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Treating the Symptoms as Well as the Root Causes: How the Digital Economy Can Mitigate the Negative Impacts of Land Resource Mismatches on Urban Ecological Resilience

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Abstract: In the era of the digital economy (DE), the traditional economic growth paradigm is no longer applicable. To explore whether the DE can improve the urban ecological problems left behind by rough economic growth, this study examines the effects of land resource mismatch (LRM) on urban ecological resilience (UER) and evaluates the mitigating influence of the DE. This analysis utilizes data from 280 prefectural-level cities in China over the period from 2007 to 2021 and reveals that LRM significantly undermines UER, with this conclusion remaining robust across a series of tests. Additionally, the detrimental impact of LRM on UER is more pronounced in megacities, cities with high levels of economic development, and those with a lower degree of advanced industrial structure. In further analysis, this study finds that the digital economy can optimize the allocation of land resources, thereby enhancing urban ecological resilience, which has the effect of "treating the root causes". In addition, digital government and digital infrastructure, as key elements of the digital economy, also mitigate the negative impacts of land resource misallocation on urban ecological resilience, having the effect of "treating the symptoms". Finally, this study proposes policy suggestions such as optimizing ecological layout, deepening land reform, and promoting digital government and infrastructure construction to provide a theoretical basis and practical guidance for local governments to enhance UER and help build a new model of greener, more resilient, and sustainable urban development.

Keywords: land resource mismatch; urban ecological resilience; digital economy; digital government; digital infrastructure

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1. Introduction

The Chinese "land for development" model has created a miracle of economic growth over the past few decades, as shown in Figure 1, where a wide-caliber industrial land supply has strongly supported Chinese economic growth. However, as China's economic growth momentum shifts and the drawbacks of uncontrolled land utilization accumulate, this development model increasingly reveals its unsustainability [1,2], with the decline in urban ecological resilience (UER) caused by land resource mismatch (LRM) being a typical example. The dominant perspective asserts that UER fundamentally encapsulates the ability of urban ecosystems to withstand, recover from, and adapt to unpredictable disruptions. Nonetheless, the suboptimal allocation of land resources has significantly altered the foundational physical conditions that sustain UER [3]. Local governments in China often use planned economic means with obvious administrative intervention to suppress the price of industrial land while expanding its size, hindering the rational allocation of land through normal market transactions, which artificially creates the phenomenon of LRM [4].

The distortion of land prices brought about by LRM will reserve room for the middle- and low-end manufacturing production activities characterized by high pollution [5]; on the one hand, this slows down the speed of industrial upgrading and reduces the motivation of enterprises to climb towards intelligence and greening [6]; on the other hand, it strengthens the rigid demand of the middle- and low-end industries [7] and is not conducive to the transformation of the center of regional industries to the service industry, which ultimately has a negative impact on UER. The inappropriate allocation of land quantities can degrade the habitats of urban biota, resulting in a loss of their ecosystem service capacity [8]. Kim et al. (2017 [9]) also found that unreasonable land development will disrupt the balance between anthropogenic landscapes and natural landscapes, which in turn undermines the ecological resilience of seaside cities. In this context, a thorough exploration of effective strategies for optimizing LRM and enhancing UER is of paramount practical significance, as it directly contributes to improving the quality of the urban ecological environment. The digital economy (DE), with its high innovation, strong permeability, and wide coverage, has brought profound progress to government governance, industrial transformation, and enterprise production [10,11] and has become a possible path for the green development of the regional economy. Based on this, this study will explore the potential impact of the DE on the phenomenon of LRM, with a view to finding realistic paths to improve ecological resilience and enhance the ability to address external disturbances.

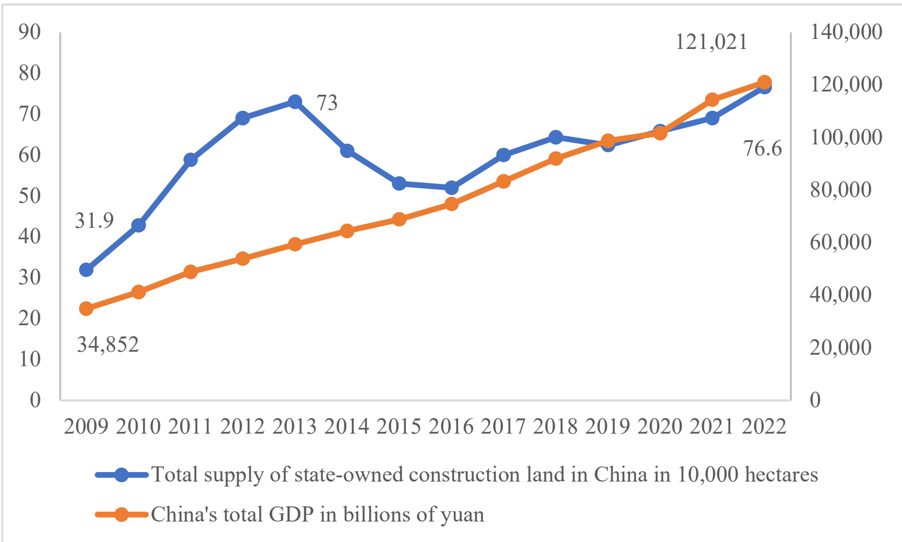


Figure 1. Supplement of state-owned construction land (10,000 hectares) and total GDP (billions of yuan) in China.

The root cause of LRM lies in the fact that the Chinese approach to land allocation is characterized by both a market economy and a planned economy, which is determined by the way in which land is granted in China. *The Regulations on Tendering, Auctioning, and Listing of State-owned Land Use Rights*, promulgated by the Chinese government, stipulate that China's public land transfer methods include listing, auctioning, and tendering, whereas agreement transfer refers to the transfer of state-owned land use rights by municipal and county land resource management departments to land users by way of an agreement, which is a transfer method that is strongly colored by government intervention. The direct cause of China's LRM phenomenon is that the fiscal decentralization brought about by the reform of the tax system has changed the behavior of China's local governments; i.e., corporate income tax has become a major revenue source for local governments, which have therefore become keen on cultivating their tax base by attracting foreign investment. In order to obtain construction funds, in terms of quantity, local governments have raised the supply of industrial, mining, and warehousing land in large quantities, which has been maintaining a high proportion in China, as shown in Figure 2; in terms of price, the cost of industrial land has been artificially depressed to sustain the competitive advantage of manufacturing goods by keeping their prices at a lower level. As depicted in Figure 3, the long-term trend reveals that the prices of industrial land in China have consistently remained subdued [12]. Effective allocation of resources has always been the basic problem of economics research, and it has always been the cutting-edge topic of economic development [13]; the academic research on the consequences of LRM mainly focuses on the regional industrial structure and production efficiency. On the one hand, LRM depresses the cost of land, which leads to the rough utilization of land: a large amount of industrial land is allocated to inefficient enterprises, which leads to the low-level duplication of industrial investment between regions and the ensuing overcapacity [14]; on the other hand, the influx of inefficient enterprises constrains the operational space available to high-tech firms, thereby impeding the overall productivity growth of the city [15]. There is also research on the impact of LRM on the urban environment showing that low-level manufacturing industries inevitably bring a large amount of energy consumption and a large amount of sulfur and nitrogen gas emissions [16], but there is no clear idea on whether the LRM will have an impact on the city's ability to address natural disasters, as well as how to cope with and solve the urban environmental problems caused by LRM. Based on this, this study endeavors to tackle the issue through the lens of the DE, aiming to address the extent of LRM and mitigate its detrimental effects. This approach not only presents a fresh perspective for comprehending the challenges associated with LRM but also introduces innovative strategies for local governments to effectively counteract and resolve this issue.

