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RESEARCH ARTICLE

Environmental Regulation and Urban Land Green Use Efficiency: China as Case Study

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Abstract: China's economy has shifted from high-speed growth to high-quality development, and the constraints of high consumption, high pollution, and low efficiency in urban land use on sustainable urban economic development have gradually emerged. In the process of urban land resources development, it is urgent to get rid of the traditional "sloppy" utilization method and shift to the green utilization of urban land with low consumption, low pollution, and high efficiency, which can adapt to the requirements of economic and social development in the new era. Based on this, this paper investigates the effect of environmental regulations (ERs) on urban land green use efficiency (ULGUE) by using slack-based model, two-way stationary panel regression and threshold regression model. The results show that: (1) the connection between ER and ULGUE is strongly U-shaped. (2) Within the bounds of land use structure optimization effect, technology innovation effect, industrial structure optimization, and upgrading effect, ER significantly impacts ULGUE. Still, its threshold impact coefficient has a gradient-decreasing characteristic. (3) In the heterogeneity analysis, the effect of ER on ULGUE is more evident in eastern cities, low-pollution cities, Type II, and large cities of Type I scale. Hence, in order to maximize the effectiveness of land use, it is essential to understand the environmental restrictions that cover a realistic spectrum, play the interactive and synergistic role of "combination box," and adjust the intensity of dominant ERs dynamically and flexibly according to the time and place.

Keywords: environmental regulation, ULGUE, inverted U-shape, threshold effect, heterogeneity

1. Introduction

Urban land green use efficiency (ULGUE) is a measure of how closely the urban land use systems are coupled and a key indicator to measure the rational allocation and efficient use of production causes for the sake of high-quality growth (Yu et al., 2019). Enhancing ULGUE is important for the economy and society's evolution (Liu et al., 2019). The People's Republic of China's Land Management Law mandates intensifying economic use of land to increase the efficiency of land usage. The regulations on Urban Green Space of China similarly stipulate building and protecting urban parks and other public green places, green areas, squares, and street greening to enhance the quality of the city ecological environment. As a part of urban renewal, residential and industrial land, and commercial land occupy the majority of the land. In contrast, the allotment of property for service facilities, green, and water areas is relatively small. The continuous expansion and disorderly construction land use severely threaten the urban ecological environment and sustainable development. Therefore, there is an urgent need to protect urban ecosystems, enhance urban air quality and water utilization efficiency, and optimize land use to reduce pollution and carbon emissions.

As the economy continues to develop and ecological and environmental awareness take root, environmental management in China has become a national development strategy (Wang et al., 2023). But the "2020 China Ecological Environment Status Bulletin" reports that 135 of China's 337 prefecture-level and higher cities have air quality that is unsafe for human health. Developing and putting into practice the thought that "green mountains and water are golden mountains," strengthening ER, reducing environmental pollution, and fostering quality economic growth in China require discussing the importance of developing a beautiful China with blue skies, green land, and clean water. Recent years have seen a number of initiatives from the Chinese government aimed at protecting the environment. These include the "Air Pollution Prevention and Control Action Plan," the "Water Pollution Prevention and Control Action Plan," and the "Soil Pollution Prevention and Control Action Plan." Thus, the urgency, strictness, and necessity characteristics of ER have penetrated all aspects of the progress of China's economy and society and have grown to be an essential factor in China's modernization's success.

As ER can effectively enhance the transparency of environmental information and avoid information asymmetry, it can better encourage local governments and the public to understand the pollution status of the urban environment and accordingly restrict the environmental damage behavior of polluting enterprises.

Local governments and the public have an overall understanding of the pollution status of the urban environment and accordingly restrict the environmentally damaging behavior of polluting enterprises and encourage the development of technological industries and service industries based on clean production. This can not only effectively

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reduce the ecological and environmental risks of urban land use but also promote the transformation of new and old kinetic energy in land space, optimize the urban land use structure, and ultimately enhance the efficiency of green urban land use. Hence, how to use environmental protection means to integrate ecological code and ULGUE development, and how to make use of the characteristics of strict ER and not subject to regional constraints to improve the level of ULGUE have grown into a significant problem that has to be resolved immediately. Based on this, this paper analyzes how ER affects ULGUE in today's high-quality growth in the economy and what are the transmission mechanisms from the theoretical level and the empirical analysis. Are there regional heterogeneity and environmental pollution heterogeneity? By exploring these questions, it will be helpful to grasp whether and how ER impacts ULGUE and provides new marginal experiences for achieving balanced economic and ecological development.

The research contribution of this paper: In terms of research content, this paper explores the impact of ER on the ULGUE, which enriches the existing literature; in terms of research methodology, this paper uses entropy method to measure the environmental regulation (ER) indicators from the perspective of solid, liquid, and gas emissions; and in terms of the research samples, this paper applies the data of prefecture-level cities, which provides a strong empirical experience and supplements the research in the field of urban land use.

The remainder of this paper is organized as shown below. The second part examines the pertinent literature. The pertinent research hypotheses are presented in the third section through theoretical analysis. The fourth section expresses the econometric model, variable selection, and data sources. The fifth part conducts an empirical study based on the hypotheses. The sixth section summarizes the research conclusions and provides policy recommendations, clarifies the paper's flaws, and identifies areas for further study.

