing the high-quality development of cities in the Northeast region.

Table 2. The explanatory power of endogenous driving factors on HUUL.

Area	IU	CU	GU	OU	SU
Overall Region	0.7967***	0.0217***	0.0476**	0.6707**	0.1395***
Eastern Region	0.8613***	0.0382***	0.0772**	0.7483***	0.0939***
Central Region	0.9011***	0.0589***	0.0276**	0.5995***	0.1615***
Western Region	0.5872***	0.0178**	0.0129	0.6539**	0.0932***
Northeast Region	0.8818***	0.2428***	0.0994***	0.5894***	0.4009***

Note: IU, CU, GU, OU, and SU represent the concepts of innovative utilization, coordinated utilization, environmentally friendly utilization, open utilization, and shared utilization, respectively. The symbols *, **, and *** represent statistical significance at the 10%, 5%, and 1% levels, respectively.

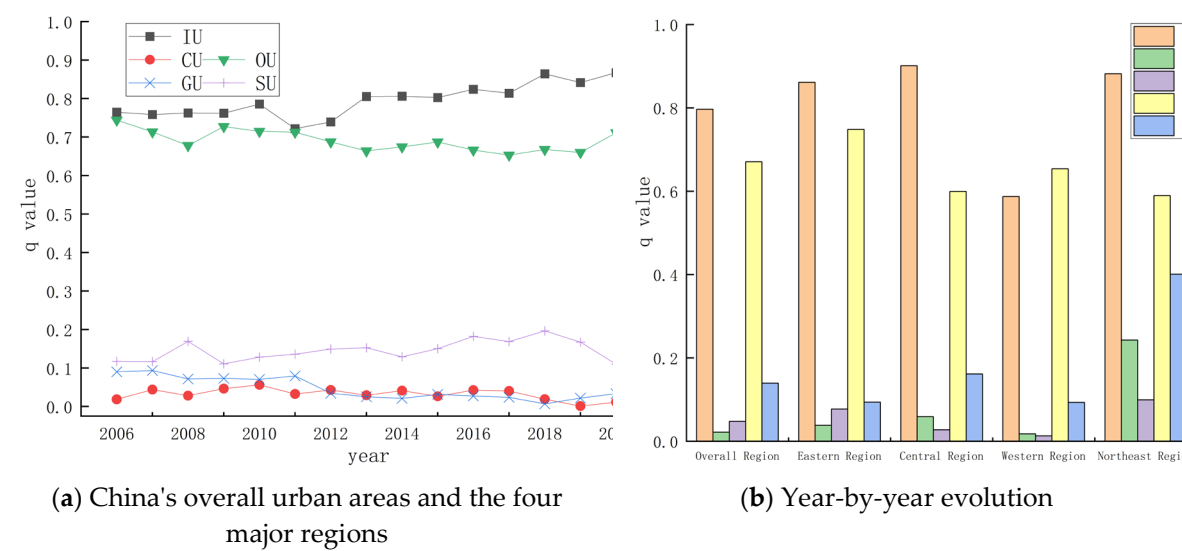


Figure 4. Results of Endogenous Driving Factor Exploration.

Figure 4(b) portrays the dynamic evolution of endogenous drivers' degree of influence on the HUUL level in China. During the sample examination period, the degree of influence of innovative utilization on HUUL was significantly stronger than that of other factors, and open utilization was the factor that had a high determining power on China's HUUL after innovative utilization. Shared, coordinated, and green utilization have a relatively small degree of influence on HUUL, and coordinated and green utilization have a smaller degree of influence than shared utilization, and the influence of both is relatively close to each other. In terms of the evolution process, the influence of innovation utilization has increased, with an average annual growth rate of 0.90%, indicating that both innovation utilization and the HUUL level maintain the dynamic evolution trend of continuous

growth. Except for innovative use, the influence of the other four endogenous drivers on HUUL tends to decline from 2006 to 2020, with average annual decay rates of 2.66 percent, 4.19 percent, 0.29 percent, and 0.41 percent, respectively, with coordinated use and green use always at the bottom of the explanatory power of HUUL.