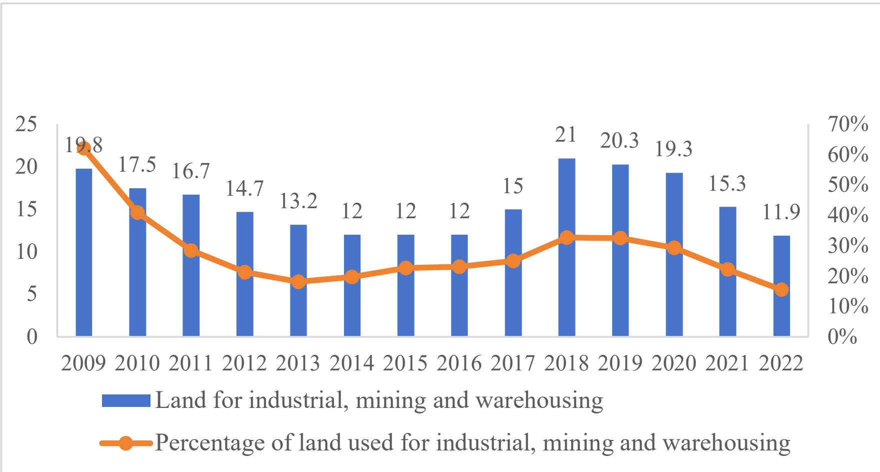


Figure 2. Land (10,000 hectares, %) used for industrial, mining, and warehousing in China.

The focus of this study, namely the repercussions of LRM on UER, stems from the accelerating pace of urbanization, which has brought to light a range of environmental issues. The expansion of road infrastructure, for instance, introduces pollutants and external contaminants, which leads to the fragmentation of plant and animal populations. This fragmentation, in turn, results in the disintegration of landscapes, thereby posing a significant threat to ecological equilibrium [17]. The swift expansion of open-pit mining has precipitated several adverse effects, including the reduction in vegetation cover, loss of biodiversity, and water pollution [18]. These consequences have, in turn, resulted in a significant deterioration of ecological environments [19] and a reduction in the primary productivity of land elements [20]. The continuous shrinkage of coastal wetlands has become an urgent ecological problem, which not only leads to the reduction in coastal species but also exacerbates habitat fragmentation and serious ecosystem degradation [21]. In addition, the heat island effect has become increasingly prominent as a significant environmental problem during urbanization, which has a complex impact on the precipitation patterns of the surrounding areas by altering the local climate system and increasing the vulnerability of the ecological environment [22]. Moreover, pollutants emitted from the production activities of industrial enterprises have become a major source of air, soil, and water pollution, posing a long-term threat to the health sustainability of the ecological environment [23]. The concept of resilience originated in the field of materials disciplines [24] and was first used to explain why materials can withstand loads without breaking [25]. In 1973, Holling [26] defined resilience in his book as the ability of an ecosystem to absorb state variables driving variables and still maintain itself, and then the related research gradually extends to human ecology; the idea of resilience has also been expanded to the urban field [27], and is proving a good analytical tool for urban systems [28]. In this study, the induced cause of reduced ecological resilience is anchored in LRM, which is because, on the one hand, inappropriate human land use and allocation behaviors shrink the scale of resources that can provide shelter for the population from natural or man-made disasters [29]. Evidence from China suggests that in the Poyang Lake area, people surrounded the lake to create fields, reducing the size of the lake and ultimately leading to an increase in the frequency of floods [30]. In addition, evidence from all over the world suggests that the unchecked felling of trees reduces the ability to withstand dust storms [31–33]. On the other hand, misbehavior itself causes disasters. Excessive industrialization leads to increased emissions [34], greenhouse gas emissions contribute to global warming [35], and industrial emissions degrade the urban environment [36]. Currently, academics are taking a more mature view about urbanization's impact on UER. However, the relationship between LRM and UER, which accompanies human activities at the same time, has been neglected for a long time. On the one hand, the mechanism between human activities and UER is complex, and quantitative research is needed to clarify the causes of UER; on the other hand, with the increasing complexity and refinement of urban management, human beings are mastering more digital means to cope with the profound changes in the relationship between human beings and geographic environments, and it is becoming imperative to conduct a targeted analysis of the interplay between urban areas and their ecological surroundings so that more operable solutions can be proposed at the planning level.

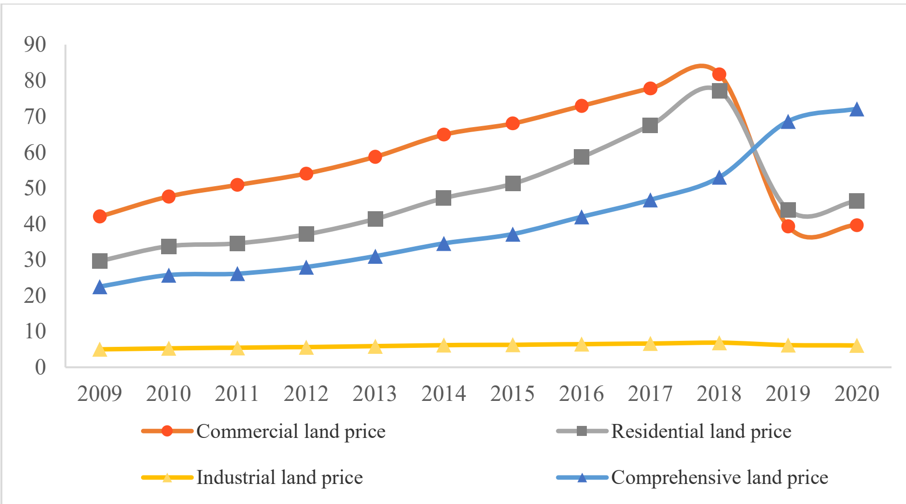


Figure 3. Average price (yuan per square meter) of various land in China.