2. Literature Review

2.1. Environmental regulation

In the extensive literature on ER, scholars have studied the Porter hypothesis with government ecological regulation as the independent variable (Cai & Ye, 2020), but the empirical and theoretical findings are still controversial. For example, Lanoie et al. (2008) argue that total factor production drops when governments intervene in the environment based on data from the manufacturing sector in Quebec. In contrast, Rubashkina et al. (2015) found the opposite of this finding in the European manufacturing industry by the instrumental variables method. Ouyang et al. (2020) argue that government restrictions in environment significantly increase firms' innovation inputs but have no significant effect on innovation output. In order to comply with ERs, firms need to invest more resources in environmental management, emission reduction measures, etc. This may lead to limited resource deployment by firms in R&D and innovation, thus affecting the growth of innovation output (Lee et al., 2015). And at the level of ER indicator measurement methods, some scholars used a single-indicator measure of ER intensity, such as ER policy (Han, 2020), ecological governance inputs (Dong et al., 2020), and ecological policy performance indicators (Hezri & Dovers, 2006). Li and Ramanathan (2018) categorized environmental laws into three groups and figured out how different tools for environmental control affect the efficiency of saving energy and cutting down on pollution.

2.2. Urban land green use efficiency

Most literature examines the advantages of land usage in particular administrative districts, such as agricultural production benefits (Yang et al., 2010), industrial production benefits (Azunre et al., 2019), urbanization level (Zhang et al., 2021a), land use intensity (Zhong et al., 2018), etc. At the same time, much literature also has to explore the factors affecting ULGUE, mainly including the natural environment (Tu et al., 2014), policies (Vejchodská et al., 2022), regulations (Dempsey et al., 2017), demographic characteristics (Min et al., 2021), economic factors (Chen et al., 2019), etc. Since improving ULGUE is the key to achieving long-term development, the focus of study in recent years has also shifted to ways to increase land use efficiency. ULGUE is an essential factor affecting progress that is both economically and socially sustainable. In future research, the evaluation indexes and influencing factors of ULGUE should be further explored in depth, and ULGUE should be improved through various ways to promote sustainable development and integrated urban and rural evolution.

2.3. Government ER and ULGUE

As a scarce and vital resource to promote national economic development, there is a dearth of literature regarding the influence of ER on ULGUE, and there is little literature linking the two. The indirect results, including the extremely efficient slack-based model (SBM) and Tobit models used by Xue et al. (2022) found that ER influences ULGUE. Song et al. (2018) intend to determine if China's "new normal" economy can encourage environmentally oriented technical growth to boost the efficiency with which industrial land is put to use. Hence, the measuring method for ER and ULGUE is built in this study based on the former study, combines theory and empirical evidence, explores the direct effect, nonlinear characteristics, and threshold impact of ER on ULGUE, and further examines locational heterogeneity, environmental pollution heterogeneity, and urban size heterogeneity to achieve theoretical and practical significance in exploring the influence of ER on effective land use.

2.4. Research review

The Brundtland Report, an important document released by the United Nations Commission on Sustainable Development, known as the Our Common Future report, called for measures to promote green development and sustainable land use in cities, including improving energy efficiency, reducing pollution and waste generation, and protecting ecosystems (Schubert & Láng, 2005). It placed the focus of ER on sustainable urban development and green land efficiency enhancement, providing a basis and reference for the subsequent development and implementation of ER (Burns & Witoszek, 2012). At present, the domestic and international research results and literature on ER and ULGUE have been relatively abundant. The research theories and technical methods are relatively advanced, and some constructive research results also provide effective references for urban planners to scientifically and reasonably develop and use land resources. Based on this, this paper stands on the shoulders of the predecessors, with the help of the mature research results and research experience of the predecessors, and carries out certain pioneering and innovation.

3. Analytical Theory and Research Hypothesis

3.1. The direct effect of ER on ULGUE

Initially, it should be noted that the implementation of ER has been found to enhance the safeguarding of arable land resources (Lu et al., 2021). Consequently, this leads to a reduction in the availability of land for construction purposes (Zhang & Li, 2020). As a result, the supply of industrial land diminishes, thereby impeding the expansion of industrial space and hindering the development of regional industrial economies. Moreover, this limitation also restricts the ability of local governments to attract investment at a desirable pace, ultimately resulting in a more pronounced decline in marginal output and reduced efficiency in land utilization. Second, governmental land use regulations will become more stringent as a result of the implementation of severe environmental protection measures (Allred et al., 2021), reducing the supply of industrial land and other developers by local governments (Lan et al., 2023), which will, to some extent, minimize land concession revenue and tax revenue, inhibit regional revenue increase, and reduce the contribution of government spending on local economic development. As a result, the land usage efficiency is decreased. However, over the long term, ER will contribute to the reform and revitalization of unreasonable and inefficient land use (Wang et al., 2022), control the scale of construction land (Wang et al., 2021), promote the economic and intensive use of land, and improve government performance (Graafland & Smid, 2017) and the effectiveness of site use for construction (Ma et al., 2020). Strict land policies can drastically alter where people live, improve regional land use planning and reorganization of industry, and promote high-caliber economic growth. Using the analysis above, this paper puts forth Hypothesis 1:

Hypothesis 1: ER has a "U"-shaped effect on ULGUE, initially lowering and then increasing.

