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Does Industrial Green Transformation Really Lead to High Land Use Efficiency? Evidence from China

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Abstract: This research aimed to investigate whether transformation of the industrial sector in a region could improve industrial land use efficiency. Taking the urban agglomeration in the middle reaches of the Yangtze River in China as the research area, we compiled socioeconomic panel data from 2000 to 2020 in order to analyze the impact of the transformation of industrial sectors in an area on industrial land use efficiency from two dimensions: industrial structural optimization and industrial spatial layout. The research results show the following: (1) The rationalization and upgrading of the industrial sector, as well as the professional agglomeration of industry and diversified industrial agglomeration, have improved the efficiency of industrial land use. (2) The impact of industrial rationalization on industrial land use efficiency presents an inverted U-shaped curve, whereby the impact of industrial upgrading on industrial land use efficiency has a relatively small spatiotemporal heterogeneity. The spatiotemporal changes in the impact of industrial specialized agglomeration on industrial land use efficiency are relatively small, while the spatiotemporal changes in the impact of industrial diversified agglomeration on industrial land use efficiency are more obvious. (3) There is obvious spatial heterogeneity in the two dimensions industrial structural optimization and industrial spatial layout in the three sub-regions when improving industrial land use efficiency.

Keywords: industrial transformation; industrial land efficiency; spatial spillover effect; spatiotemporal heterogeneity; threshold effect

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1. Introduction

Since the beginning of China's reform and opening-up in the late twentieth century, China has experienced rapid industrialization, moving from a large agricultural country to an industrialized country [1], and its industrial development has now entered the late stage of industrialization [2–5]. However, despite being a world industrial leader since entering the middle and late stages of industrialization [6], China's industrial development has not yet been fully transformed from its reliance on the "traditional" development mode, where the investment-driven and extensive development model is still prevalent. In particular, its industrial structure still has a large proportion of industries with low added value, high resource consumption, and serious pollution emissions and a factor input structure characterized by an over-reliance on general production factors, such as land and labor. There are many inconsistencies between China's industrial structure and land use [7–12]. In particular, the ratio of secondary and tertiary industries is uncoordinated, while the proportion of industrial land in areas is high. At the same time, during this era of

industrialization, the scale at which urban land has been transformed for industrial use has expanded rapidly, triggering a range of issues, such as the increasing industrialization of large amounts of cultivated land and ecological land, and a low industrial land use efficiency (ILUE). China's existing urban land has been only basically developed to date but has the potential for further development. However, due to some unreasonable utilization methods, a series of problems have arisen in land use in many regions, such as the rapid expansion of the scale of new land given over to industrial purposes, extensive industrial land use, and the inefficiency of construction land. Increasingly [13], problems are arising from mismatches between growth demands and the requirement for new construction land and the availability of land that is not subjected to cultivated land protection. Such protection aims to ensure that developments will not pose a risk to the ecological environment or lead to a series of associated issues, such as food security concerns.

To address these issues, the Chinese government has proposed important strategies to modify and optimize the economic structure of the country and promote industrial transformation. It is hoped that through industrial transformation in the industrial sector (ITI), the creeping industrialization of land could be reduced, ILUE could be improved, and sustainable development could be promoted. This research seeks to answer the following question: Can the industrial transformation promoted by the Chinese government play a role in enhancing ILUE?

To date, existing research has focused on exploring industrial transformation and land use efficiency, with the research considering three key aspects: (1) The first is research based on economic development, specifically, examining the connection between industrial transformation and ILUE in economic development and construction. For example, Gao et al. (2019) explored the changes in urban land use structure brought about by the promotion of regional economic integration through transformation of the industrial sector and market factors. They found that changing the land structure affects urban land use efficiency by changing the inputs and outputs of the land [14]. Scholars have drawn on the theory of smart growth and relied on high-quality social and economic development as the premise to construct an analysis framework for industrial land adjustment covering five dimensions: industrial transformation, urban planning, social and economic benefits, transportation convenience, and environmental protection [15–22]. The research results have shown that industrial transformation is an effective means to improve the internal structure of industrial land use, promote the intensification of industrial land, and improve the efficiency of industrial land utilization. Lu et al. (2020) analyzed the implications of land marketization on land use efficiency by considering changes in the industrial structure. They believed that land marketization could change the land use structure, thereby allowing for an optimization of resource allocation and improvements to land use efficiency. In parallel, from a regional perspective, in particular considering the western section to the central and eastern regions, they found that the role of the industrial structure in improving land use efficiency gradually weakened. (2) The second is research exploring the association between industrial transformation and land use efficiency at a more micro-scale. For example, Chen et al. (2018) focused on the manufacturing industry and studied the impact of manufacturing industrial transformation on ILUE. Their research results showed that industrial transformation could change the proportion of machinery manufacturing industries in the local land structure, and this process had a positive effect on improving the ILUE [23]. Chen et al. (2019) explored the ILUE of resource-oriented cities in China. They found that economic development, industrial transformation, and technological development all had significant effects on changing the land use types of resource-based cities and on improving the ILUE, while the internal labor structures of the enterprises and the ownership structures of the enterprises had serious negative outcomes on the

ILUE [24]. (3) The third is research analyzing the spatial and temporal differences in the effects of industrial restructuring on land use efficiency. For instance, Han et al. (2019) studied the impact of China's industrial transformation on land use efficiency and found that industrial transformation affects land use efficiency by changing the land structure, and this impact has regional heterogeneity. The impact was found to be more significant in large urban agglomerations, such as the Delta and the Pearl River Delta [25]. Similarly, Yin et al. (2019) explored how the transformation of leading industries guides urban land use. They found that the modernization and enhancement of leading industries in different cities have significantly different impacts on the ILUE, that changes in the leading industries can bring about changes in the land use intensity and land use patterns, and that these changes in land use structure have different impacts on the ILUE [26]. On a similar basis, Liu et al. (2021) explored the spatiotemporal differences in land use efficiency caused by transformation of the industrial structure. They found that from 2000 to 2015, China's land use patterns had changed through its promotion of industrial structural transformation, and this had improved the land use efficiency [27].

Undoubtedly, existing research has provided many interesting findings and inspiration for studying the impact of ITI on ILUE, but there are still some shortcomings in the research. For instance, in terms of theoretical logic, it is not uncommon for existing studies to explore the relationship between ITI and ILUE, but few consider land use as a way to establish the impact of land transformation brought about by ITI on ILUE from a comprehensive economic–environmental perspective. Also, existing research mostly analyzes the impact of ITI from one aspect: structural optimization of industrial transformation or the industrial spatial layout. Few studies have explored its impact from the two dimensions industrial structural optimization and industrial spatial layout. However, analyzing the impact of industrial structural optimization and industrial spatial layout brought about by ITI could allow for a more in-depth analysis of ITI, making the research results more valuable for practical reference. Lastly, ITI and ILUE have long-term and dynamic characteristics. The complexity of the ITI process can cause differences in the impact of ITI on ILUE at different stages in the development and transformation process. Yet, few existing studies have analyzed the spatiotemporal heterogeneity of ITI on ILUE from a dynamic perspective.

Based on the above discussion, this paper aimed to investigate whether ITI could improve the ILUE. Taking the urban agglomeration in the middle reaches of the Yangtze River (UMY) in China as the research area, we compiled socioeconomic panel data from 2000 to 2020 and then used them to analyze the effect of transformation of the industrial sector on ILUE from the two dimensions industrial structural optimization and industrial spatial layout.

2. Theoretical Analysis and Research Hypotheses

The ITI process inevitably causes land transformation, bringing about changes in the land use structure, methods, and intensity, which will then change the input–output that occurs on industrial land and affect the ILUE. This paper analyzes this impact from the changes in land use intensity and input level, land use structure and layout, land use subject behavior, and the comprehensive benefits of the changed land output caused by ITI.

Existing research has shown that the mechanism by which ITI affects land use transformation is by changing the proportion of land occupied by different industries in a city [28–30]. ITI leads to a transformation of the leading industries and their choice of location. Specifically, ITI changes the urban land structure as the city spreads out and leads to the reorganization of different land types within the city. ITI promotes agglomeration of the urban population and brings about a free flow and resetting of the production factors, which can lead to the reallocation of land resources in different industrial sectors. The

expansion of urban land can lead to modifying the land use structure and patterns, which is one of the ways that ITI affects the ILUE. That is, different industrial developments will bring about changes in the regional land use proportions, which will in turn cause changes in the land use structure.

With the advancement of ITI, the proportion of high-polluting industries in the industrial sector, such as coal, metallurgy, wood, and chemicals, in the entire industrial system has gradually decreased, replaced by new industries based on new materials, medicine, digital information, and green energy [31–33]. In this process, areas with a low allocation and low efficiency of production land have dropped sharply, and been replaced by high-allocation emerging industrial land use. As the financial commitment to technology, innovation, and management in production processes has continued to increase, the ILUE has increased. The process of ITI can thus bring about the replacement of a city's leading industries [34], and this transformation of the leading industries will lead to changes in the ILUE. Leading industries are important as they lead the way in the industrial structure of economic systems. They not only play an important leading role in optimizing the industrial structure and industrial spatial layout in their location and neighboring areas but also drive the rise of emerging industries. From the perspective of the location selection process of the city's leading industries, the adjustment process of a city's industrial structure also involves transformation of the city's leading industry sectors. Leading industries have established their dominant position in the competition for urban land use space with their high-efficiency characteristics and tend to be distributed in urban centers with higher aggregation benefits [35–37]. The development of emerging leading industries prompts enterprises to increase investment in advanced production factors. Enterprises can improve their production efficiency by developing advanced production technologies and increasing their investment in scientific research. In this process, advanced production factors, such as technology, capital, and scientific management concepts, gradually replace natural production factors, such as land, which produces a factor substitution effect. In the production process, the land factor input is reduced, output is increased, and the ILUE is improved. At the same time, the spatial distribution of the urban land use structure will also be affected by the location selection of leading industries. Under the influence of the "retrospective effect" and "side effects" of leading industries, industries that are closely related to leading industries tend to gather around them to form an industrial complex, generating economies of scale and improving the regional ILUE.