4.2. Exogenous Drivers of high-Quality Utilization of Urban Land Level

Table 3 reports the magnitude of the explanatory power of exogenous drivers on HUUL and their significance levels. All exogenous drivers pass the 1 percent significance level test, indicating that these factors significantly impact the spatio-temporal evolution of HUUL. As a whole, the level of economic development and the level of government support are the main drivers of HUUL. The primary driver of increasing HUUL is the level of economic development. Firstly, it attracts more capital and technology to the city, which can be used to invest in and develop the land. Secondly, the influx of technology can lead to innovative approaches to urban land utilization, resulting in improved efficiency and quality. Finally, increased economic development will enhance the city's scientific, technological, and managerial capabilities, thereby directly facilitating the efficient and high-quality utilization of urban land. Furthermore, government support also contributes to boosting the HUUL level enhancement process. The government can implement land policies to regulate and control land use, optimize resource distribution on urban land, and improve land use efficiency. Additionally, the government can provide financial support for land development and utilization, promote advanced land use technology and management techniques, stimulate market participation, promote more factors of production to be invested in urban land, and boost high-quality utilization of urban land.

As shown in Figure 5(a), there is some variation in the explanatory power of exogenous factors for the four regions:

The explanatory power of exogenous drivers in the eastern region is ranked as economic development level> energy consumption level > urban development carrying level > government support level > population agglomeration level, and the explanatory power of all the driving factors is higher than the explanatory power of the factors at the national level. Among them, the explanatory power of economic development level and energy consumption level is 0.4404 and 0.3462, respectively, indicating that economic development and energy consumption have a good promotion effect on urban land use; The explanatory power of exogenous drivers in the central region is ranked as economic development level > government support level > urban development carrying level > energy consumption level > population agglomeration level, the five exogenous driving factors have higher explanatory power. The overall factor explanatory power level, the central region exogenous driving factors for HUUL, is higher than other regions, indicating that the exogenous factors play a more obvious role in the central region HUUL. While in the urban construction, the explanatory power of the urban development carrying level on the high-quality development of urban land in the central region is as high as 0.4336, indicating that enhancing the urban construction land area in the central region can better promote the high-quality utilization of urban land; The explanatory power of exogenous drivers in the western region is ranked as economic development level > government support level > population agglomeration level > urban development carrying level > energy consumption level, the level of economic development and the level of government support are the most important drivers of high-quality development of urban land in the western region. The population agglomeration brought by economic development can also promote HUUL better; The explanatory power of exogenous drivers in the northeast region is ranked as economic development level > government support level > energy consumption level > urban development carrying level > population agglomeration level, in which the level of economic development and the level of government support are the two main factors driving the efficient use of urban land in the Northeast region. The serious population loss in the Northeast region in recent years and the lack of urban development impetus are the main reasons why the explanatory power of its population agglomeration level is lower than that of other factors in the Northeast region.

This paper further examines the evolution of the intensity of exogenous drivers on the spatio-temporal evolution of HUUL levels from a dynamic perspective. As shown in Figure 5(b), the explanatory power of the five factors is roughly distributed in an inverted "U" shape. Among them, the explanatory power of the level of economic development is always higher than that of other factors, and it is in the position of the external dominant factor, with an average annual growth rate of 2.33 percent. The explanatory power of government support level and energy consumption level to HUUL is in second and third place, with annual average decay rates of 1.20 percent and 0.40 percent, respectively. The explanatory power of urban development carrying level and population concentration level tends to decline, with annual average decay rates of 0.84 percent and 0.57 percent, respectively, and population concentration level consistently has the least impact on HUUL.

Table 3. The explanatory power of exogenous driving factors on HUUL.