3.2. Analysis of the mechanism of ER affecting ULGUE

3.2.1. Land use structure optimization effect

By directing the most valuable uses of land, ER boost ULGUE and encourage the use of intensive lands such as existing towns and industrial land. Firstly, the formulation of policies to regulate the allocation of space for urban development and urban renewal (Cai & Peng, 2021) is crucial. These policies should guide developers and urban planners to prioritize existing sites within cities, while discouraging the construction of new urban areas in remote locations. Implementing such measures can effectively maximize the productive potential of land and enhance land use efficiency. Secondly, it is important to encourage enterprises to optimize industrial land conversion and enhance the efficiency of industrial production and land utilization (Gao et al., 2020). In addition, there should be enhanced supervision of land use and appropriate penalties for entities and individuals who do not utilize land resources in a rational manner. These measures will ensure the effective utilization of resources. Finally, improving land efficiency is facilitated by accelerating urban–rural integration, including low-utility land in rural areas in the scope of urban planning, and encouraging urban–rural integration (Liu et al., 2016).

However, with the progress of economic and social development, high-quality land resources are becoming increasingly scarce, making land development more challenging. Moreover, certain traditional industries pose significant environmental pollution concerns and necessitate treatment, transformation, and upgrading. These processes often require substantial time and costs, with potential implications for local employment and the economy. As a result, this may lead to a weakening influence of ERs. Using the analysis above, this paper puts forth Hypothesis 2:

Hypothesis 2: Through the optimization of land use structure, ER can enhance ULGUE, but its influence tends to wane.

3.2.2. Science and technology innovation effect

ER realizes efficient utilization of land resources through smart city construction. First, the government can introduce a land use regulation system in the construction of smart cities to efficiently use land resources through comprehensive and refined management of land resources. The system can conduct real-time monitoring and data analysis of land use and provide relevant departments with empirical decision-making support (Han et al., 2022). Second, environmental protection departments can increase investment in public transportation (Moudon et al., 2011), such as rail transit, in constructing smart cities to encourage people to use public transport to travel, thus reducing the number of motor vehicles and saving land resources. Finally, environmental protection requires encouraging cities to implement green and low-carbon buildings (Huo et al., 2019).

Despite the vital role of science and technology in ER, there are still some technical difficulties and challenges. For example, data collection and processing, model prediction and analysis for land regulation, and assessment require more advanced and efficient methods (Li et al., 2019). Meanwhile, there is still a lack of coordination between current environmental policies and regulations and a lack of supporting mechanisms (Banerjee et al., 2021), and how to link various policies together to form a systematic means for environmental protection requires more in-depth research and improvement. Therefore, this paper puts forth Hypothesis 3:

Hypothesis 3: Environmental regulation can improve ULGUE through technological innovation and the strength of the effect becomes slower with time.

3.2.3. Industrial structure upgrading effect

ER promotes ELGUE through industrial structure modernization. First, some non-dominant businesses may benefit from a regulatory push toward technological advancement and increased value creation if environmental standards are tightened (Song et al., 2021), this reduces the occupation and consumption of land resources, improves the synergy effect among sectors, and succeeds in creating an eco-friendly economy and developing sustainably. Secondly, ER can strengthen the control of pollutant emissions of enterprises (Wei et al., 2021), prompt them to adopt more environmentally friendly production methods, and reduce the pressure on land resources. Finally, ER can improve the land evaluation mechanism, rationalize land allocation according to productivity, and efficiently use land resources.

However, because of ongoing improvements to the manufacturing infrastructure, many traditional industries have been eliminated or disappeared. Coupled with enterprises to achieve higher environmental standards and requirements, enterprises need to increase environmental protection investment, including the transformation of equipment, upgrade processes, procurement of environmentally friendly materials, etc.; these environmental protection investments will also increase the financial burden on businesses (Qiao et al., 2022). Therefore, this paper therefore proposes Hypothesis 4:

Hypothesis 4: Environmental regulations can improve ULGUE by upgrading the industrial structure and the strength of the effect becomes slower with time.

4. Methods and Data

4.1. SBM model

ULGUE refers to the return generated by various types of capital invested in a unit of land area and the ecological cost borne by a unit of land under that return. In this paper, taking into account the impact of adverse environmental externalities, the SBM model with unexpected output under the assumption of continuous payoffs of scale is built to assess ULGUE, following the research method of Lee (2021). Its expression is

$$min \frac{1-\frac{1}{N}*\sum_{n=1}^{N}\frac{S_n^x}{X_{k'n}^{t'}}}{1+\frac{1}{M+I}\left(\sum_{m=1}^{M}\frac{S_m^y}{Y_{k'm}^{t'}}+\sum_{i=1}^{I}\frac{S_i^b}{b_{k'i}^{t'}}\right)}$$

$$s.t\sum_{t=1}^{T}\sum_{k=1}^{K}Z_k^tX_{kn}^t+S_n^x=X_{k'n}^{t'}(n=1,2,\cdots N) \tag{1}$$

$$\sum_{t=1}^{T}\sum_{k=1}^{K}Z_k^tY_{km}^t-S_m^y=Y_{k'm}^{t'}(m=1,2,\cdots M)$$

$$\sum_{t=1}^{T}\sum_{k=1}^{K}Z_k^tb_{ki}^t+S_i^b=b_{k'i}^{t'}(i=1,2\cdots I)$$

In Equation (1), ρ is the land use efficiency with a value range between (0, 1); N, M, I stand for inputs, desired, and undesired outputs; and their relaxation vectors characterized by $\left(S_{\mathrm{n}}^{\mathrm{x}},S_{\mathrm{m}}^{\mathrm{y}},S_{\mathrm{i}}^{\mathrm{b}}\right)$ are input–output variables; $Z_{\mathrm{k}}^{\mathrm{t}}$ embodies decision unit weights; and k and t are region and time variables.