In recent times, China's economy has entered the 4.0 era of industry, with the DE as the main driving force [37,38]. The DE is pivotal in driving the transition from traditional economic drivers to emerging ones [39], and it has also achieved significant progress in optimizing the allocation of production factors and facilitating the green development of the economy [40]. For the allocation of production factors, academics have proved that the DE can provide a docking platform for both supply and demand through big data algorithms to increase the number of flexible employment, thus optimizing the allocation of labor [41]; the DE identifies and records the credit behavior of the "long-tailed group" through the underlying technology such as blockchain networks, mitigating information asymmetry between the financial sector and the production sector, and enhancing information security within the financial sector [42]; however, there is no relevant research on whether and how the DE can optimize land resource allocation. The literature indicates that the DE fosters technological innovation and facilitates industrial structure upgrading, thereby contributing to the sustainable development of regions such as the Yangtze River Delta [43]. However, there remains a lack of definitive evidence regarding whether the DE can enhance UER by optimizing the efficiency of resource allocation, particularly with respect to non-renewable land resources. Now that the world is in the key opportunity period of the new round of technological revolution, how to better manage the DE's resource cohesion, integration, and optimization of the allocation of factors and enhance the stability of the urban ecological environment system, and the livability of the city can not only make a contribution to the theory of the DE to help green development, but also help digital policymakers to clarify future policy directions, so it is of great theoretical significance.

Based on this, this study will be based on the perspective of DE, from the perspective of improving the phenomenon of LRM and mitigating the negative impacts of LRM, to explore the "treating the symptoms" channels and "treating the root causes" channels of ecological resilience. Firstly, the empirical analysis conducted in this study confirms that LRM significantly diminishes UER, underscoring the need to address LRM. This conclusion has been validated through a series of robustness tests. Furthermore, the heterogeneity analysis reveals that the detrimental impact of LRM on UER is more pronounced in megacities, cities with high levels of economic development, and cities with lower levels of advanced industrial structure. Secondly, the development of DE can improve the phenomenon of LRM, thus improving UER, which has the effect of "treating the root causes." Finally, the development of DE can play a moderating role in alleviating the decline of UER caused by LRM, which has the effect of "treating the symptoms."

The research contributions of this study are as follows:

First, this study broadens the scope of research on LRM. Based on the existing body of research on LRM, this study further explores its environmental impacts. While traditional research on LRM focuses on regional industrial structure [44], green productivity [45], and economic growth [46], this study innovatively combines it with urban ecological issues, revealing the phenomenon that LRM reduces UER through empirical analysis. This finding not only enriches the research perspective of the consequences of LRM but also provides new clues for understanding urban ecological problems.

Second, this study enriches the research on UER. Most considerations of UER in the existing literature have concentrated on the perspectives of population agglomeration [47] and urbanization [48]. This study not only pioneers the in-depth examination of LRM as a critical factor undermining UER but also explores its potential for enhancing resilience through the lens of the DE.

Third, this study comprehensively analyzes the role of the DE in mitigating the negative impacts of LRM from the perspectives of "treating the symptoms" and "treating the root causes". First, this study explores the potential of DE in optimizing land resource allocation, which fills the gap in current research. Second, it reveals that the DE can serve as an intermediary regulatory mechanism, mitigating the impact of existing LRM on UER. The revelation of this dual-action mechanism provides a more comprehensive understanding of the application of the DE in environmental governance, which not only provides new research perspectives and theoretical support for academics but also provides valuable references for policymakers.

The research layout of this manuscript is as follows: the second part is the theoretical derivation; the third part is the research design, including data sources, variable definitions, and model design; the fourth part is the empirical analysis, including descriptive test, basic regression, and robustness test, the fifth part is the further analysis, including the "treating the root causes" channels and the "treating the symptoms" channels of DE, and the sixth part is the conclusion and recommendations.

2. Theoretical Analysis and Research Hypothesis

2.1. Land Resource Mismatch and Urban Ecological Resilience

From the preceding paragraph, LRM is attributed to the "land for development" strategy of local governments in China, i.e., selling industrial land at lower prices while selling commercial and residential land at higher prices [49], which triggers a series of negative impacts such as rough economic growth [45], the pollution of the ecological environment [50], and the degradation of land resources [51]. UER refers to the ability to maintain stability against human or natural disturbances and the ability to self-adjust and recover after experiencing disturbances, i.e., impact resistance, self-adaptation, and recovery ability [52–54]. Therefore, how will UER change when subjected to the external disturbance of LRM and the series of negative effects it brings?

Firstly, LRM increases the ecological pressure on cities. When the market fails, or the government intervenes, land elements cannot realize effective allocation [55], and the inefficiency of land use triggers the problem of over-industrialization of industrial structure [56]. Driven by performance appraisal targets, local government officials often tend to introduce the quantity rather than the quality of industrial enterprises to rapidly expand the scale of fiscal revenues. Although this strategic choice can boost economic performance in the short term, it fosters the overexpansion of inefficient and highly polluting industries, thereby posing a significant threat to the ecological environment and exacerbating the long-term vulnerability of urban ecosystems [57]. Secondly, LRM hinders the optimization of ecological spatial layout. The disorderly spread of industrial land will squeeze and encroach on the ecological space, leading to the shrinkage of green space, wetlands, and other ecological functional areas [58]. The "heat island effect," air quality deterioration, and other problems are becoming more and more serious, weakening the ability of urban ecosystems to resist impact, adaptive capacity, and recovery ability. Finally, there is the "heavy" GDP growth and "light" ecological construction investment. Under the background of LRM, local governments allocate a substantial portion of land revenue to infrastructure development within industrial parks [59]. On the one hand, there is a relative lack of investment in cultivating R&D personnel and supporting technological innovations, which restricts enterprises from carrying out green technological innovations with strong positive externalities and neglects the long-term environmental benefits and the positive impact of green technological innovations on pollution control. On the other hand, the short-sightedness of investing in ecological environmental protection further weakens the UER. Based on the above analysis, this study proposes the following hypothesis:

H1. *LRM reduces the ecological resilience of cities.*

2.2. Mechanisms of the Digital Economy to Mitigate the Negative Impacts of Land Resource Mismatch on Urban Ecological Resilience

The DE corrects factor mismatches, and guides factor flows through the wide application of information technologies and the deep integration of digital technologies, thereby improving the efficiency of land allocation [38]. Further, the digital government provides policy support for the DE, and digital infrastructure is the "hardware" foundation for the DE, and the three are complementary to each other. According to the existing literature, although LRM seriously inhibits the efficiency of green development, the DE can mitigate this negative impact [60]. Therefore, this study argues that the DE can alleviate the negative impact of LRM on UER mainly through the "treating the root causes" channels of the DE and "treating the symptoms" channels of digital government and digital infrastructure.