Promoting the optimization of the land use spatial layout is another way for IT to change the ILUE [38]. Land rent in urban centers is typically expensive, as consumption levels and land costs are high. Due to the high rents and taxes, it is difficult for general industrial enterprises to obtain good benefits. Therefore, to reduce production expenses, industrial firms pursuing profit maximization tend to gradually migrate from the urban core to the city outskirts. This forms a driving force for industrial enterprises in the heart of the city to migrate to the periphery of the city.

Heavy industrial enterprises, such as metallurgy, chemicals, machinery, and metal smelting, which are highly dependent on market environments, such as production materials and transportation conditions, have mostly withdrawn from urban centers and gradually moved to urban suburbs where land costs are relatively low, promoting the agglomeration of industries on the edges of cities and creating scale effects, which can improve the ILUE to a certain extent. The relocation of traditional enterprises makes room for the development of emerging industries and high-efficiency industries. Emerging industries that occupy less land, with a high degree of land intensiveness, and that have high unit land output rates have the ability to pay higher land rents and tend to gradually cluster in the city center, where they can benefit from the good infrastructure and

transportation conditions. These enterprises in the city center can generate higher product ancillary value, increase the land output, and improve the ILUE. Industries form two types of agglomeration distributions in urban centers and urban fringe areas, thereby achieving effective matches between the land elements and suitable enterprises. This process forms a "survival of the fittest" mechanism that enhances the allocation efficiency of the land production factors and enhances the ILUE.

In the ITI process in urban central areas, there are obvious differences in land use location requirements for different industrial developments. For instance, industries such as commerce, leisure, and entertainment have a high location requirement and need to be located in central areas with good transportation conditions and a large concentration of urban residents [39,40]. At the same time, these enterprises tend to have the characteristics of high profits and high output, which allows them to be able to pay high land rents and supports their choice to cluster in urban areas where land resources are tight. The proportion of land in the city center that covers large areas such as residences and warehousing has a low intensive land utilization and low output efficiency, and is gradually reducing as the urban land use structure and spatial layout change [41]. As a result, the urban building density and floor area ratio continue to increase, land use intensity continues to increase, and the ILUE is improving. Many investors in different industries in the city center want a central location with the most convenient transportation options and the highest economic benefits. There will be fierce competition for land in this location. On the one hand, the high land prices in the city center promote a simultaneous increase in investment intensity in the land by producers who aim to maximize their economic interests. On the other hand, the limited land resources in the city center and the demand for land for industrial development are pushing developers to turn to urban areas. The redevelopment and utilization of the existing land improves the ILUE.

The rapid expansion of tertiary industries during the ILUE process brings about a substantial increase in land use, while the increasing scarcity of urban land resources leads to an increase in land prices. Scarce land resources are allocated solely to efficient production companies at elevated prices through the market. According to land rent theory, the closer the land is to a city center, the higher the land rent and the land price that needs to be paid. In order to maintain survival and maximize profits, companies must find corresponding measures to reduce their production costs. Enterprises may gradually increase investment in non-land factors, such as manpower and technology to replace the original land investment, thereby increasing the ILUE. Value-added effects brought about by improvements to the urban infrastructure and rail transit in the city center to the surrounding land further deepens the factor substitution effect and accelerates the improvement in ILUE.

Another way that IT changes the ILUE is by promoting the market-oriented allocation of land resources. IT promotes the gradual expansion of the local and adjacent market demand scale [42], clearer production and division of labor in various industries, and the agglomeration of enterprises within a region, resulting in economies of scale. The production of different enterprises promotes economic investment within the region and changes the input intensity and utilization intensity of the land. The fierce competition among various types of enterprises in the process of pursuing profit maximization will also lead to a reduction in enterprise production costs, which can help expand the breadth and depth of the market. Expansion of the market scale will promote the flow of regional production factors, while more advanced investment factors will increase the intensity of land investment. Expansion of the market scale will also strengthen enterprise production capabilities, increase land output, and improve the ILUE.

From a spatial perspective, the spatial distribution of regional industries brought about by ITI essentially promotes the clustering of production factors, such as labor and capital, in a certain area. ITI promotes the agglomeration of different enterprises within a certain land space, and thereby creates a scale effect. The agglomeration of various related enterprises on different land gives them the ability to share production factors in the district and therefore promotes the flow of various factors of production to the agglomeration area [43]. The rapid accumulation of production inputs, including capital and labor, reduces production input, increases the economic output of the industrial land, and promotes improvement of the ITI.

Specifically, from the viewpoint of companies, having access to the same type of land in the city center brings about the agglomeration of similar enterprises in the same geographical space, resulting in industrial specialized clustering (KSL), which strengthens the advantages of the leading industries in the region. This continuous expansion improves the economic benefits of the land and promotes improvement of the ILUE. The agglomeration of similar industries brings about advanced production technology, and enterprises can be strengthened by cooperation, conducting relevant business training, sharing training and management costs, and reducing their production costs. The flow of production technology and technological innovation among enterprises in the same industry promotes cooperation between enterprises of the same type, promotes knowledge spillover, and is conducive to improving the overall regional production capacity.

Every enterprise can improve their resource utilization efficiency, reduce undesired outputs, and promote ILUE improvement. In the process of KSL, the agglomeration of similar enterprises on industrial land will cause competition. With the intention to dominate the competition and acquire more economic benefits, an abundance of homogeneous enterprises will compete against each other based on their production processes and products. On the one hand, enterprises will increase investment in research, improve production efficiency, and expand production scale through the application of more advanced production concepts. On the other hand, enterprises may promote innovation through the use of technology. These measures can reduce resource input in the production process, achieve greater economic outputs, and increase the ILUE. Additionally, enterprises from different industries may gather in urban centers, creating diversification agglomeration (DIV). This process promotes mutual learning and communication between enterprises, creating a learning effect. These can help reduce the risk of a single enterprise carrying out technology research, allow for optimizing technical resources, and increase the scope of technology application [44]. DIV can not only promote technological progress within various industries from spillover effects but also increase the benefits brought about by technological progress, increase the land output, and thereby improve the ILUE.

During the DIV process, the core technologies of various industries generate knowledge spillover benefits within and between enterprises, promoting productivity improvements in the entire region. Different enterprises gathered in the city center can share diverse production inputs, like production financial resources and technological innovation, promoting the concentration of different production factors in the region, especially the construction of shared infrastructure. Enterprises can reduce transportation costs by sharing infrastructure construction dividends, which can increase the economic benefits of the industrial land, and promote improvements in the ILUE [45]. Enterprises in various fields form advanced technology and knowledge diffusion effects through exchange and cooperation with each other, which can also promote the emergence of advanced production concepts. Diversified industries can also help build a solid economic structure. The development of various industries will drive the land economic output of the entire region and enhance the ILUE.

From the perspective of the labor force, on the one hand, the KSL process is conducive to promoting the accumulation of productive capital by labor at the same level, especially core technical talents, forming a labor matching effect. Within the KSL area, for enterprises that rely on technology to carry out production, KSL reduces learning and production costs through cross-industry production. The agglomeration of professional talent is also conducive to reasonably matching enterprises and the talent they need, thereby strengthening the regional talent market structure. Enterprises can save costs by being able to efficiently find the labor they need, which also reduces the production cost of recruiting labor. The agglomeration of the same types of skilled labor brought about by KSL can reduce the capital investment in land production, improve production efficiency, and increase the ILUE. On the other hand, DIV promotes a concentration of skilled labor with expertise in various production technologies in the same area, and creates a labor "reservoir" function to meet the employment needs of enterprises with various production technologies to the greatest extent. Meanwhile, the labor force has more opportunities to choose job options to work in professionally related enterprises, which reduces the production costs of training workers new to the sector and increases the economic effects from them being able to get up to speed quicker, which increases firm and land output. If a firm in an agglomeration area faces bankruptcy, its internal labor force would not need to look for jobs across other regions or move cities as their skills could be transferable to other nearby industries. The "reservoir" of labor brought about by DIV therefore effectively reduces unemployment risks for the labor force. During the agglomeration process, the labor force can also learn different skills and gain new knowledge and technology expertise to improve their employment security. A good employment environment can also absorb more high-quality labor, improve production efficiency, and enhance the ILUE.

Overall, land transformation brought about by ITI causes changes in the allocation relationship of capital, labor, and other resources on the land, which leads to changes in the structure of the input resources. According to the C-D production function [41], at different stages of the production technology level and economies of scale, changes in the land input structure will lead to an increase or decrease in land economic output, thus affecting the land input–output structure, that is, the ILUE (Figure 1).