4.2. Two-way fixed effects model

Theoretical investigation suggests a potentially nonlinear connection between environmental rules and land use effectiveness. With reference to Kumar et al. (2018) and Liu et al. (2021), we set the following basic model:

$$EFFICIENCY_{it}=\alpha_0+\alpha_1ER_{it}+\alpha_2(ER_{it}{}^2)+\alpha_cZ_{it}+\mu_i+\delta_t+\varepsilon_{it} \tag{2}$$

In the above equation, $\mathrm{EFFICIENCY}_{\mathrm{it}}$ is the level of land use efficiency of city i in period t, ER_{it} represents the level of ER of city i in period t, Z_{it} stands for a set of control variables, μ_i indicates the specific fixed effect of city i that is constant over time, δ_t is the time fixed effect, and $\varepsilon_{\mathrm{it}}$ denotes the random disturbance term. In order to enhance the reliability of the regression results, this paper also performs the following essential treatment: Considering the heteroskedasticity and serial correlation of the disturbance terms, in all regression equations, we use the adjusted standard errors clustered at the prefecture level in the regression.

4.3. Threshold regression model

As the level of ER varies among different urban development stages, the following panel threshold model with a double threshold was set in this study.

$$\begin{aligned}EFFICIENCY_{it}=\varphi_0+\varphi_1ER_{it}\times I(A_{it}\le\theta_1)+\varphi_2ER_{it}\\ \times I(\theta_1<A_{it}<\theta_2)+\varphi_3ER_{it}\times I(A_{it}\ge\theta_2)\\ +\varphi_cZ_{it}+\mu_i+\delta_t+\varepsilon_{it}\end{aligned} \tag{3}$$

In the above equation, A_{it} stands for the threshold variable; the control variable is Z_{it}; $I(\cdot)$ stands for the indicator function; θ is the threshold value; φ is the coefficient of each variable; and the remaining variables support the previously stated meaning.

4.4. Variable selection

4.4.1. Explained variables

In this paper, ULGUE is used as an explanatory factor on the basis of the reference to related research results; in this study, land, capital, and labor are portrayed as the three main inputs. The expected output is selected based on the perspectives of the key variables from the economic, social, and ecological angles, and the non-expected output is reflected by calculating the environmental pollution index with reference to Fu et al. (2021). Table 1 gives the corresponding index system and the connotation of variables.

Table 1
ULGUE input–output index system

Tier 1 indicators	Tier 2 indicators	Tier 3 indicators	Unit
ULGUE	Labor	The number of workers in tertiary and secondary industries	Million people
	Capital	Total fixed asset investment	Billion yuan
	Land	Area of built-up area	Square kilometers
	Economic benefits	Secondary and tertiary industries' value added	Billion yuan
	Social benefits	Average employee salary	Million yuan
	Ecological benefits	Greening coverage of built-up areas	%
	Environmental pollution index	Wastewater treatment plant effluent, sulfur dioxide emissions, and smoke (dust) from industry	%

4.4.2. Core explanatory variables

This paper's main explanatory variable is ER. Due to the likelihood of bias in research results caused by the single-indicator method to ER measurement (Ji et al., 2020), the classifications of public participation, market incentives, and command-and-control must be founded on the perspectives of various environmental regulating themes (Gao et al., 2022). With reference to Wang and Shen (2016), the level of environmental control is measured using the comprehensive index method of numerous views. Table 2 depicts the index system.

Table 2
System of environmental regulation evaluation

Tier 1 indicators	Tier 2 indicators	Unit
Environmental regulation	Rate of industrial dust and fume removal	%
	Industrial SO2 removal rate	%
	General rate of disposal of industrial solid waste	%
	Rate of safely discarding household garbage	%
	Sewage treatment systems that use centralized treatment	%

4.4.3. Control variables

Economic development stage (*PGDP*): With reference to Xiao et al. (2023), the real GDP per person is used as a benchmark.

Population size (*PD*): With reference to Xu et al. (2023), this variable is expressed by population density.

Openness to the outer world on a scale (*OPEN*): With reference to Zehri and Chouaibi (2013), the quantity of foreign capital that was utilized in the current year. The extent of financial aid from the government (*GOV*): With reference to Jiang et al. (2021), the proportion of government spending that is budgeted to regional GDP.

4.4.4. Threshold variables

Land use structure optimization *(LSO*). With reference to Li et al. (2021), the proportion of government spending that is budgeted to regional GDP. The ratio of built-up area to administrative area in this study reveals the level of land use structure optimization.