2.2.1. Mechanisms of the Digital Economy in Mitigating the Adverse Impacts of Land Resource Mismatch on Urban Ecological Resilience: "Treating the Root Causes" Channels

The rise of the DE is profoundly transforming the traditional economic growth paradigm, causing disruptive changes in land resource allocation [61], reducing regional pollution emissions [62], and increasing UER [63]. First, the DE makes use of cutting-edge information technology such as big data. By collecting and analyzing massive land data, it can accurately identify the functional needs of different regions, optimize the layout planning of urban roads, industrial land, residential land, ecological functional zones, etc., and achieve accurate monitoring and planning of land resources, thus preventing and controlling the negative impacts of LRM from the source. Second, the DE can improve the green land use efficiency [64], optimize the allocation of land by upgrading the industrial structure [65] and increasing green technological innovation [66] channels, reduce resource consumption and environmental pollution, and comprehensively enhance the overall efficacy of urban systems in responding to external pressures at their origins [67]. Based on the above analysis, this study puts forward the following hypothesis:

H2. *The DE reduces the negative impact on UER by alleviating LRM.*

2.2.2. Mechanisms of the Digital Economy in Mitigating the Adverse Impact of Land Resource Mismatch on Urban Ecological Resilience: "Treating the Symptoms" Channels

In China, the allocation of land has traditionally been led by the government, but the establishment of digital government represents an unavoidable trajectory in the modernization of governance within the DE era and has progressively emerged as a robust driver for the optimization of natural resource allocation [68]. The development of digital government construction is based on the openness of public information resources, and on the one hand, the openness of public data provides a rich data source and broad application scenarios for enterprise technological innovation [69], promotes technological progress in the fields of clean energy, etc., and then guides the transformation of industries in the direction of green, alleviates the negative impacts of LRM, and bolsters the city's capacity to manage external impacts and enhances its resilience in responding to external shocks. On the other hand, it helps the public to conveniently access ecological and environmental information [70] and understand the utilization status of land resources and its impact on the environment; it promotes the self-regulation of enterprise behavior, guiding them to follow the planning blueprint to carry out orderly development, and promoting the efficient utilization of land resources; and it enhances the transparency of the government's behavior [71], so that the government must be more cautious in weighing the advantages and disadvantages of the land resources, and avoid sacrificing environmental and social well-being for the purpose of short-term financial revenue. Based on the above analysis, this study proposes the following hypothesis:

H3. *Digital government construction can mitigate the negative impact of LRM on UER.*

Urban digital infrastructure, as the cornerstone of DE development, covers core elements such as 5G communication networks and efficient big data platforms to ensure the full integration and efficient application of digital technologies. The implementation of the DE to promote sustainable development goals must be realized through digital infrastructure linkage [72,73], as digital infrastructure can provide important support for enhancing UER. On the one hand, digital infrastructure not only reduces the cost of acquiring and processing information for enterprises by providing high-speed, low-latency network connections, and powerful data processing capabilities [74], but also accelerates the diffusion and application of technological innovation, helps enterprises develop environmentally friendly production technologies and products, and mitigates the fragility of UER caused by inefficient use of land resources. On the other hand, digital infrastructure makes a positive contribution to facilitating the structural transformation of industries [75]. The application of digital technology has led to profound changes in the production model and organizational modes, promoted the rapid development of intelligent manufacturing and other emerging industries, brought a greater degree of higher value-added elements to the industrial structure, and reduced the dependence of traditional industries on land resources and pollution emissions. The refinement of industrial structure facilitates the efficient utilization of land resources and underpins sustainable development. This process mitigates inefficient and redundant land use practices and significantly augments UER. Based on the above analysis, this study proposes the following hypothesis:

H4. *Digital infrastructure development can mitigate the negative impact of LRM on UER.*

The theoretical mechanism for this article is shown in Figure 4.

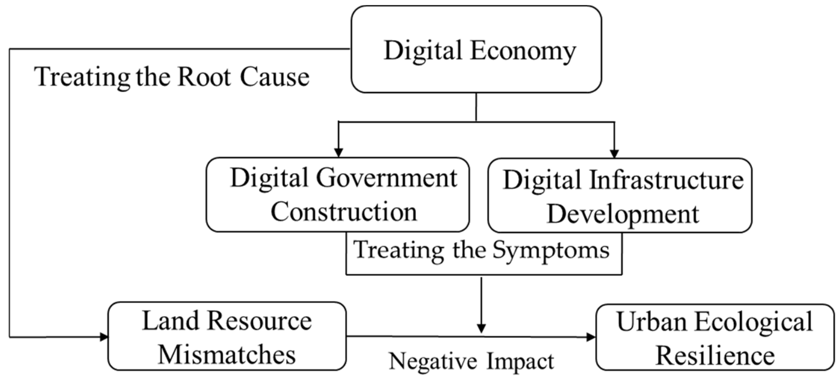


Figure 4. Theoretical mechanism.

3. Research Design

3.1. Data

This study focuses on 280 cities at prefectural level and above in mainland China, with the research period spanning from 2007 to 2021. The data utilized primarily comes from the *China Urban Statistical Yearbook*, *China Regional Statistical Yearbook*, *China Energy Statistical Yearbook*, provincial and municipal statistical yearbooks, and the Wind and CSMAR databases. After deleting the missing values, 3221 sample data were obtained. In addition, this study shrinks UER and LRM by 1% and 99%.

3.2. Model Setting

3.2.1. Benchmark Regression Model

This study firstly needs to empirically test the negative impact of LRM on UER, and the model is constructed as follows:

$$UER_{it} = \alpha_1 + \beta_1 LRM_{it} + \gamma_1 \sum Controls_{ijt} + \mu_i + \delta_t + \varepsilon_{it} \quad (1)$$

where i denotes the city; t denotes the period; j denotes the type of control variable; μ_i and δ_t denote the individual fixed effects and time fixed effects; and ε_{it} denotes the random perturbation term.

3.2.2. "Root Causes" Channel Model

To analyze the effect of the DE on UER through the mechanism of reducing LRM, this study employs two-step method to strengthen the causal interpretation of the variables [76]. The model is constructed as follows:

$$UER_{it} = \alpha_3 + \beta_3 DigEco_{it} + \gamma_3 \sum Controls_{ijt} + \mu_i + \delta_t + \varepsilon_{it} \quad (2)$$

$$LRM_{it} = \alpha_4 + \beta_4 DigEco_{it} + \gamma_4 \sum Controls_{ijt} + \mu_i + \delta_t + \varepsilon_{it} \quad (3)$$

That is, in the first step, the role of the DE in improving UER is tested through empirical analyses; the second step is to verify the role of the DE in improving UER through testing the negative impacts of DE on LRM, which can be argued that the DE has the effect of "treating the root causes" on UER [77].