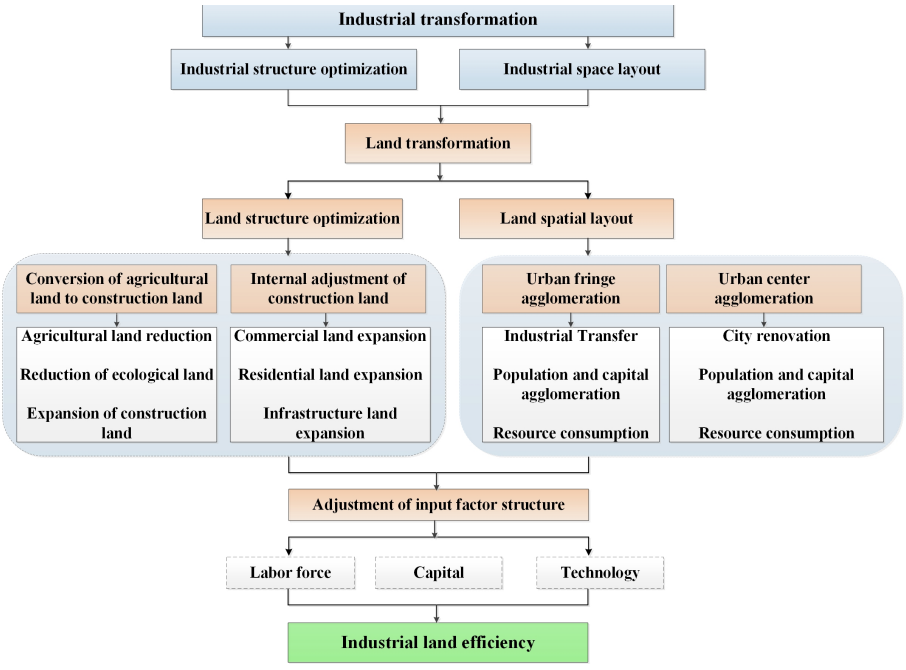


Figure 1. Theoretical framework for the impact of industrial transformation on industrial land use efficiency.

Based on the above analysis, this paper puts forward a research hypothesis: ITI affects the input–output structure of land, which then affects the ILUE.

3. Study Area, Data, and Methodology

3.1. Study Area

For this study and as discussed in this paper, the urban agglomeration in the middle reaches of the Yangtze River (UMY) in China, including the three provinces of Hunan, Hubei, and Jiangxi, was chosen as a representative area for the research. UMY is a large urban agglomeration mainly formed by Wuhan urban agglomeration and urban agglomeration around Changsha, Zhuzhou, and Lake Poyang. Due to the lack of some data in Tianmen City after 2010, Tianmen City was not included in the study area. Excluding Tianmen City, the study area of this paper was made up of 30 prefecture-level cities in the three provinces of Hunan, Hubei, and Jiangxi in the UMY (Figure 2).

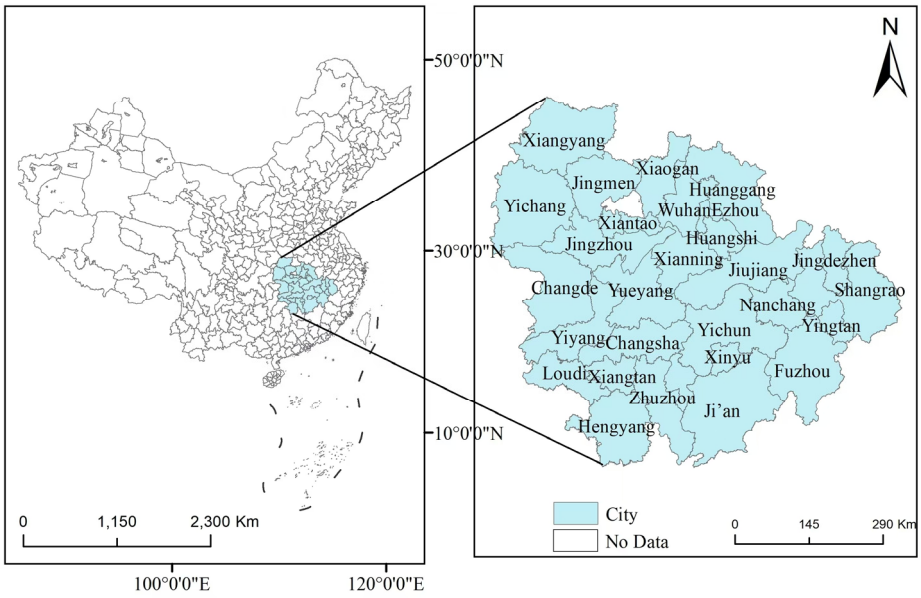


Figure 2. Location of study area.

The UMY is a new growth pole of China's economy, a pioneer area for new urbanization in Central and Western China, a demonstration area for inland opening-up and cooperation, and a guiding area for the construction of a "two-type" society. ITI in this region has a typical demonstration role to play in China.

3.2. Data Sources

The ITI data in this paper come from the statistical year book of each city, while the ILUE calculation data come from the China Land Market Network, https://www.landchina.com (accessed on 27 July 2021). The statistical year book of each city, the "China City Statistical Year book", and the national economic and social development of each city gazette. The data for the control variables were sourced from the China Urban Statistical Year book and the National Economic and Social Development Bulletin of each city. Because the Qianjiang Municipal Bureau of Statistics did not collect data on the output value of industrial sectors from 2000 to 2010, the output value of each industrial sector in Qianjiang City was replaced by the main business income of each industrial sector. Missing values in some years were interpolated.

3.3. Methods

3.3.1. Measurement of the ILUE: Data Envelopment Analysis by the DEA-SBM Model

In this research, we chose the SBM model, including undesired outputs, built by Zhao et al. (2014) [43] based on tone. The formula is as follows:

$$\mathrm{ILUE} = \min \frac{1 - \frac{1}{N}\sum_{n=1}^{N} \frac{n_x^s}{k' n_{t'}^x}}{1 + \frac{1}{M+I}\left(\sum_{m=1}^{M} \frac{m_y^s}{k' m_{t'}^y} + \sum_{i=1}^{I} \frac{i_b^s}{k' i_{t'}^b}\right)}$$

$$\begin{cases} \sum_{t=1}^{T}\sum_{k=1}^{K} k_t^z k n_t^x + n_x^s = k' n_{t'}^x, n = 1, \ldots, N, \sum_{t=1}^{T}\sum_{k=1}^{K} k_t^z k m_t^y - m_y^s = k' m_{t'}^y, m = 1, \ldots, M \\ \sum_{t=1}^{T}\sum_{k=1}^{K} k_t^z k i_t^b + i_b^s = k' i_{t'}^b, i = 1, \ldots, I \\ k_t^z \geq 0, n_x^s \geq 0, m_y^s \geq 0, i_b^s \geq 0, k = 1, \ldots, K \end{cases} \quad (1)$$

In the formula, ILUE is the ILUE value to be calculated; N, M, and I are the number of inputs, desired outputs, and undesired outputs, respectively; $\left(n_x^s, m_y^s, i_b^s\right)$ represents the input–output relaxation vector; $\left(k' n_{t'}^x, k' m_{t'}^y, k' i_{t'}^b\right)$ is k''s input–output value of a production unit in period t'; and k_t^z represents the weight of the decision-making unit. The objective function ρ strictly decreases monotonically with respect to n_x^s,m_y^s,i_b^s.

3.3.2. Measurement of the ILUE

Based on existing research [40], the input–output indicators for ILUE measurement were chosen as follows (Table 1):

Table 1. Calculation index system of industrial land use efficiency.

Indicator Selection	Classification Indicator	Single Indicator	Unit
Input variable	Land	Industrial land area	Hectare
	Labor force	Secondary industry employment	Thousands of people
	Capital	Industrial fixed asset investment	Billion RMB
Desired output	Economic output	Industrial output	Billion RMB
Undesired output	Environmental pollution	Carbon emission	Million tons

Input: industrial land area, number of employees in the secondary industry, and industrial fixed asset investment. Output: the desired as well as undesired outputs. The desired output value is the total industrial output value, and the undesired output value here is the industrial carbon emissions. The carbon emissions data used in this paper come from the China Carbon Accounting Database (CEADs) (https://www.ceads.net.cn/) created by Professor Guan Dabo's team at Tsinghua University.

3.3.3. Measurement of Industrial Industry Rationalization (ITL)

This paper refers to Gan et al. (2011) [46] and uses Theil's coefficient to calculate the ITL:

$$\mathrm{ITL} = \sum_{i=1}^{n} \left(\frac{V_i}{V}\right) \ln\left(\frac{\frac{V_i}{P_i}}{\frac{V}{P}}\right) \quad (2)$$

In Formula (2), V_i represents the industrial added value of i industrial sector; P_i represents the number of laborers engaged in i industrial sector; V represents the gross production value of 33 industrial sectors; P represents the sum of the labor force of

33 industrial sectors; and n represents the number of industrial sectors. If ITL were to gradually approach zero, the industrial industry would reach an economic equilibrium state. Therefore, the smaller the ITL value, the more optimized the industrial structure of the industrial industry is.

3.3.4. Measurement of Industrial Sector Upgrading (IW)

Existing studies mostly employ the quotient of the tertiary industry's production value over the secondary industry's production value as an indicator to measure how advanced the industrial structure is [47]. On the basis of this method, this study innovatively used high-tech industries to account for the output value of industrial industries to represent the IW. Through data matching and deletion, the selected high-tech industrial industries included instrumentation, medicine, electronic and communication equipment, computers and office equipment, aerospace equipment, and machinery. The IW calculation formula was as follows:

$$IW = IH/IO \tag{3}$$

In this formula, IO represents the production value of the industrial sector, and IH represents the output worth of the high-tech industry. The larger the value of IW, the greater the proportion of high-tech industry in the industrial sector and the higher the level of IW.