Innovation in Science and Technology (*INN*). With reference to Amankwah-Amoah. (2016), the volume of issued patents is used in this study to gauge the degree of scientific and technological innovation.

Industrial structure upgrading (*INDUP*). Most studies have been conducted to portray industrial structure upgrading through a weighted summation of the output value of three industries as a proportion of GDP. Shao et al. (2021) argue that industrial structural improvement comes from the integration of technological progress and economic growth, which promotes industrial structure turnover's progression; therefore, an upgraded industrial structure will show signs of rationalization and progress in each of these areas. The Theil index is used to evaluate the degree of industrial structure rationalization in urban areas, drawing on the research method of Zhang et al. (2022). This is the precise calculating formula:

$$TL = \sum_{i=1}^{n} \left(\frac{Y_i}{Y}\right) \ln\left(\frac{Y_i}{L_i} / \frac{Y_i}{L}\right) \tag{4}$$

where Y_i stands for the output value of industry i, Y is the total GDP, L_i is the employment in industry i, and total employment is L.

The specific calculation process is as follows:

Step 1: Constitute a set of three-dimensional vectors $X_0 = (x_{1,0}, x_{2,0}, x_{3,0})$ of the output value of the three industries as a share of GDP;

Step 2: Calculate the angle between the vectors X_1=(1,0,0), X_2=(0,1,0), X_3=(0,0,1) of the industry from the low level to the high level;

$$\theta_j = arccos\left(\frac{\sum_{i=1}^{3}\left(x_{i,j} \cdot x_{i,0}\right)}{\sum_{i=1}^{3}\left(x_{i,j}^2\right)^{1/2} \cdot \sum_{i=1}^{3}\left(x_{i,0}^2\right)^{1/2}}\right)$$

$$j = 1, 2, 3 \tag{5}$$

Step 3: Calculate the index of advanced industrial structure TS;

$$TS = \sum_{k=1}^{3} \sum_{j=1}^{k} \theta_j \tag{6}$$

Further, to show the industrial structure optimization and upgrading, the quantitatively computed industrial structure rationalization and industrial structure advanced indicators are integrated. This is how the industrial structure upgrading index is determined:

$$INDUP = (TS + TL)/2 \tag{7}$$

4.5. Data sources

The study unit was a panel of 283 prefecture-level cities from 2011 through 2020, and each indicator's source data came from the China Statistical Yearbook, China Environmental Yearbook, China Environmental Statistical Yearbook, National Bureau of Statistics, and EPS data platform in previous years. A few missing indicators were interpolated to complete the data. Descriptive statistics for the key variables are shown in Table 3.

5. Empirical Results and Discussion

5.1. Base regression results

Is the effect of ER on ULGUE linear or nonlinear? To explore this question, model (2) introduced its squared term based on the corresponding ER category. All models were subjected to the Hausman test. Table 4 displays the findings of the regression analysis.

The findings in Table 4 demonstrate that, in the linear model test, the initial stage of the impact of ER on ULGUE is negative, but the *p*-value is not significant, so the relationship between the two needs to be further verified. After the introduction of the squared term, the link between ER and ULGUE is "U" shaped, with a negative primary coefficient and a positive secondary coefficient at the 5% significance level. The effect of ER on land utilization efficacy appears to be initially negative and then positive, this is similar to the findings of Zhang et al. (2021b) and Lu et al. (2018). Zhang et al. (2021b) indicated that with the awakening of environmental protection awareness and policy promotion, ERs are gradually strengthened, and some traditional land use methods that have a greater impact on the environment, such as high energy-consuming and high-polluting industrial projects and real estate projects that occupy a large amount of land, are banned or restricted. The restrictions of these industries may have a short-term detrimental effect on the effectiveness of land use. However, long-term, these constraints can lessen

Table 3
Descriptive statistics of variables

Variables	Count	Mean	SD	Min	P50	Max
EFFICIENCY	2830	0.391	0.327	0.000	0.376	1.000
ER	2830	0.669	0.187	0.132	0.690	0.995
ER2	2830	0.482	0.240	0.018	0.476	0.991
PGDP	2830	53702.555	34126.421	6457.000	44024.000	467749.000
PD	2830	437.007	338.278	4.000	366.000	2648.000
OPEN	2830	9.488	22.146	0.000	2.378	308.256
GOV	2830	0.078	0.027	0.023	0.073	0.227
LSO	2830	0.019	0.044	0.000	0.008	0.497
INN	2830	5936.159	14288.869	2.000	1394.000	222412.000
INDUP	2830	3.410	0.160	2.758	3.410	5.081

Table 4
Base regression results

Variables	Efficiency
ER	−0.430**
	(0.167)
ER2	0.290**
	(0.121)
Control variables	YES
Urban fixed effects	YES
Time fixed effects	YES
Observations	2830
R^2	0.691

over-exploitation and contamination of the land, as well as encourage the sustainable use of land resources, thus achieving a balance between efficiency and the environment (Su & Jiang, 2021). At the same time, Lu et al. (2018) indicated that with the growing popularity of environmental technologies, we can adopt more environmentally friendly, energy-saving, and efficient land use methods, such as the use of clean energy, precision agriculture, and waste resourcing. These new land use methods will increase the effectiveness of land usage while minimizing its detrimental effects on the environment. Therefore, Hypothesis 1 is verified.