3.2.3. "Symptoms" Channel Model

To investigate whether the DE can mitigate the impact of LRM on UER, this study constructs a moderating effect model, outlined as follows:

$$UER_{it} = \alpha_5 + \beta_5 LRM_{it} + \varphi LRM_{it} \times Digital_{it} + \mu Digital_{it} + \gamma_5 \sum Controls_{ijt} + \mu_i + \delta_t + \varepsilon_{it} \quad (4)$$

Digital represents DE-related variables that mediate between LRM and UER, including digital government construction (DigGover) and digital infrastructure development (DigInfra).

3.3. Variable Definitions

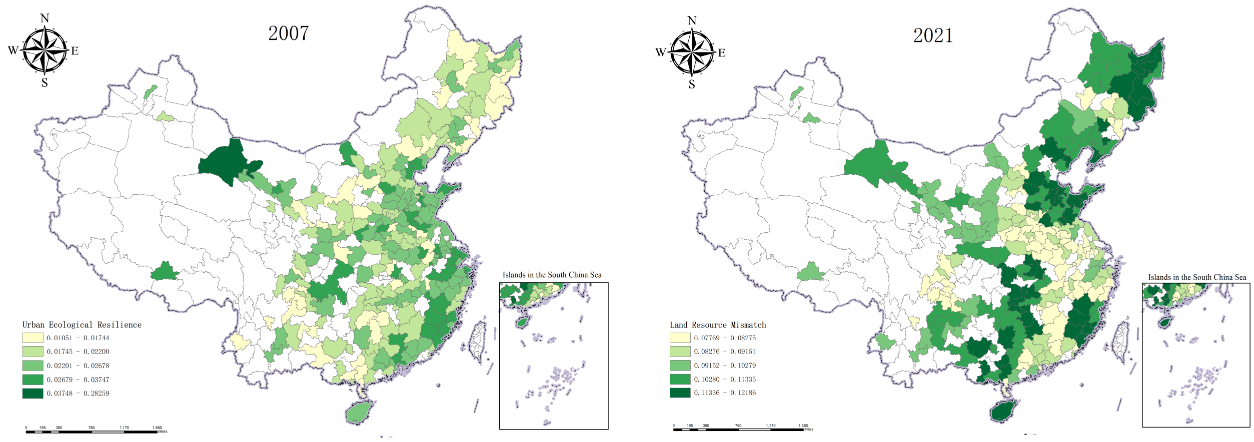
3.3.1. Urban Ecological Resilience

The explanatory variable in this study is the UER index, which primarily assesses the overall effectiveness of constraining pollution emissions, preserving ecological status, and enhancing governance capacity within a city's ecological environment system in the face of pressure or sudden shocks. Considering the economic and social characteristics of the city, while referring to the existing literature [52,78,79] for the assessment method of ecological resilience, this study deconstructs the UER into three sub-dimensions (PSR framework) of state resilience, pressure resilience, and response resilience, totaling 14 tertiary indicators, which are specifically measured in Table 1. Given the varying positive and negative impacts of different indicators on the overall resilience index, this study employs dimensionless normalization of the indicator values. By utilizing the entropy value method to assign weights, we can comprehensively evaluate the ecological resilience index for each city.

Table 1. Indicator system used for the assessment of the UER based on the PSR model.

Primary Indicators	Secondary Indicators	Tertiary Indicators	Properties
UER	Urban pressure resilience	Industrial wastewater discharge per capita	Negative
		Industrial sulfur oxide emissions per capita	Negative
		Industrial soot emissions per capita	Negative
		Industrial nitrogen oxides per capita	Negative
		Average concentration of PM2.5	Negative
	Urban state resilience	Water resources per capita	Positive
		Greening coverage in built-up areas	Positive
		Green space per capita in municipal districts	Positive
		Built-up area per capita in municipal districts	Positive
	Urban response resilience	Industrial sulfur dioxide removal	Positive
		Industrial fume removal	Positive
		Non-hazardous domestic waste disposal rate	Positive
		Centralized treatment rate of sewage treatment plants	Positive
		Comprehensive industrial solid waste utilization rate	Positive

After computing the UER using the entropy value method, this study illustrates the spatial distribution of UER for the years 2007 and 2021. As illustrated in Figure 5, there is a pronounced disparity in the spatial distribution of UER between the east-central and western regions. Notably, the UER in the eastern and central regions has seen a substantial increase from 2007 to 2021, indicating a significant enhancement in the ecological resilience of Chinese cities over the past fifteen years.



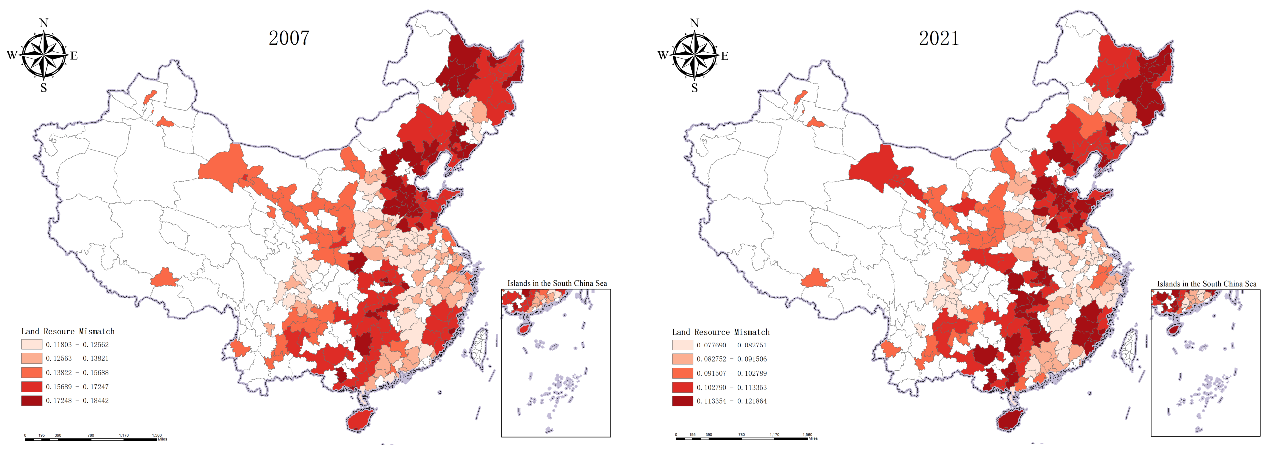
(**a**) (**b**)

Figure 5. Spatial distribution of UER in China. (**a**) Spatial distribution of UER in China in 2007; (**b**) Spatial distribution of UER in China in 2007.