3.3.5. Measurement of Industrial Sector Industry Specialization Agglomeration (IKSL)

$$Iksl = \sum_{i=1}^{I} \left| \frac{L_{i,r}}{L_r} - \frac{L_i}{L} \right| \tag{4}$$

In the formula above, i represents an industry sector, r represents the city, and L represents the amount of people. The bigger the Iksl index, the higher the Iksl level.

3.3.6. Measurement of Industrial Sector Industry Diversification Agglomeration (IDIV)

Drawing on the research of Zhang et al. (2019) [48], this paper uses the Herfindahl index to judge the extent of industrial diversification and agglomeration, using the formula below:

$$IDiv = 1/\sum_{i=1}^{I} (L_{i,r}/L_r)^2 \tag{5}$$

The definitions of the items in the equation are the same as those in the Iksl formula above. The larger the IDiv index, the more dispersed the industrial and the higher the IDiv.

3.3.7. Industrial Sector Transformation on the ILUE Using the Spatial Durbin Model

Effect of Industrial Structure Optimization on the ILUE

$$\begin{aligned} ILUE = {} & \rho AlnILUE + \partial_1 ITL + {+}\partial_2 IW + \partial_3 lnGDP \ + \varphi_4 CZB + \varphi_5 InGZ + \varphi_6 SCHL + \varphi_7 KJB + \varphi_1 AITL + \varphi_2 AIW \\ & + \partial_3 AlnGDP \ + \varphi_4 ACZB + \varphi_5 AInGZ + \varphi_6 ASCHL + \varphi_7 AKJB + \gamma l_n + \varepsilon \end{aligned} \tag{6}$$

This paper uses the spatial Durbin model to explore the effect of ITI on the ILUE. In Formula (6), ρ is the spatial autocorrelation coefficient, A represents the spatial weight matrix, and l_n represents n × 1 vector. In addition, the control variables lnGDP, KJB, CZB, InGZ, SCHL that affect the ILUE were added. Also, ∂, φ, and γ are vectors of their respective regression coefficients, while ε is the error term.

Impact of the Industrial Space Layout on the ILUE

$$\begin{aligned} ILUE = {} & \rho AlnILUE + \partial_1 InIKsl + {+}\partial_2 InIDiv + \partial_3 lnGDP \ + \varphi_4 CZB + \varphi_5 InG + \varphi_6 SCHL + \varphi_7 KJB + \varphi_1 AIKsl + \varphi_2 AInIDiv \\ & + \partial_3 AlnGDP \ + \varphi_4 ACZB + \varphi_5 AInGZ + \varphi_6 ASCHL + \varphi_7 AKJB + \gamma l_n + \varepsilon \end{aligned} \tag{7}$$

The definitions of the variables are consistent with those in Formula (6).

3.3.8. Industrial Transformation Effect on the Spatial and Temporal Heterogeneity of the ILUE

Geographically weighted regression (GWR) is a local linear regression method based on modeling spatially relationships. This regression method can generate a regression model describing local relationships by exploring each part of the region, thereby allowing for an accurate analysis of localized variable relationships and spatial heterogeneity. The geographically time-weighted regression (GTWR) model used in this paper adds time effects to the GWR model as an extension of the GWR model [49,50]. This paper uses this model to explore the spatiotemporal heterogeneity of carbon emissions caused by industrial transformation at different times and in different spatial dimensions (Table 2).

Table 2. Descriptive statistics of all variables used.

Variable	Meaning	Mean	Std	Min	Max
ILUE	Industrial land efficiency	0.688	0.266	0.215	1
ITL	Industrial industry rationalization	0.097	0.083	0.004	0.549
IW	Industrial industry upgrading	0.147	0.073	0.007	0.522
IKSL	Industrial industry specialization agglomeration	0.767	0.215	0.091	1.441
InIDIV	Industrial industry diversified agglomeration	2.219	0.435	0.747	2.924
InGDP	The level of economic development	15.888	1.072	13.198	18.905
KJB	Technology investment	0.005	0.007	0.00001	0.057
InGZ	Urban residents' wages	10.106	0.781	7.999	11.586
SCHL	Land marketization level	0.701	0.332	0.063	1
CZB	Government management	0.142	0.060	0.032	0.394

4. Results

4.1. Spatiotemporal Distribution of the ITL

From 2000 to 2020, the ITL of the UMY dropped from 0.250 in 2000 to 0.033 in 2020. The ITL coefficient became significantly smaller and the degree of ITL became higher (Figure 3).

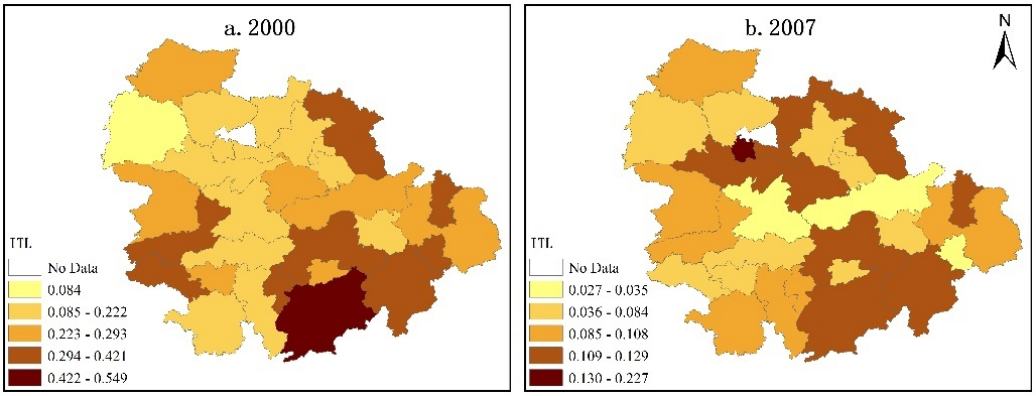


Figure 3. *Cont.*

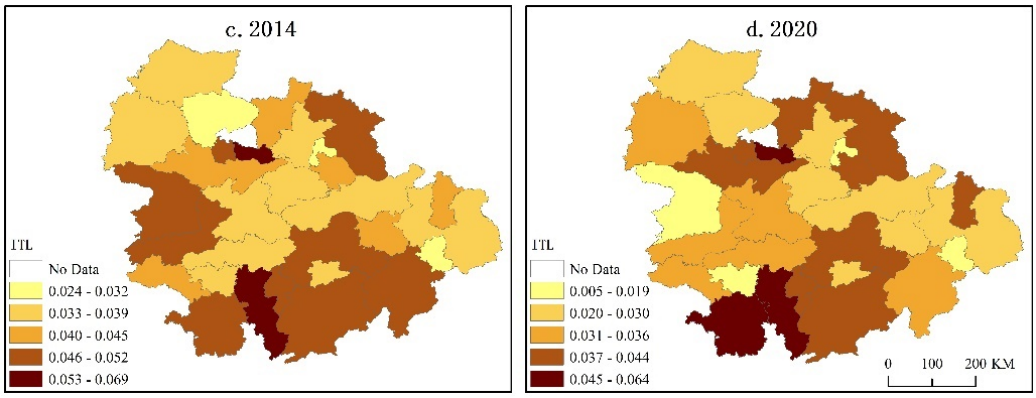


Figure 3. Spatiotemporal distribution of the industrial rationalization of industrial industries in UMY.

4.2. Spatiotemporal Distribution of the IW

IW increased from 0.121 in 2000 to 0.184 in 2020. The IW coefficient also increased, indicating that the proportion of high-tech industries in the industry gradually increased, high-tech industries gradually expanded, and the IW level increased (Figure 4).

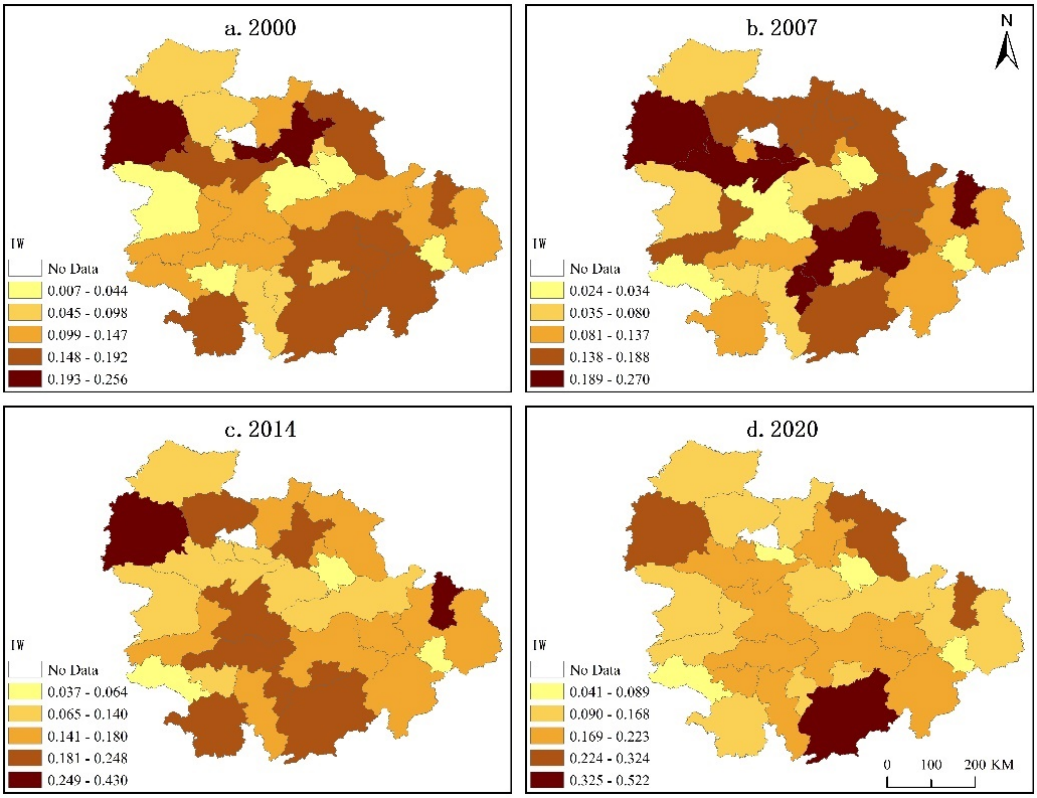


Figure 4. Spatiotemporal distribution of industrial upgrading in UMY.