5.2. Robust testing

Regression by time. The study period is divided into two-time samples, 2011–2015 and 2016–2020, according to the "five-year plan"; Table 5's columns (1) and (2) reflect that the development of ERs in both the 12th and 13th five-year plan periods has a suppressing and then promoting effect on land use efficiency, this agrees with the findings of the baseline regression and determines if the results of the baseline regression are resilient. The fact that the modification is in line with the outcomes of the benchmark regression validates the robustness of those results.

Bilateral Tailoring Treatment. Considering that the data of relevant indicators in 2020 may be affected by the new crown pneumonia epidemic, this paper winsorizes the continuous variables in the empirical test at the 1% and 99% levels to exclude the influence of extreme values and ensure the robustness of the study findings. Also, considering that different levels of tailoring may influence the baseline findings, this paper further performs tailoring at 5% and 1%. Table 5's columns (3) and (4) display the regression findings for the 1% and 5% levels of tailoring, respectively. It can be found that the development of ERs still has a nonlinear relationship between inhibiting and then promoting land use efficiency, which demonstrates how more solid and trustworthy the conclusions of this research are.

Controlling the time trend. When there are continuous or dummy variables in the model, the method of controlling the time trend can be used to assess whether the regression results are stable. In this study, the starting year of the study sample is 2011. The regression analysis is conducted after controlling the distinction between study year and beginning year, and column (5) of Table 5 contains the final results. At the 5% level, the projected coefficient of ER becomes significantly positive but is still notably negative, and the baseline regression conclusion is still robust.

5.3. Threshold regression with multidimensional effect constraints

5.3.1. Threshold test

According to Table 6, when land structure optimization is the threshold variable, the *F*-statistic is significant at least at the 5% level in both the one and two thresholds, i.e., the *p*-value is less than 0.05. When the threshold variable is industrial structure upgrading, the *F*-statistic is significant at the 1% and 5% levels, respectively, and the *p*-values are less than 0.01 and 0.05, respectively. The *F*-statistic is significant at the 5% level for both the one and two thresholds when technological innovation is the threshold variable. The *p*-values are less than 0. 05. When technological innovation is the threshold variable, the *F*-statistic is significant at the 5% level in both single and double thresholds, and the *p*-values are less than 0.05.

5.3.2. Threshold regression results

Structural optimization effect of land use. Table 7 shows that the coefficient of ER on ULGUE is 0.717 and significant at the 1% level when the value of land use structure optimization is less than 0.002; the coefficient of ER on ULGUE is still significant at the 1% level when the value of land use structure optimization crosses 0.002 but is less than 0.008, and the coefficient drops to 0.334; when the value of land use structure optimization value is more significant than 0.008, the effect of ER on ULGUE is not significant, and the coefficient size continues to decline but is still positive. Thus, as can be observed, land use structure is continuously optimized; the extent of effective environmental control on the efficiency of green land use is steadily waning. Hypothesis 2 is verified.

This result supports the studies of Yu et al. (2019) and Gao et al. (2020). Yu et al. (2019) indicated that the restructuring of land use takes time to achieve. Therefore, the extent to which ERs positively contribute to ULGUE in the near future may be

Table 5
Robust testing

Variables	(1) 2011–2015	(2) 2016–2020	(3) 1% shrinkage of the tail	(4) 5% shrinkage of the tail	(5) Controlling the time trend
ER	−0.430** (0.167)	−0.391** (0.171)	−0.442** (0.172)	−0.421** (0.169)	−0.430** (0.167)
ER2	0.290** (0.121)	0.350** (0.132)	0.293** (0.124)	0.312** (0.115)	0.290** (0.121)
Control variables	YES	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES	YES
Urban fixed effects	YES	YES	YES	YES	YES
Constant	0.584*** (0.0817)	0.584*** (0.0817)	0.653*** (0.0921)	0.653*** (0.0921)	0.237*** (0.0743)
Observations	2830	2830	2830	2830	2830
R^2	0.731	0.731	0.734	0.733	0.560

Table 6
Test of threshold effect of environmental regulation

Threshold variables	Number of thresholds	*F*-statistic	*P*	Threshold value	Threshold value 10%	5%	1%
LSO	Single threshold	33.460**	0.020	0.002	23.582	27.834	36.285
	Double threshold	68.660***	0.000	0.008	31.160	34.343	39.877
INDUP	Single threshold	96.260***	0.000	3.378	54.224	58.405	66.757
	Double threshold	172.610**	0.040	3.571	152.120	166.984	185.820
INN	Single threshold	50.330**	0.040	538.000	44.102	48.570	55.180
	Double threshold	132.470**	0.010	1895.000	102.994	115.085	131.097