Area	UDC	PA	GDP	GS	EC
Overall Region	0.1237***	0.1130***	0.3009***	0.2249***	0.1741***
Eastern Region	0.2708***	0.1675***	0.4404***	0.2521***	0.3462***
Central Region	0.4336***	0.3537***	0.5882***	0.4866***	0.3709***
Western Region	0.2059***	0.2429***	0.3927***	0.2985***	0.1838***
Northeast Region	0.3129***	0.2765***	0.5469***	0.4587***	0.3268***

Note: UDC, PA, GDP, GS, and EC denote the levels of urban development carrying capacity, population agglomeration, economic development, government support, and energy consumption, respectively.

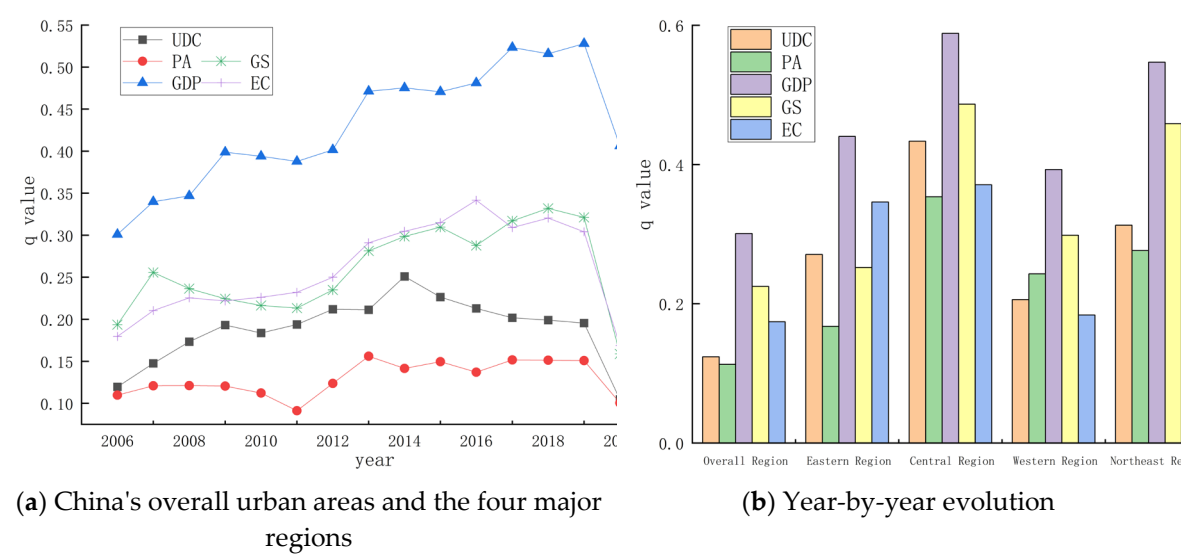


Figure 5. Results of Exogenous Driving Factor Exploration.

5. Discussion

Based on a comprehensive analysis of the spatio-temporal evolution of the HUUL level and driving factors in each region, this paper puts forward recommendations and countermeasures to further improve the HUUL level, taking into account the characteristics of the current state of urban land use in the four major regions and resource endowments:

On the one hand, to promote the efficient use of urban land and high-quality development, it is necessary to take innovative use as the core, open use as the path, the green use as the basis, the coordinated use as the guarantee, and the shared use as the fundamental, from the perspective of the overall situation, to classify and implement policies for the regional advantages, to clarify the key development direction, and to enhance the HUUL level in a coordinated manner.