4.3. Spatiotemporal Distribution of the IKSL and IDIV

The IKSL of the UMY dropped from 0.797 in 2000 to 0.735 in 2020, and the level of industrial professional agglomeration declined (Figure 5). The IDIV level increased from 8.570 in 2000 to 10.766 in 2020 (Figure 6).

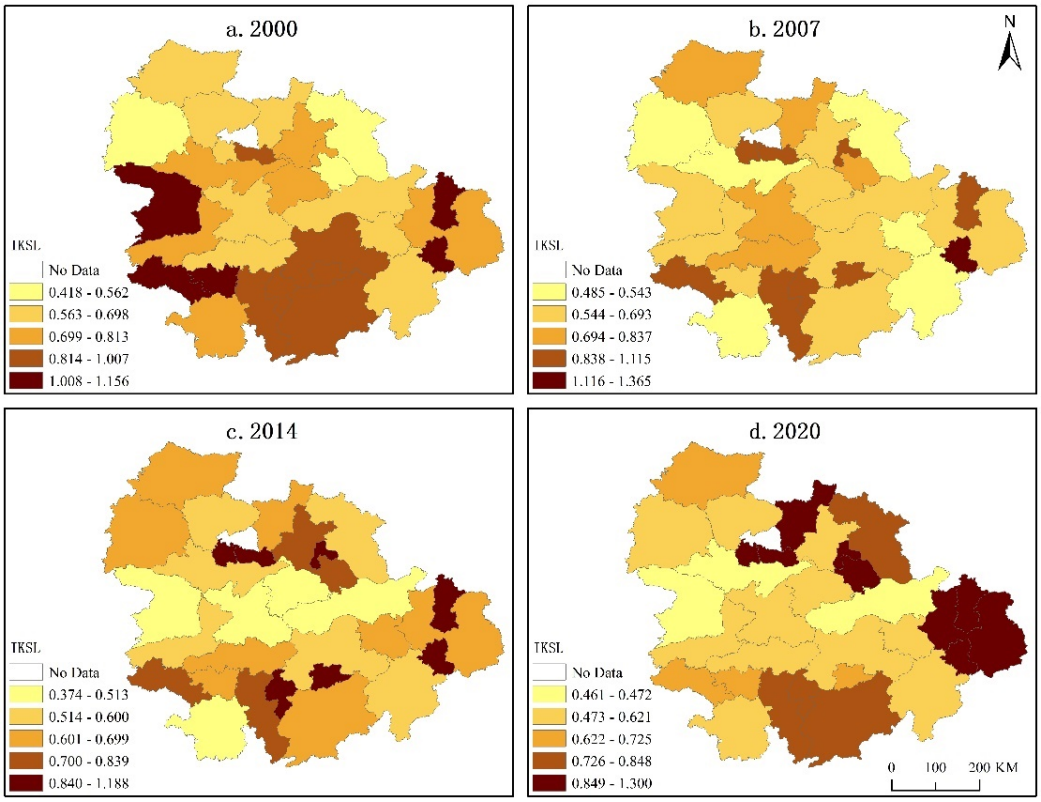


Figure 5. Spatiotemporal distribution map of industrial specialization agglomeration in UMY.

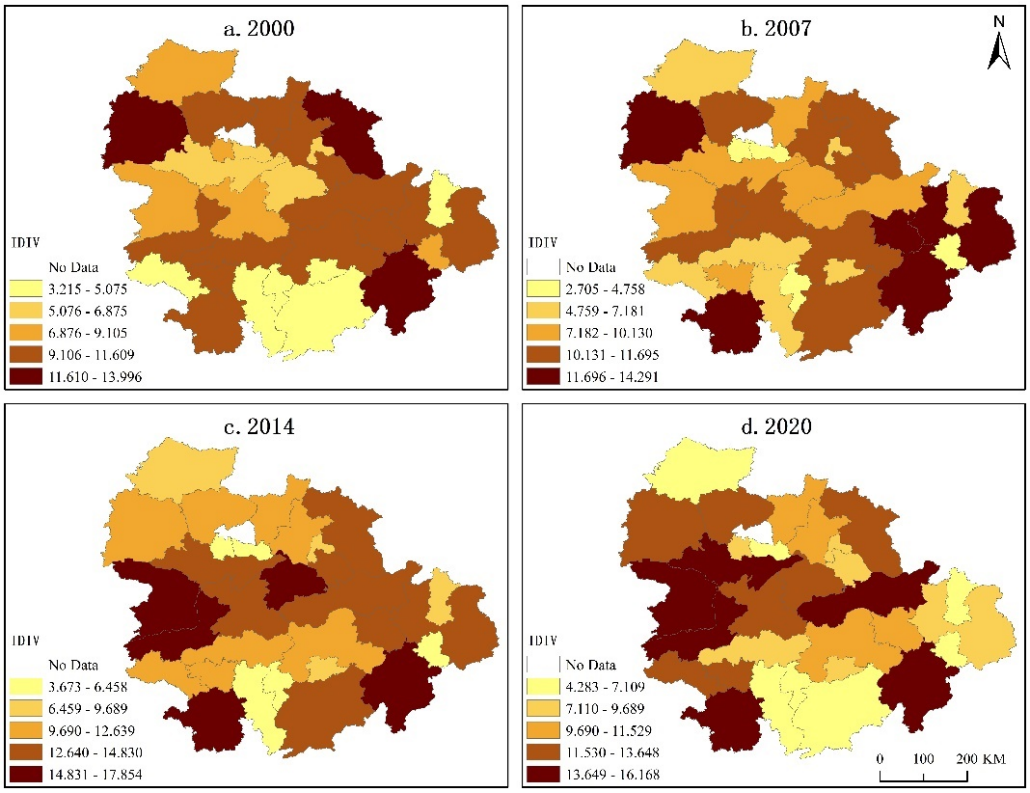


Figure 6. Spatiotemporal distribution of industrial diversification in UMY.

4.4. Spatiotemporal Distribution of the ILUE

The ILUE of the urban agglomeration in the UMY increased from 0.635 in 2000 to 0.779 in 2020. During this time, the lowest ILUE value was 0.601 in 2010, while the highest ILUE

value appeared in 2020 as 0.779. Generally speaking, from 2000 to 2020, the ILUE of the UMY showed an upward trend year by year (Figure 7).

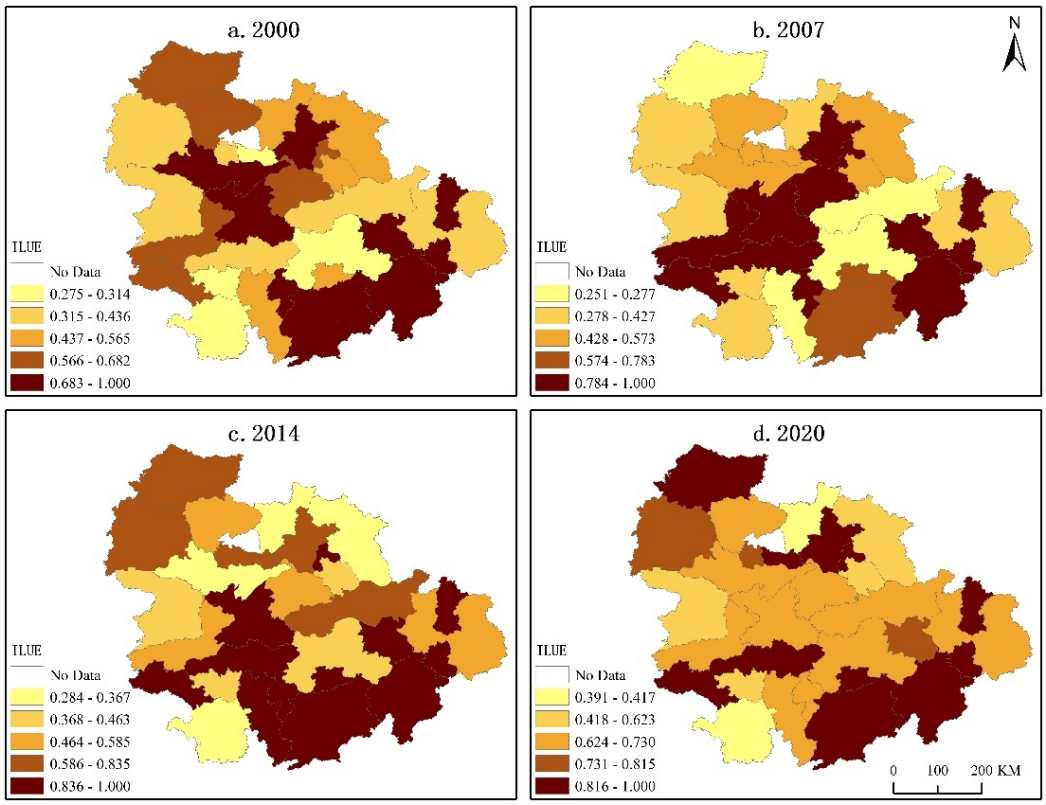


Figure 7. Spatiotemporal distribution of industrial land efficiency in UMY.