Table 7
Threshold regression results

Threshold variables	Threshold interval	Parameter value
LSO	LSO ≤ 0.002	0.717*** (0.0834)
	0.002 < LSO ≤ 0.008	0.334*** (0.0529)
	LSO > 0.008	0.0570 (0.0495)
INDUP	INDUP ≤ 3.3784	0.620*** (0.0564)
	3.3784 < INDUP ≤ 3.571	0.390*** (0.0481)
	INDUP > 3.571	0.117** (0.0494)
INN	INN ≤ 538.000	0.607*** (0.0596)
	538.000 < INN ≤ 1895.000	0.410*** (0.0507)
	INN > 1895.000	0.149*** (0.0475)

obscure. Gao et al. (2020) indicated that land use involving conflicting interests among multiple parties and ERs is closely related to the level of regulation. However, owing to geographical variations and other factors, the level of ER is uneven, with some areas being more strictly enforced and others being relatively less so. This may lead to irrational and abusive use of some utilization patterns, and thus the positive promotion effect of ERs begins to show a decreasing trend (Gao et al. 2020). Therefore, although there is an impact of continuous optimization of land use structure on the degree of positive promotion of ER, in order for ER to play a stronger regulatory function, it is still important to develop and strengthen the environmental regulatory mechanism as part of the process of modifying land use structure.

Industrial structure upgrading effect. In light of what Table 7 shows, the coefficient of ER on ULGUE is 0.620 and statistically significant at the 1% level when the value of industrial structure upgrading is less than 3.3784; when the value of industrial structure upgrading is greater than 3.3784 but less than 3.571, the impact of ER on land use efficiency remains significant at a 1% significance level, but the coefficient decreases to 0.390; when the value of land use structure optimization is more remarkable than 3.571, ER has a significant impact on land use efficiency at the 5% level. The coefficient size continues to decrease to 0.117. ER can enhance the ULGUE through industrial structure modernization, but the degree of positive promotion shows a slowing trend. Hypothesis 3 is verified. This result supports the studies of Lu et al. (2022) and Li et al. (2023). Lu et al. (2022) indicated that with the continuous improvement of production technology, many industries have adopted more environmentally friendly and energy-efficient production processes, making enterprises use land resources more efficiently in the production process. Given such a scenario, the positive contribution of ERs to land use efficiency may be relatively insignificant. Li et al. (2023) indicated that adjusting industrial structure necessitates the reorganization and redistribution of stakeholders, which may lead to some contradictions and conflicts, thus affecting ERs' implementation. At the same time, because of the need of

Table 8
Results of heterogeneity analysis

Variables	(1) East	(2) Middle	(3) West	(4) Low polluted cities	(5) Highly polluted cities	(6) Type II large cities	(7) Type I large cities	(8) Megacities
ER	−0.643*	−0.332	−0.286	−0.416**	−0.081	−0.282**	−0.430**	−0.249
	(0.332)	(0.210)	(0.374)	(0.202)	(0.344)	(0.580)	(0.167)	(0.309)
ER2	0.222**	0.208	0.303	0.297**	0.0478	0.157**	0.290**	−0.019
	(0.231)	(0.157)	(0.276)	(0.149)	(0.234)	(0.409)	(0.121)	(0.244)
Control variables	YES	YES	YES	YES	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES	YES	YES	YES	YES
Urban fixed effects	YES	YES	YES	YES	YES	YES	YES	YES
Constant	0.816***	0.458***	0.781***	0.669***	0.211	0.466*	0.584***	0.528***
	(0.165)	(0.103)	(0.192)	(0.0965)	(0.171)	(0.262)	(0.0817)	(0.155)
R^2	0.675	0.792	0.767	0.760	0.786	0.694	0.731	0.791

balancing economic growth and environmental protection, industrial restructuring must take these factors into full consideration.

Science and technology innovation effect. According to Table 7, when STI is less than 538.000, the coefficient of ER on ULGUE is 0.607, which is statistically significant at the 1% level; when the value of STI is greater than 538.000 but less than 1895.000, ER's impact on land use efficiency remains significant at the 1% level, but the coefficient decreases to 0.410; when STI is greater than 1895, the ER coefficient on land use efficiency remains significant at the 1% level, and the coefficient continues to decrease to 0.149. The impact of ER on effective land use continues to decline to 0.149 at the 1% level when the value of STI is greater than 1895. Hypothesis 4 is verified. This result supports the studies of D'Amato et al. (2019) and Xie et al. (2022a). D'Amato et al. (2019) indicated that certain environmental technologies with high development costs can affect their application and promotion in actual production. In that case, even if environmental technologies exist, it is not easy to significantly impact land use efficiency. Xie et al. (2022b) showed that ER's positive promotion of land use efficiency needs to rely on these backward technologies. In that case, it is not easy to achieve the expected effect in terms of long-term development. Therefore, although the degree of the positive contribution of continuous innovation in the level of science and technology to ER is noticeable, the strengthening of research and promotion of environmental technologies also focuses on solving problems such as high costs of environmental technology application and backward technologies (Galeana-Pizaña et al., 2018).