3.3.2. Land Resource Mismatch

This study's theoretical framework is predicated on the observation that industrial land concessions at reduced prices in cities are a predominant characteristic. Additionally, the practice of granting land through agreements is frequently associated with LRM. In this study, we adopt the methodology outlined in the mainstream literature [80,81] and utilize the ratio of the land area granted through agreements to the total area of newly allocated land as the explanatory variable. When the proportion of land allocated through agreements relative to the total land granted in a city is elevated, the city is more susceptible to extensive land utilization by development zones and reduced entry barriers for enterprises. This situation can subsequently result in LRM.

Here, the distribution of LRM in 2007 and 2021 is also plotted to visualize the distribution of this phenomenon across different regions. As illustrated in Figure 6, the LRM phenomenon exhibits an uneven spatial distribution across the eastern–central and western regions. Compared with 2007, the degree of LRM in the east and center in 2021 is reduced, indicating that the degree of LRM has improved in the last 15 years. Considering the observed enhancement in UER over the past fifteen years, it is pertinent to explore whether there exists an intrinsic connection between this improvement and the aforementioned factors. If such a link is present, identifying the key drivers of this positive change becomes crucial.



(**a**) (**b**)

Figure 6. Spatial distribution of LRM in China. (**a**) Spatial distribution of LRM in China in 2007; (**b**) Spatial distribution of LRM in China in 2007.

3.3.3. Digital Economy

The DE, as the most rapidly developing, innovative, and widespread new form of economic activity, has become a key development direction for smart city construction. Smart cities are the key carriers for unleashing the vitality of the DE and promoting innovative development of the DE. The two complement each other and jointly promote social and economic development. Therefore, referring to the research method of Wang and Zhong (2023 [82]), this article selects the pilot policy of smart cities as a proxy variable for the DE, denoted as DigEco.

3.3.4. Control Variables

Leveraging the pertinent mainstream literature, this study incorporates several control variables: the degree of economic development (EcoDev), the rate of economic growth (EcoGrow), the extent of government intervention (GovInt), the intensity of foreign capital (ForeCap), the level of financial development (FinDev), and the scale of social consumption (SocCon). The variables addressed in this study are detailed in Table 2.

Table 2. Main variable definition.

Variable Type	Variable Name	Variable Construction
Explanatory variable	UER	Assign values to multiple sub-indicators in the state–pressure–response dimensions by the entropy weighting method.
Explanatory Variable	LRM	The percentage of the newly agreed-upon land area relative to the total new land area transferred in each region.
Mechanism Variables	DigEco	If a city is designated as a Smart City Pilot in the current year, it is assigned a value of 1 for that year and for all subsequent years; otherwise, it is assigned a value of 0.
	DigGover	The variable is a dummy variable that assigns a value of 1 to Beijing, Shanghai, Zhejiang, Fujian, and Guizhou for the entire 18-year period and to subsequent years while assigning a value of 0 to all other regions.
	DigInfra	The index of digital infrastructure is constructed by using entropy planting method from two dimensions of input and output.
Control variables	EcoDev	Natural logarithm of total regional GDP.
	EcoGrow	Total regional GDP growth rate.
	GovInt	Expenditures in the general budget of local finances divided by GDP.
	ForeCap	Amount of foreign capital actually used in the year divided by GDP.
	FinDev	The balance of loans from financial institutions at the end of the year is divided by GDP.
	SocCon	Total retail sales of consumer goods divided by GDP.

4. Empirical Results

4.1. Descriptive Statistics

Table 3 reveals substantial variation in UER across regions, with the maximum value being ten times greater than the minimum value; the mean LRM value was 0.124, indicating that 12.4% of the annual new land concessions by agreement; the DE development index (DigEco) of regional differences is also large, with a standard deviation of 0.747.

Table 3. Descriptive statistics.

Variable	N	Mean	Min	Max	p50	SD
UER	3221	0.0278	0.0105	0.283	0.0270	0.0102
LRM	3221	0.124	0.0821	0.184	0.121	0.0236
DigEco	3221	0.183	0	1	0	0.387
DigGover	3221	0.168	0	1	0	0.128
DigInfra	3221	0.286	0.005	0.357	0.220	0.267
EcoDev	3221	16.39	13.65	19.76	16.32	0.946
EcoGrow	3221	0.107	−0.194	1.090	0.106	0.0460
GovInt	3221	0.175	0.0437	2.223	0.155	0.0905
ForeCap	3221	0.0029	1.62×10^{-06}	0.019	0.002	0.00278
FinDev	3221	0.881	0.112	7.450	0.702	0.563
SocCon	3221	0.368	3.11×10^{-05}	0.996	0.359	0.104

4.2. Benchmark Regression

The existence test of LRM and UER is presented in Table 4 below. The results show that the coefficients for LRM are significantly negative, irrespective of the inclusion of control variables. This indicates that LRM consistently leads to a significant decline in UER. This finding not only underscores the significance of optimal land resource allocation in preserving urban ecological security but also emphasizes the urgency and necessity of undertaking further research to devise effective strategies for mitigating these adverse impacts. Based on this finding, this study innovatively introduces the DE perspective, aiming to explore the potential and path of the DE as an emerging force in mitigating the negative impacts of LRM on UER. This shift in perspective not only enriches the theoretical understanding of land resource management and UER but also offers new insights and directions for future policy development and practical exploration.

Table 4. Benchmark regression.

	(1)	**(2)**
VARIABLES	**UER**	**UER**
LRM	−0.0264 **	−0.0265 **
	(−2.40)	(−2.41)
Constant	0.0307 ***	0.0324 ***
	(22.47)	(21.06)
Observations	3221	3221
R-squared	0.780	0.784
Controls	NO	YES
City FE	YES	YES
Year FE	YES	YES
r2_a	0.759	0.762
F	5.749	6.266

Note: Robust t-statistics in parentheses; *** $p < 0.01$, ** $p < 0.05$.

4.3. Robustness Tests

4.3.1. Change the Sample Time Interval

Due to the "Limited Purchasing Order" and "Three Red Lines policy", the number of land acquisitions by Chinese real estate firms and others has changed significantly; consequently, this study excludes the 2010 and 2020 samples, with the regression results presented in columns (1) and (2) of Table 5. The findings remain significant at the 5% level, regardless of whether control variables are included.

Table 5. Robustness tests.

	(1)	(2)	(3)	(4)	(5)
VARIABLES	UER	UER	UER	UER	UER
LRM	−0.0231 **	−0.0233 **			
	(−1.98)	(−2.01)			
LRM2			−0.0041 ***	−0.0041 ***	
			(−3.56)	(−3.58)	
LRM3					−0.0008 **
					(−2.15)
Constant	0.0305 ***	0.0248 **	0.0283 ***	0.0265 **	−0.0017
	(21.13)	(2.14)	(127.76)	(2.35)	(−0.10)
Observations	2951	2951	2885	2885	1548
R-squared	0.786	0.790	0.781	0.784	0.820
Controls	NO	YES	NO	YES	YES
City FE	YES	YES	YES	YES	
Year FE	YES	YES	YES	YES	YES
r2_a	0.763	0.767	0.756	0.760	0.778
F	3.902	6.122	12.70	8.145	2.777

Note: Robust t-statistics in parentheses; *** $p < 0.01$, ** $p < 0.05$.