4.5. Spatial Spillover Effects of Industrial Transformation on the ILUE

4.5.1. Spatial Spillover Effect of Industrial Structure Optimization on the ILUE

Both IKSL and IDIV in the UMY played a role in improving the ILUE. Table 3 reports the impact of industrial structure optimization on the ILUE under three types of spatial weight matrices. The spatial autoregression coefficients of the three models were 0.228, 0.251, and 0.156, respectively. Notably, all Spearman's rho showed positive numbers and all passed the 1% significance level test. Overall, the model results show that under the three weights, ITL played a role in improving the ILUE. Under the adjacency distance weight matrix, ITL increased by 1% and ILUE increased by 0.370%, while under the economic distance weight matrix, ITL increased by 1% and ILUE increased by 0.898% and under the economic geography nested weight matrix, ITL increased by 1% and ILUE increased by 0.193%. This is because ITL reduces enterprise production costs and environmental losses by promoting a sharing of knowledge, technology, and labor within industrial enterprises, which improves the ILUE. Meanwhile, ITL can promote the extent of the industrial chain, promote the integration of urban advantageous resources, and improve the ILUE. Pollution-intensive industries, as represented by the energy industry and chemical industry, will eventually achieve internal upgrades through high-tech and clean transformation. On the one hand, pollution and energy consumption will be reduced, and on the other, the undesired land output will be reduced. The transformation and upgrading of industrial sectors rely on high-tech industries and new technologies, with technological innovation the main driving force for development. Advanced technology increases the intensity of land use, increases the land economic benefits while promoting ecological and environmental benefits, and is conducive to the rational use of land to increase the land economic output and improve the ILUE.

Table 3. Spatial spillover effects of industrial structure optimization on ILUE.

ILUE	Adjacency Distance			Economic Distance			Economic Geography Nesting		
rho	0.228 *** (4.090)			0.251 *** (3.120)			0.156 *** (4.42)		
	direct effect	indirect effect	total effect	direct effect	indirect effect	total effect	direct effect	indirect effect	total effect
ITL	0.099 (0.660)	0.271 (1.010)	−0.370 (1.380)	0.066 (0.450)	0.832 ** (2.580)	−0.898 *** (2.780)	0.114 (0.78)	0.079 (0.42)	−0.193 (0.95)
IW	−0.155 (−1.020)	−0.128 (−0.310)	0.283 (−0.620)	−0.157 (−1.060)	−0.247 (−0.370)	0.405 (−0.590)	0.269 * (−1.80)	−0.324 (1.52)	0.055 (0.20)
InGDP	0.136 *** (3.320)	−0.194 ** (−2.040)	0.058 (−0.590)	0.134 *** (3.080)	−0.014 (−0.100)	0.120 (0.880)	0.122 *** (3.21)	−0.215 *** (−4.25)	0.093 (−1.55)
KJB	−0.814 (−0.710)	1.518 (1.030)	0.704 (0.500)	−1.398 (−1.090)	2.772 (1.290)	1.373 (0.790)	0.431 (0.39)	−0.650 (−0.53)	0.219 (−0.19)
CZB	0.266 (1.010)	−0.227 (−0.370)	−0.039 (0.060)	0.325 (1.250)	−1.094 (−1.020)	−0.770 (−0.700)	0.282 (1.11)	−0.604 * (−1.81)	−0.322 (−0.79)
InGZ	0.088 (1.430)	0.065 (0.630)	0.153 (1.520)	0.027 (0.440)	0.057 (0.450)	0.084 (0.710)	0.010 (0.19)	0.200 *** (3.37)	0.211 *** (3.31)
SCHL	0.034 (0.690)	−0.083 (−0.960)	−0.049 (−0.580)	0.058 (1.270)	−0.205 (−1.560)	−0.147 (−1.070)	0.097 ** (2.05)	−0.207 *** (−3.48)	−0.111 * (−1.68)
R^2	0.012			0.007			0.015		

Note: * statistical significance at the $p < 0.10$ level, ** $p < 0.05$ level, *** $p < 0.01$ level.

Looking at IW, the model results show that under the three weights, IW played a role in improving the ILUE. Under the adjacency distance weight, IW increased by 1% and ILUE increased by 0.283%, while under the economic distance weight, IW increased by 1% and ILUE increased by 0.405% and under the economic geography nested weight, IW increased by 1% and ILUE increased by 0.055%. The main way that IW affects the ILUE is by first optimizing the internal land resource utilization structure and industrial layout of industry. IW can accelerate the elimination of polluting industries, such as coal, textiles, and electricity, while also accelerating the development of emerging industries, like pharmaceuticals, electronic communication equipment, computers, and supplies. In this process, the land area used for production plants and other related facilities of industrial enterprises with high inputs and low outputs is gradually decreased, while the land used by high-tech enterprises with low inputs and high outputs is increased, and the output of the industrial land is thereby increased. Another way in which IW affects the ILUE is through its driving role in optimizing the peripheral land use layout of industrial enterprises. In order to reduce costs, companies must find locations suitable for their development and adjust their industrial layout. On the one hand, heavy industrial industries, such as machinery and metals, are gradually being squeezed out of the city center and are moving to the suburban districts. The original idle and extensive land resources in the suburbs have now been developed and utilized, and ILUE has improved. On the other hand, high-tech industries that can pay high land rents have gathered in urban centers, forming new industrial agglomeration groups, which has not only expanded the scale of industrial production but also increased the intensive utilization of industrial land, significantly improving ILUE. Among the control variables, the stage of economic development, investments in science and technology, and the wage level of urban residents all increase the ILUE, while the level of government management and land marketization decrease the ILUE.

4.5.2. Spatial Spillover Effect of the Industrial Spatial Layout on the ILUE

The two dimensions of the industrial layout in the UMY, IKSL and IDIV, have played a role in improving the ILUE. Table 4 reports the impact of the industrial spatial layout on the

ILUE under three types of spatial weight matrices. The spatial autoregression coefficients of the three models were 0.240, 0.257, and 0.157, respectively, while Spearman's rho was positive and passed the 1% significance level, indicating the existence of spatial spillover effects. Looking at IKSL first, all three weight matrices showed that IKSL increased the ILUE. With the adjacency distance weight matrix, a 1% increase in IKSL increased the ILUE by 0.259%. In the economic distance weight matrix, every 1% increase in IKSL increased the ILUE by 0.479%. With the economic geography nested weight matrix, for every 1% increase in IKSL, ILUE increased by 0.188%. On the one hand, IKSL promoted the agglomeration of the same industries within the market and sharing of production materials, such as capital, technology, and labor, within the industry, generating spillover effects and improving the ILUE. On the other hand, the IKSL process was conducive to promoting the accumulation of productive capital by labor at the same level, especially core technical talents, and forming a labor matching effect. The labor pool formed by IKSL reduces the unemployment risk of the labor force to a certain extent. Industrial enterprises can also access a suitable labor force to carry out production, improve productivity, and enhance the ILUE. Marshall's externality theory believes that the input–output correlation between producer services and manufacturing is strong, and labor sharing occurs during the agglomeration process. This process reduces production costs, increases land output, and improves the ILUE. Looking at IDIV, IDIV also improved the ILUE under the three weights. In the adjacency distance weight, every 1% increase in IDIV increased the ILUE by 0.017%, while with the economic distance weight, every 1% increase in IDIV increased the ILUE by 0.176% and under the economic geography nested weight, every 1% increase in IDIV increased the ILUE by 0.003%. On the one hand, under the agglomeration effect of IDIV, the operating costs of industrial enterprises were reduced, which helped to enhance corporate competitiveness, improve corporate productivity, and promoted an improvement in the ILUE. Additionally, IDIV will also promote interactions between industrial enterprises and generate a synergistic effect of "the whole is greater than its parts", which helps improve overall competitiveness and enhances the ILUE.

Table 4. Spatial spillover effect of industrial spatial layout on ILUE.

ILUE	**Adjacency Distance**			**Economic Distance**			**Economic Geography Nesting**		
Rho	0.240 *** (4.410)			0.257 *** (3.240)			0.157 *** (4.450)		
	direct effect	indirect effect	total effect	direct effect	indirect effect	total effect	direct effect	indirect effect	total effect
IKsl	−0.084 (−1.370)	0.343 *** (2.960)	0.259 ** (2.160)	−0.054 (−0.900)	0.532 *** (3.020)	0.479 *** (2.600)	−0.077 (−1.320)	0.264 *** (3.640)	0.188 ** (2.090)
InIDiv	−0.095 *** (−2.680)	0.112 (1.430)	0.017 (0.200)	−0.082 ** (−2.330)	0.257 ** (2.340)	0.176 (1.560)	0.074** (−2.150)	−0.071 * (1.650)	0.003 (−0.050)
InGDP	0.123 *** (3.100)	−0.178 * (−1.900)	−0.055 (−0.570)	0.122 *** (2.860)	−0.109 (−0.810)	0.013 (0.100)	0.112*** (3.040)	−0.191 *** (−3.960)	−0.079 (−1.400)
KJB	−0.510 (−0.450)	2.093 (1.410)	1.583 (1.130)	−1.100 (−0.870)	4.061 * (1.740)	2.961 (1.560)	0.580 (0.530)	−0.426 (−0.350)	0.154 (0.130)
CZB	0.326 (1.290)	−0.509 (−0.860)	−0.183 (−0.280)	0.375 (1.480)	−1.386 (−1.260)	−1.011 (−0.890)	0.372 (1.530)	−0.789 ** (−2.390)	−0.417 (−1.020)
InGZ	0.091 (1.570)	0.044 (0.430)	0.135 (1.330)	0.042 (0.710)	0.082 (0.640)	0.124 (1.030)	0.036 (0.710)	0.163 *** (2.830)	0.199 *** (3.140)
SCHL	0.034 (0.710)	−0.072 (−0.840)	−0.038 (−0.460)	0.070 (1.530)	−0.201 (−1.560)	−0.131 (−0.970)	0.074 * (1.650)	−0.196 *** (−3.310)	−0.121 * (−1.940)
R^2	0.012			0.017			0.023		

Note: * statistical significance at the $p < 0.10$ level, ** $p < 0.05$ level, *** $p < 0.01$ level.