5.3.3. Heterogeneity analysis

Location heterogeneity. This paper investigates the locational heterogeneity of ER on ULGUE by categorizing the sample cities into three geographically distinct categories, namely eastern, central, and western, and three distinct groups were created. Columns (1)–(3) in Table 8 show how different regions' ULGUE is affected by ER. In all main regions, ERs have a "U"-shaped effect on ULGUE. However, its impact is notable in eastern cities but not in the central and western cities. This result supports the studies of Wang et al. (2020) and Hu et al. (2022). Wang et al. (2020) indicated that the eastern cities are economically developed, and concerns with environmental quality are more widespread, so the government pays more attention to environmental protection and regulation; in addition, the eastern cities are densely populated and have frequent production activities, so the demand for ER is more urgent (Han et al., 2020). Hu et al. (2022) indicated that cities in the central and west are more productive than those in the east. Compared to eastern cities, central and western cities see less economic development, more abundant natural resources, and less environmental pollution; consequently, the government focuses less on ER and protection, and central and western cities have a lower population density and fewer production activities (Chen et al., 2019). Hence, ER has less of an effect on land use efficacy in western cities than in eastern cities.

Heterogeneity of environmental pollution levels. In this study, the environmental contamination index's median is used as the differentiation boundary to classify cities into two categories: low-pollution cities and high-pollution cities. Columns (4)–(5) in Table 8 reflect that ER is significant at the 5% level for ULGUE in cities with low levels of air pollution and of land use efficiency in cities with high levels of air pollution. This result supports the studies of Lu et al. (2022) and Zhong et al. (2022). Lu et al. (2022) indicated that in low-pollution cities, the quality of urban environment is relatively good, and environmental control is simpler for the government to adopt and enforce, thus promoting more rational use of land resources by enterprises and individuals and, therefore, can effectively improve land use efficiency. In highly polluted cities, however, the environmental quality has been seriously damaged, and it is difficult urging the government to implement environmental regulating measures to immediately address the environmental issues, and enterprises and individuals may also have irregularities, thus limiting the influence of ER on ULGUE. Zhong et al. (2022) proved that there may be some "gray industries" in high-pollution cities, which have an increased negative environmental impact but are often difficult to ban or prohibit due to their higher profits, thus making the effect of ER less obvious than in low-pollution cities.

City scale heterogeneity. In this paper, based on the Notice on Adjusting City Size Classification Standards, city sizes are classified as Type II large cities, Type I large cities, and megacities. Columns (6)–(8) in Table 8 represent the variations in how ER affects the ULGUE in cities of various sizes. The effect of ER on ULGUE is found to be "U" shaped and statistically significant at the 5% level in both Type II and Type I cities, but suppressed and insignificant in megacities. This result supports the studies of

Liu et al. (2018) and Xiao et al. (2023). Liu et al. (2018) proved that in smaller and moderate cities, the government is more likely to implement and enforce ERs, thus effectively improving land use efficiency. Xiao et al. (2023) proved that mega-sized cities often have huge populations, logistics, and industrial systems, which are difficult for the government to control and supervise fully, and some violations are relatively common. At the same time, the development of mega-sized cities often requires more land resources, and the government may obtain more land by relaxing land regulations, which, to a certain extent, also decreases the negative effects of ERs on effective land use.

6. Conclusions, Policy Recommendations, and Limitations

In this study, the ULGUE of each city is determined using the super-efficient SBM model based on panel data from 283 prefecture-level cities in China from 2011 to 2020. The severity of ER is determined using the thorough evaluation approach. The hypothesis is verified by linear and nonlinear multiple regression econometric empirical methods, and the threshold effect model determines the threshold value of ER on ULGUE under the mediating impact.

The findings indicate that: (1) there is a "U"-shaped relationship between environmental restrictions and the efficiency with which land is used. (2) ER affects ULGUE through land use structure optimization, scientific and technological innovation, and industrial structure optimization, and the strength of its influence slows down with the increase of time. (3) ER have a variable effect on the ULGUE, having a greater impact in eastern cities, low-pollution cities, Type II and Type I large cities, and having less of an impact in western cities, high-pollution cities, and megacities.

The following policy conclusions are distilled from the foregoing conclusions: (1) Local governments are required to strengthen the construction of environmental governance systems, improve laws and regulations and administrative supervision measures, increase environmental protection investment, and ensure that ERs can be effectively implemented. At the same time, by strengthening land resource management, rational planning of land use, preventing over-exploitation and waste, and improving land use efficiency and ecological benefits. (2) Establish the point at which environmental control starts to alter the effectiveness of land use and empirically develop a reasonable set of ER tools. Cities with low levels of regulation can be promoted to cross the inflection point by improving environmental protection laws and regulations, optimizing compensation and incentive mechanisms, and widening public opinion feedback channels; provinces with a high level of regulation need to actively explore the environmental governance system with joint participation of government, market, and public and reasonably weigh the weight of the three to ensure long-term viability and maximum productivity in land use. (3) Adapt the regulatory tools to time and place and adjust them dynamically. For cities of different regions, scales, and degrees of environmental pollution, local governments should flexibly use ER types in conjunction with local characteristics and their own positioning and development status to further promote higher levels of industry, technology, and openness and achieve balanced development of economic and land use efficiency.

Limitations of this study: The next step can be to classify heterogeneous ERs as a way to investigate the effect of various environmental regulatory strengths on city land utilization; meanwhile, the next step can also be to use the spatial Durbin model to do whether ERs have a spillover effect on land use efficacy in neighboring areas, to enrich the paper's findings.

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Conflicts of Interest

Jianlong Wang is an editorial board member for Green and Low-Carbon Economy, and was not involved in the editorial review or the decision to publish this article. The authors declare that they have no conflicts of interest to this work.

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