4.3.2. Replacement of Explanatory Variables

Building upon the existing literature on LRM, this study utilizes the ratio of industrial land area to urban built-up area as a proxy variable (LRM2). The regression results reveal that the coefficient for LRM2 remains significantly negative, as shown in columns (3) and (4) of Table 5, regardless of the inclusion of control variables. This indicates that the new LRM indicator continues to exhibit a significant negative correlation with UER.

4.3.3. PSM Test

To exclude the influence of control confounders, this study employed PSM approach to match samples based on the degree of LRM. Samples exceeding the mean value were designated as the treatment group (LRM3), while the other samples were categorized as the control group. A 1:1 nearest neighbor matching without replacement was performed according to the control variables. The propensity score plots before and after matching, as depicted in Figure 7, illustrate a significant reduction in the characteristic disparities between the treatment and control groups, thereby indicating the success of the matching process. The regression results, displayed in column (7) of Table 5, reveal that the coefficient for LRM3 remains significantly negative, corroborating the findings from the benchmark regression.

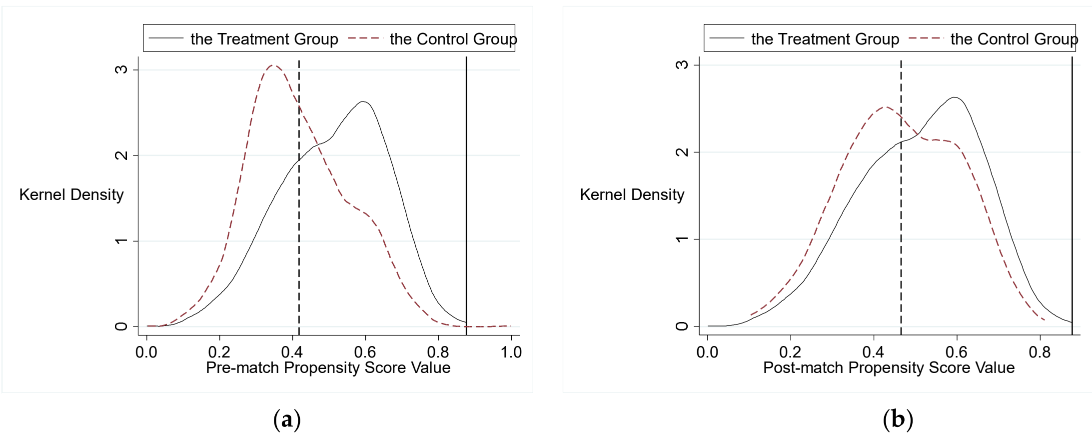


Figure 7. Propensity score plots before and after matching. (**a**) Propensity score before PSM matching; (**b**) Propensity score after PSM matching.

4.4. Heterogeneity Tests

4.4.1. City Scale

To investigate the heterogeneous impact of city size on the decline in UER resulting from LRM, this study classifies cities into megacities and non-megacities based on their permanent resident population, using a threshold of 5 million residents. The regression results are presented in columns (1) and (2) of Table 6. In comparison to non-megacities, LRM has a more pronounced adverse effect on UER within megacities. This heightened impact is attributable to the population agglomeration effects and the intense economic activities characteristic of megacities [53]. LRM exacerbates these pressures, resulting in a deterioration of UER.

Table 6. Heterogeneity tests.

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
	Megacities	**Non-Megacities**	**High Economic Development**	**Low Economic Development**	**High Industrial Structure**	**Low Industrial Structure**
VARIABLES	**UER**	**UER**	**UER**	**UER**	**UER**	**UER**
LRM	−0.0728 ***	−0.0078	−0.0344 **	−0.0144	−0.0116	−0.0331 **
	(−3.81)	(−0.60)	(−2.04)	(−1.00)	(−0.70)	(−2.40)
Constant	0.0326	0.0244 **	0.0360 *	0.0393 ***	0.0112	0.0063
	(1.24)	(2.05)	(1.77)	(2.78)	(0.60)	(0.37)
Observations	1048	2169	1480	1717	1178	2005
R-squared	0.815	0.762	0.795	0.764	0.884	0.791
Controls	YES	YES	YES	YES	YES	YES
City FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
r2_a	0.792	0.735	0.762	0.727	0.856	0.761
F	2.845	6.457	3.968	2.359	4.201	3.580

Note: Robust t-statistics in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

4.4.2. Level of Economic Development

The economic development level of cities is identified as a crucial factor contributing to heterogeneity in the assessment of the impact of LRM on UER. This study classifies cities into two categories based on per capita GDP: cities with per capita GDP exceeding the mean are designated as exhibiting a high level of economic development, while those with per capita GDP falling below the mean are categorized as having a low level of economic development. The results, as detailed in columns (3) and (4) of Table 6, demonstrate that LRM exerts a more severe detrimental impact on ecological resilience in regions characterized by high levels of economic development. As noted in the previous section, local governments have historically relied on "land finance" to boost GDP growth. While this approach may yield short-term economic benefits, it exacerbates LRM in the long term, encroaches upon ecological land, and further heightens the vulnerability of the urban ecological environment.

4.4.3. Industrial Structure

As demonstrated by Peng et al. (2022 [44]), LRM has emerged as a critical factor constraining the transformation and upgrading of industrial structures, particularly in cities dependent on low-end manufacturing industries characterized by high pollution and energy consumption, which leads to significant environmental pressure [83]. Conversely, cities with advanced industrial structures typically exhibit enhanced resource utilization efficiency and reduced environmental pollution, contributing to the stability and self-recovery capacity of urban ecosystems, thus improving UER. Consequently, this study employs the ratio of the value added by the tertiary industry to the value added by the secondary industry as a measure of industrial structure advancement and categorizes the sample into two groups based on the mean value: high and low levels of industrial structure advancement. The results, presented in columns (5) and (6) of Table 6, indicate that cities with a low level of industrial structure advancement experience a more pronounced negative impact from LRM compared to cities with a high level of industrial structure advancement.

5. Further Analysis

5.1. "Root Causes" Channel Tests

The preceding theoretical analysis indicates that the DE, through its extensive application of communication technologies and the deep integration of digital innovations, possesses the capability to rectify LRM, thereby improving the efficiency of land resource distribution. This advantage directly hit the root of the LRM problem, which is expected to fundamentally reverse the adverse consequences of LRM and provide a cure for the enhancement of UER. The empirical results of the DE "treating the root causes" channels are shown in Table 7. The first column demonstrates that the DE contributes to reducing the extent of urban LRM, while the second column indicates that the DE enhances UER by mitigating LRM.