4.5.3. Robustness Check

In order to test the robustness of the results, we conducted a robustness test on the model by changing the sample period and matrix, reducing the research time by 4 years, that is, changing the research time period to 2000–2016, and using the inverse distance weight matrix to verify the research robustness of the results. Tables 5 and 6 present the results of the robustness test. The results for the industrial structure optimization and industrial spatial layout on the ILUE were basically the same as in the original model, which shows that the estimation results of the original model had good stability.

Table 5. Robustness test of the impact of industrial structure optimization in industrial industries on industrial land use efficiency.

Explained Variable ILUE			
Explanatory variable	Direct effect	Indirect effect	Total effect
ITL	0.069 *** (3.020)	0.145 ** (−2.550)	−0.214 * (−1.910)
IW	0.164 (−0.890)	0.200 (−0.390)	0.364 (−0.64)
InGDP	0.135 *** (2.950)	−0.114 (−1.040)	0.021 (0.180)
KJB	−0.601 (−0.490)	2.183 (1.390)	1.582 (1.020)
CZB	0.086 (0.250)	−0.234 (−0.320)	−0.148 (−0.180)
InGZ	0.057 (0.790)	−0.008 (−0.070)	0.048 (0.380)
SCHL	0.011 (0.210)	−0.419 (−0.440)	−0.030 (−0.330)
Rho	0.222 *** (3.660)		
R^2	0.034		

Note: * statistical significance at the $p < 0.10$ level, ** $p < 0.05$ level, *** $p < 0.01$ level.

Table 6. Robustness test of the impact of industrial spatial layout of industrial industries on industrial land use efficiency.

Explained variable ILUE			
Explanatory variable	Direct effect	Indirect effect	Total effect
IKsl	0.111 (−1.630)	0.377 *** (2.950)	0.266 ** (2.030)
InIDiv	−0.102 ** (−2.520)	0.169 ** (1.850)	0.067 *** (3.020)
InGDP	0.130 *** (2.910)	−0.103 (−0.920)	0.028 (0.240)
KJB	−0.194 (−0.160)	2.422 (1.550)	2.228 (1.500)
CZB	0.195 (0.600)	−0.502 (−0.700)	−0.307 (−0.380)
InGZ	0.063 (0.940)	−0.036 (−0.300)	0.027 (0.210)

Table 6. *Cont.*

Explained variable ILUE			
SCHL	0.010	−0.031	−0.022
	(0.180)	(−0.340)	(−0.240)
Rho	0.230 ***		
	(3.860)		
R^2	0.053		

Note: ** statistical significance at the $p < 0.05$ level, *** $p < 0.01$ level.

4.6. Industrial Transformation Effects on the Temporal and Spatial Heterogeneity of the ILUE

The impact of ITL on the ILUE showed an inverted U-shaped curve in the box (Figure 8). From 2000 to 2014, the length of the box showed an increasing trend year by year, with a small change. The box was longest in 2014, indicating that the spatiotemporal heterogeneity of the impact of ITL on the ILUE was the largest in 2014. Since 2015, the box length has been weakening year by year, indicating that the spatiotemporal heterogeneity of the impact of ITL on the ILUE has been gradually reducing since 2015. This shows that after 2015, the role of ITL in improving the ILUE gradually became stable. The spatiotemporal heterogeneity of the effect of IW on the ILUE changed slightly, whereby, from 2000 to 2005, the box length increased and the spatiotemporal heterogeneity increased. From 2006 to 2015, the length of the box gradually decreased, and the spatiotemporal heterogeneity gradually weakened. After 2016, the box length gradually increased, and the spatiotemporal heterogeneity increased again. The spatiotemporal changes in the impact of IKSL on ILUE were relatively small, and the box curve remained always relatively stable. The impact of IDIV on the ILUE showed a large change in length and obvious spatiotemporal changes. From 2000 to 2008, the box curve increased from small to large. During this period, the impact of IDIV on the ILUE gradually increased each year. From 2009 to 2015, the impact of IDIV on the ILUE gradually decreased each year. After 2015, the impact of IDIV on the ILUE gradually increased each year.

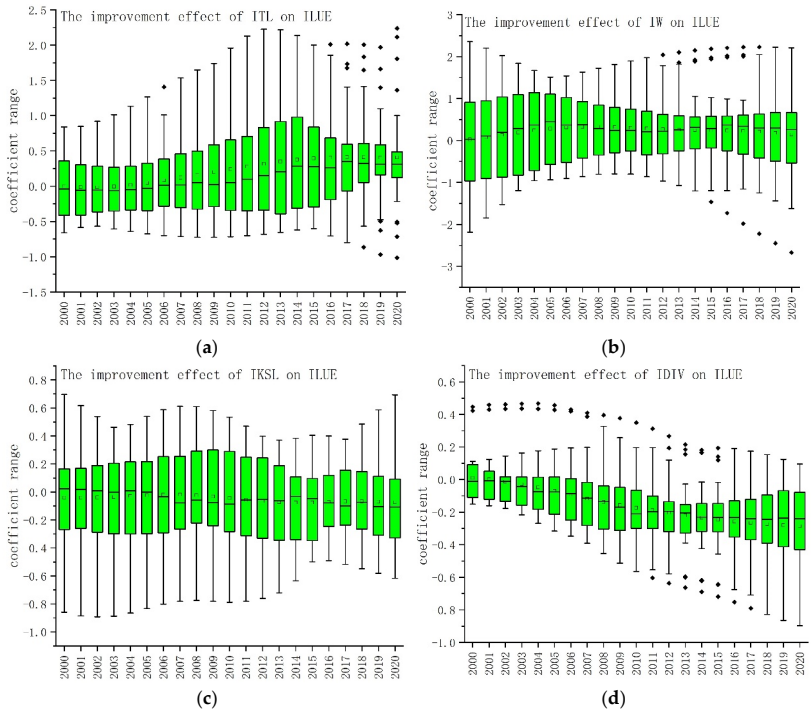


Figure 8. The impact of industrial transformation on ILUE of space–time heterogeneity.

From 2000 to 2010, the effect of IKSL in Hubei Province on improving the ILUE decreased year by year, then increased from 2010 to 2015, and finally gradually decreased from 2015 to 2020 (Figure 9). The effect of IKSL in Jiangxi Province on improving the ILUE showed an inverted U-shaped curve, increasing year by year from 2000 to 2010 but then decreasing year by year from 2010 to 2020. Compared with Hubei Province and Jiangxi Province, the effect of IKSL on improving the ILUE in Hunan Province varied greatly, and the curve was not smooth, with highs and lows observed during the study period. From 2000 to 2005, the effect of IDIV on ILUE in Hubei Province was linear and relatively stable. After 2005, it showed a downward trend year by year. The effect of IDIV on ILUE in Jiangxi Province was relatively stable, with a slight increase from 2000 to 2005, a slight decrease from 2005 to 2015, and a stable trend from 2015 to 2020. For IKSL, the effect of IDIV on the ILUE in Hunan Province varied greatly, and the curve was not smooth. It had highs and lows during the study period and generally showed a downward trend.