Specifically, the eastern region shows greater economic development and higher land utilization, with limited land resource availability. In promoting urban land use, emphasis should be placed on the transformation of old urban areas and shanty towns, releasing the internal potential of urban land, promoting green building and smart city construction, and improving the quality of land use; The central region has a moderate level of economic development and HUUL, and is relatively rich in land resources. In promoting urban land use, encouraging complex land use and spatial sharing, optimizing the land use structure, focusing on the development of new urban districts and industrial parks, and promoting the rational allocation of land resources and the significant improvement of market efficiency; The level of economic development and HUUL in the western region is relatively low, with abundant land resources but fragile ecological environment. In promoting high-quality use of urban land, attention should be paid to ecological protection and environmental management to protect the ecological environment and biodiversity. At the same time, infrastructure construction should be strengthened, basic conditions such as transport, water, and energy supply should be improved, and industrial transfers and population movements should be actively guided to promote the urbanization process; Northeast region is an old industrial base in China, with a relatively lagging level of economic development, abundant land resources but a low level of overall high-quality land use, and the existence of many old industrial zones and urban neighborhoods. Promoting the HUUL level in the Northeast should focus on transforming old industrial land, releasing land resources within the city, optimizing the industrial structure, promoting economic transformation and innovative development, and improving the economic efficiency and added value of land.

On the other hand, the main driving roles of the endogenous driving factors of innovative use and open use and the exogenous driving factor of economic development level in promoting HUUL should be given full play to provide solid support and impetus for urban land use by innovating new technologies and management concepts, attracting foreign investment and talents, and increasing economic development inputs, to realize the high-quality development of the urban economy and the high-quality use of land.

6. Conclusions

In the context of economic transformation in the new period, this paper explains the theoretical connotation of HUUL, which is suitable for high-quality development. It constructs the indicator system of HUUL under the guidance of the new development concept. On this basis, the spatio-temporal patterns of HUUL levels in China and various regions are further measured and characterized. Then, we employ the kernel density map to analyze the dynamic evolution of the pattern. Lastly, we utilize the geodetector model to examine the explanatory power of various factors on HUUL levels at the cities above the prefecture level in China. Here are the main findings:

(1) Further measurements based on HUUL levels showed that between 2006 and 2020, the HUUL levels in the country and its four main regions experienced yearly increases. Throughout the measurement period, the HUUL levels in each region and the entire country followed the order of eastern region > central region > entire country > western region > northeastern region.

(2) The kernel density map shows that the overall and the four major regions' HUUL levels in the period 2006-2020 are, on the whole, on a rising trend, showing a development towards good and excellent. From the evolution trend of the four regions, on the one hand, except for the western region, the level span of the main peak position of the high-quality land use level among the cities in the other three regions tends to expand to different degrees. There is a high-high aggregation and a low-low aggregation of the HUUL level in the majority of the cities. On the other hand, individual HUUL levels are much higher than other cities in the eastern and western regions. In contrast, this distributional extension trend does not exist in the central and northeastern regions.

(3) The factor detector results show that in terms of endogenous factors, innovative utilization and open utilization are significantly stronger than other endogenous factors in explaining HUUL in both the whole and the four regions. They are the endogenous dominant factors in the spatio-temporal evolution of HUUL levels, and the explanatory power of the remaining endogenous factors,

except for innovative utilization, declines to vary extents over the sample period. In terms of exogenous factors, the level of economic development is the main driving factor for Chinese cities as a whole and the four major regions, followed by the level of government support and the level of energy consumption, with the levels of urban development carrying and population concentration at the bottom of the list, and the explanatory power of all the drivers other than the level of economic development decreasing to varying degrees over the sample period.

Supplementary Materials: Figure 1. Calculation of HUUL for the whole and the four regions of China; Figure 2. Three-dimensional kernel density estimation of HUUL in Chinese cities; Figure 3. Three-dimensional kernel density estimation map of HUUL in four regions; Figure 4. Results of Endogenous Driving Factor Exploration; Figure 5. Results of Exogenous Driving Factor Exploration; Table 1. HUUL level Evaluation Index System; Table 2. The explanatory power of endogenous driving factors on HUUL; Table 3. The explanatory power of exogenous driving factors on HUUL.

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