Table 7. "Root causes" channel tests.

	(1)	**(2)**
VARIABLES	**LRM**	**UER**
DigEco	−0.0007 **	0.0019 ***
	(−2.00)	(3.37)
Constant	0.0944 ***	0.0926 ***
	(5.45)	(2.67)
Observations	3221	3221
R-squared	0.936	0.528
Controls	YES	YES
City FE	YES	YES
Year FE	YES	YES
r2_a	0.930	0.480
F	3.853	3.360

Note: Robust t-statistics in parentheses; *** $p < 0.01$, ** $p < 0.05$.

5.2. "Symptoms" Channel Tests

5.2.1. Digital Government Construction

Against the backdrop of today's booming DE, the government's governance capacity is accelerating its transformation towards digitization and intelligence. Open government data resources, as a pivotal initiative for revolutionizing government effectiveness, exert profound impacts across various dimensions—political, economic, social, and cultural. They have emerged as a vital catalyst in augmenting governance capacity. This study examines the landmark policy document, *Pilot Program for Open Public Information Resources*, which seeks to establish a unified open data platform system. This initiative involves five pioneering provinces and cities implementing the program, with the goal of developing replicable practices that will be scaled and promoted nationwide. To explore how the development of digital government can alleviate the adverse effects of LRM on UER, a dummy variable (DigGover) representing the openness of public information resources is introduced and incorporated into the "symptoms" channel model.

The results, presented in column (1) of Table 8, reveal a significantly positive interaction term for LRM × DigGover, which validates hypothesis H3. The development of digital government can effectively mitigate the challenges to UER caused by LRM, thereby providing substantial evidence and support for enhancing a city's capacity to withstand external shocks and ensuring sustainable urban development.

Table 8. "Symptoms" channel tests.

	(1)	(2)
VARIABLES	**UER**	**UER**
LRM	−0.0235 **	−0.0358 ***
	(−2.19)	(−3.12)
LRM × DigGover	0.0553 ***	
	(2.74)	
DigGover	−0.0040 *	
	(−1.90)	
LRM × DigInfra		0.5520 ***
		(3.43)
DigInfra		−0.0652 ***
		(−3.56)
Constant	0.0324 ***	0.0285 **
	(21.36)	(2.48)
Observations	3221	3221
R-squared	0.788	0.783
Controls	YES	YES
City FE	YES	YES
Year FE	YES	YES
r2_a	0.767	0.761

Note: Robust t-statistics in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

5.2.2. Digital Infrastructure

Digital infrastructure, as essential hardware for the development of the DE, is critical for driving social progress and sustainable development. The DE relies on an efficient and well-structured digital infrastructure system to create a synergistic effect [72] and collaboratively advance the achievement of various digital strategic objectives. The preceding theoretical analysis demonstrates that digital infrastructure can significantly enhance land use efficiency [73], thereby mitigating the adverse effects of LRM on UER. This study adopts the research methodology of Yang et al. (2023 [84]) and other relevant approaches and constructs digital infrastructure index from the two dimensions of input and output (DigInfra). This variable is incorporated into the "symptoms" channel model to examine its moderating effect and to explore the specific mechanisms and effectiveness of digital infrastructure in improving UER.

The results, presented in column (2) of Table 8, indicate that the interaction term LRM × DigInfra demonstrates that the digital infrastructure can effectively mitigate the vulnerability of UER caused by LRM, thereby validating hypothesis H4.

6. Conclusions and Policy Implications

6.1. Conclusions

Building upon the premise that LRM leads to a decline in UER, this study explores the potential role of the DE in mitigating this adverse effect. It proceeds from two core perspectives: first, decreasing the extent of LRM, which aims to address the root causes of the negative impacts on UER, i.e., the "treating the root causes" approach; and second, mitigating the extent of the negative impacts of LRM on UER through the moderating role of the DE, i.e., the "treating the symptoms" approach. Firstly, the empirical research presented in this study confirms that urban LRM significantly diminishes UER. Therefore, it is imperative to address urban LRM, and this conclusion is substantiated through a series of robustness tests. Additionally, the detrimental impact of LRM on UER is particularly pronounced in megacities, cities with high levels of economic development, and cities with less advanced industrial structures. Secondly, the development of the DE can improve LRM, thereby improving UER, which has the effect of "treating the root causes". Finally, digital government and digital infrastructure, which are crucial elements of the DE, can exert a moderating effect in alleviating the decline in UER resulting from urban LRM, thus providing a symptomatic remedy.

6.2. Policy Suggestions

UER requires attention. The urban ecological environment is the foundation of sustainable urban development and an important line of defense against natural and man-made disasters, especially at a time when extreme weather and natural disasters occur frequently. Local governments should pay attention to the stability and restoration of urban ecology, avoiding the encroachment and cutting of urban ecological resources by urban construction sites, and paying extra attention to environmental and ecological monitoring to ensure that ecological sites play their role as ecological barriers, blocking the impact of unfavorable factors and disasters.

The negative impact of land resource allocation on UER should be emphasized. First, it is necessary to ensure that the market, rather than the government, plays a leading role in land resource allocation, and that land elements are efficiently and equitably allocated. Secondly, governments at all levels should do a good job and strictly implement a land use master plan to prevent the disorderly expansion of industrial land. Finally, the performance appraisal mechanism needs to be reformed. The government should incorporate ecological environmental protection into the appraisal system, which will help guide local governments to change from "land for development" to "quality for development", and ultimately realize high-quality economic development and sustainable development.

The heterogeneous impact of land resource allocation on UER also deserves to be emphasized. First, megacities should pay special attention to maintaining regional ecological resilience, accelerating the remediation of shortcomings in resilience, and improving emergency response capacity. Second, cities with high economic development should change their development mode and optimize their industrial layout. Finally, cities with a low level of industrial structure should accelerate the advancement of energy conservation and environmental protection, clean production, clean energy, ecological environment, green services, and other industries, so as to realize the transformation of urban industries into green and energy-saving ones.

It is essential that the impact of the DE on land resource allocation and UER should be emphasized. On the one hand, digital government construction should be continuously promoted. The construction of digital government is not only an innovation at the technical level, but also a profound change in the concept and mode of governance. Governments at all levels should attach great importance to accelerating the comprehensive opening and sharing of public information resources, building a unified and efficient data open platform to enhance the scientific and transparent nature of government decision making, and providing data support for enterprise technological innovation and public participation. On the other hand, the strategic position of digital infrastructure should be strengthened. Governments at all levels should recognize the importance of digital infrastructure for the development of DE, and build a comprehensive, efficient, and convenient digital infrastructure systems by increasing investment and optimizing resource allocation. In addition, attention should be paid to the assessment and enhancement of eco-efficiency in the construction of digital infrastructure.

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