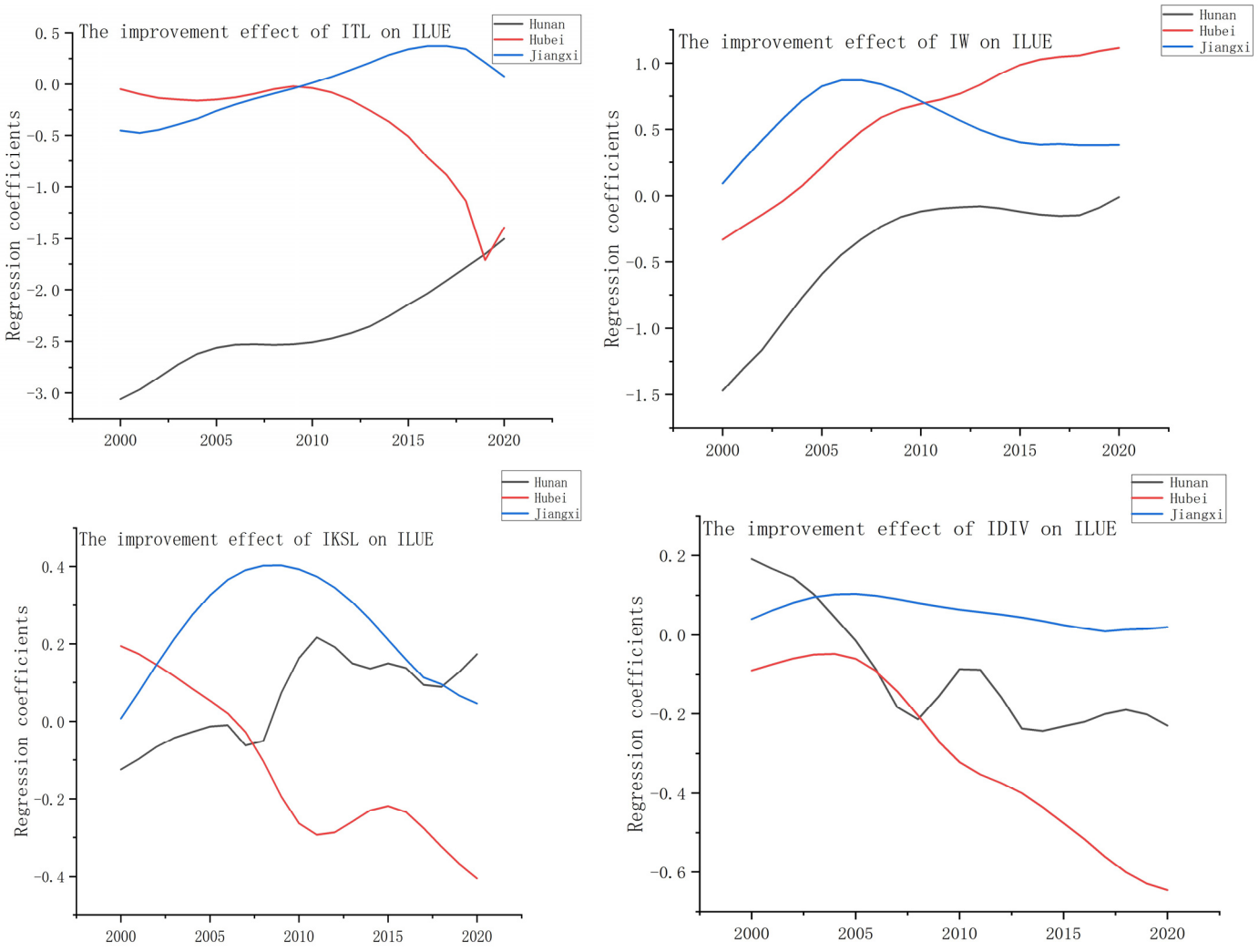


Figure 9. Spatial heterogeneity of the effect of industrial spatial layout on ILUE in industrial sectors.

5. Discussion

This study used land as a carrier to establish a complete logical system of the impact of land transformation brought about by ITI on ILUE in an integrated economic–environmental system.

An attempt was made to establish a theoretical analysis framework for the effect of ITI on the ILUE. We incorporated IT into a CO_2 emissions analysis to build a logical analysis framework for CO_2 emissions caused by land transformation in the IT process and then

analyzed the socioeconomic effect of CO_2 emissions caused by land transformation driven by ITI.

We detailed our analysis of how the two dimensions industrial structural optimization and industrial layout brought about by land use transformation in the ITI process affects the ILUE. Specifically, we explored the impact of ITI from the two dimensions structural optimization and spatial layout, taking into account both industrial structural optimization and spatial layout, with four industrial transformation measurement index systems established to empirically analyze the carbon reduction effect of IT at different scales.

We also used a local variable parameter model that considers spatiotemporal heterogeneity to explore the influence of economic activities on the ILUE, which allows for new analytical perspectives on the changes in different dimensions of time and space in the research. We also sought to analyze the dynamic process of ITI's effect on ILUE from a dynamic perspective, and the results provide a significance reference for governmental decision-making and policy regulation to promote ITI and achieve high land use efficiency goals based on different economic development stages.

However, this study has some limitations to note. The industry can be subdivided into different industries that are labor-intensive, capital-intensive, and technology-intensive. Further research could further subdivide the industry to explore the impact of its internal transformation on the ILUE. In addition, this study still has some unfinished research on the impact mechanism of IT on changes in the ILUE, which could inform and motivate subsequent research. Furthermore, the theoretical analysis framework constructed in this paper is not absolutely complete, and further research is needed to analyze the interactive effects of IT and ILUE and expand the theoretical framework to more deeply explore the relationship between IT and ILUE.

6. Conclusions

This research took the UMY as a representative area for investigation, compiled socioeconomic panel data from 2000 to 2020, and analyzed the impact of ITI in 33 industrial sectors on ILUE from the two dimensions industrial structural optimization and industrial spatial layout. The research results of this paper can be summarized as follows:

Firstly, from 2000 to 2020, the ITL of the UMY dropped from 0.250 in 2000 to 0.033, and the ITL level became higher. IW increased from 0.121 in 2000 to 0.184 in 2020, and IW increased. ILUE increased from 0.635 in 2000 to 0.779 in 2020, and ILUE showed an upward trend year by year.

Secondly, the industrial transformation had a spatial impact on the ILUE. ITL and IW as well as IKSL and IDIV all improved the ILUE.

Thirdly, ITL's impact box on the ILUE was indicated by an inverted U-shaped curve, while the spatiotemporal heterogeneity of the impact of IW on ILUE changed only a little. The spatiotemporal changes of IKSL's impact on the ILUE were relatively small, while the spatiotemporal changes of IDIV's impact on the ILUE were more obvious.

Fourthly, by analyzing the regression coefficients for Hunan, Hubei, and Jiangxi provinces, it was found that there was an obvious spatial heterogeneity in the ILUE in the two dimensions structural optimization and spatial layout of industries in the three regions.

Based on the research results of this paper, we put forward the following recommendations:

It is important to strengthen regional cooperation and promote joint governance. The results of this paper indicate that there is a spatial correlation between IT and ILUE. This means that industrial structural adjustments or changes in industrial spatial layout between adjacent areas will likely have spatial spillover effects on the surrounding areas, affecting the ILUE in neighboring areas. This shows that it is not feasible for each city in the region to develop unilaterally in isolation from its surrounding environment, and the

economic activities of cities in a region influence each other. Therefore, in the process of future industrial transformation, cooperation between regions should be promoted, and a cross-regional collaborative development mechanism should be established to improve the ILUE through regional cooperation. Also, the spatial spillover effect of IT should be fully utilized to achieve overall regional economic development. Local governments should actively promote healthy economic competition among regions while promoting regional cooperation. By establishing a benign regional cooperation mechanism, we can reduce the potential harm caused by vicious competition between regions on the market and economic efficiency and eliminate wastage of resources caused by barriers to the flow of factors of production between areas. Strengthening the flow of capital, labor, technology, energy, data, and other factor resources between cities in the region and optimizing the efficiency of production factor allocation are critical factors for regions to improve the ILUE. At the same time, it is also important to promote the comparative advantages of cities of different sizes and levels; form a development pattern of functional complementarity, industrial interaction, and knowledge and technology interoperability; enhance the spatial spillover effect of industrial transformation on improving ILUE; and promote IT to improve the ILUE. Cities at various levels can establish regional internal governance based on their different resource endowments and location characteristics, while strengthening active cooperation between cities at various levels. A regional community of interests could be built by promoting cross-regional governance. During the period of regional cooperation, it is necessary to actively carry out technical cooperation and exchange, promote the complementarity of advantages between regions, and focus on the linkage effects between cities. Differentiated development plans should be formulated based on the industrial structure, and economic development needs of different areas. Cross-regional industrial collaborative layouts should be promoted through regional cooperation, while facilitating industry linkage development, accelerating communication among local governments, industries, and enterprises in the industry chain and using the comparative advantages of each industry chain, while relying on funds, knowledge, and information through other methods, Through the above measures, we can achieve the sharing of resources and technology, use developed regions to drive underdeveloped regions, improve the ILUE of the entire region.

Focus on the long term, and promote IT according to local conditions. The results of this paper show that the distribution of IT and ILUE in the UMY shows obvious stage characteristics and regional non-equilibrium characteristics, while empirical tests found that IT has a spatiotemporal heterogeneity in improving the ILUE in the region, which means that in the process of promoting IT, long-term and differentiated industrial policies need to be formulated to promote regional IT. On the one hand, IT is dynamic and transformation requires a certain process. Whether it is industrial rationalization and industrial upgrading or the agglomeration of industrial specialization and industrial diversification, it is a gradual dynamic evolution process. To prevent the emergence of problems, such as uncoordinated industrial structural development and industrial oversupply, a long-term concept must be implemented throughout the entire process of IT, improving the ILUE, and a long-term mechanism should be established to collaboratively promote transformation and improve the ILUE. On the other hand, governments should consider the development positioning of each region, pay attention to regional differences, and formulate industrial policies tailored to actual local conditions according to the current industrial structure and energy structure. Each region should promote IT according to its own actual situation, and the IT model should be adapted to the actual situation. Regions with good economic development tend to have abundant technology and capital, while they may have a relative shortage of resources. Regions with lower economic development levels tend to lack

advanced technology and capital but have relatively abundant natural resources. These regional differences are all related to differences in formulation and implementation and provide a realistic basis for the policy of globalized IT and for further promoting IT by formulating industrial policies tailored to local conditions. For regions with developed economies and high levels of industrial structure and agglomeration, the role of IT in traditional departments in improving ILUE in developed regions has been very limited. In the future, industrial policies should focus on driving the development of new industries and in promoting the development of ILUE in developed regions. At the same time, IT also provides IT experiences to other regions. For regions with backward economic development and a low industrial structure, supportive industrial policies can be appropriately tilted toward underdeveloped cities and IT can be promoted in underdeveloped cities.

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