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A Spatial Convergence Analysis of China's Urban Eco-efficiency: Perspectives based on Local Government Competition

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Abstract: Regional collaborative governance of the ecological environment is an important way to promote the sustainable development of urbanization, and local government competition is a characteristic institutional factor that is often ignored in the process of regional ecological environmental governance in China. This study selected the panel data of 278 prefecture-level cities from 2006 to 2018 in China, and used the spatial convergence regression model and the mediation effect model to analyze the spatial convergence of urban eco-efficiency (UEE) and its mechanism from the perspective of local government competition. The results show several empirical patterns. First, the UEE follows a tendency of convergence that narrows the regional gap of urban eco-efficiency, and spatial interaction factors are the keys affecting the convergence of UEE. Second, local government competition, as a characteristic institutional factor, plays an important role in promoting the spatial convergence of UEE, and the effect of administrative distance proximity competition is stronger than that of geographical distance proximity competition. The UEE increases by 0.114 percentage points when its degree of competitive pressure increases by 1 percentage point. Third, the competitive pressure leads to strict environmental regulation policies, which generally improve UEE and thus narrow its gap with advanced cities. Finally, local government competition has heterogeneous effects on urban eco-efficiency. Specifically, under the pressure of local government competition, the environmental regulations improve the UEE in the east and key environmental protection cities, while the central and non-key environmental protection cities experience the opposite effect. The results of this study suggest that if UEE is further introduced into the administrative performance evaluation index systems of local officials, the regional gap of environmental and economic development could be narrowed through ecological competition.

Key words: spatial convergence; urban eco-efficiency; local government competition; environmental regulation

1 Introduction

In recent decades, the accelerated pace of industrialization and urbanization in China has led to rapid economic growth, but they have also brought the excessive consumption of natural resources, and increases in pollutant emissions and environmental damage. Eco-efficiency is an effective tool for comprehensively evaluating the coordination of resources, environment and economy, which emphasizes that resource saving and environmental improvement should be taken into account as much as possible while economic growth is achieved (WBCSD, 1996). So far, China has proposed a total of 737 new towns or districts with a total planned area of more than 83500 km^2. They consume a large amount of land resources, and large-scale urban construction has mo-

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tivated a large number of people to migrate to the cities, resulting in a continuous increase in water demand, and the problem of water shortages in some cities has become increasingly prominent (Zhou et al., 2022). The National Bureau of Statistics showed that the total energy consumption in 2021 was 5.24 billion t of standard coal, most of which was concentrated in cities, and the per capita domestic energy consumption was 456 kg of standard coal, representing an increase of 46.2% over 2012 and an average annual growth rate of 4.9% (National Bureau of Statistics, 2022). According to the *Bulletin of the State of Ecological Environment in 2021*, 339 cities have experienced a total of 1732 days of heavy or severe pollution, among which the number of days of severe pollution has increased by 494 days compared with 2020 (Yang et al., 2022). Clearly, Chinese cities still face great challenges in both resource utilization and environmental quality improvement. Therefore, the sustainable development of China's urbanization is urgently needed in order to promote the continuous improvement of urban eco-efficiency and narrow the gaps among regions.

In order to achieve the continuous improvement of eco-efficiency and narrow the gaps among regions, the Chinese government has implemented rigid restrictions on macro energy consumption and pollutant emissions in various regions. Since the 11th Five-Year Plan, China has set legally binding targets for reducing energy consumption per unit of GDP and the total emissions of major pollutants (Yu et al., 2020). The National New Urbanization Plan (2014–2020) points out that China's urbanization is promoted against the background of a large population, a relative shortage of resources, a fragile ecological environment and unbalanced regional development. The 20th CPC National Congress clearly pointed out that the harmonious symbiosis between man and nature is an inherent requirement of Chinese-style modernization. Naturally, the regional gap of eco-efficiency has attracted academic attention. Some studies have pointed out that the eco-efficiency of eastern China is significantly higher than that of central and western China, and there is also a huge gap within the region (Shang et al., 2022). Wei et al. (2021) found large spatial gaps in the eco-efficiency of urban clusters in China, and the differences between urban clusters are the main source of the overall gap. At the same time, environmental regulation (Feng et al., 2020), regional integration policies (Kang et al., 2022) and green technology innovation spillover (Shang et al., 2022) are the main factors which can narrow the regional eco-efficiency gap.

In recent years, the central government has gradually increased the weight of ecological and environmental indicators in administrative performance evaluation, and local governments now face stricter assessments of their performance in ecological and environmental governance, as the focus of administrative performance evaluation is shifting from economic growth to ecological and environmental governance (Wang et al., 2021). In China, the standards of administrative performance evaluation are determined by the higher level of government. Different performance evaluation directions will bring different competitive orientations to local governments, which will cause the local governments to adopt different competitive strategies, thus forming different interest coordination mechanisms (Huang et al., 2018). So, does the transformation of administrative performance evaluation orientation bring new competitive pressures to local governments? Can this competitiveness narrow the gap of urban ecological efficiency among regions? What is the mechanism by which local government competition influences urban eco-efficiency? The answers to these questions are undoubtedly conducive to an in-depth understanding of the important role of government behavior in the coordination of various interests, and would provide experience reference and policy inspiration for optimizing the performance assessment standards and mechanisms. Those answers would also provide a reference for countries and regions facing severe eco-environmental challenges all over the world.

Although some studies have investigated the convergence of urban eco-efficiency, most of them focus on its empirical analysis, while the evaluation of convergence rates and the main factors influencing urban eco-efficiency convergence are both relatively weak. In particular, as the influencing factors that cannot be ignored, institutional factors are a field that has received little attention in the existing research. Therefore, this study focuses on the institutional factors of local government competition and analyzes the direct and indirect mechanisms of local government competition on urban eco-efficiency, against the background that the central government has increased the proportion of ecological environmental governance in the performance assessment of government officials. In the empirical strategy of this study, the indexes of administrative distance proximity competition and geographical distance proximity competition were constructed, and the spatial convergence model and mediation effect model were comprehensively used to test the spatial convergence of urban eco-efficiency. This study examined the differences in the two kinds of local government competition on urban eco-efficiency, in order to provide evidence-based guidance for improving urban eco-efficiency and narrowing the regional gap. Figure 1 shows the research framework of this study.

2 Literature reviews and research hypotheses

2.1 Literature reviews

The convergence issue originates from the neoclassical growth theory proposed by Solow (1956), who pointed out that regions with lower per capita capital would obtain higher economic growth rates, suggesting that underdeveloped regions should catch-up to developed regions over time. In recent years, the concept of convergence has also been extended to the field of environmental governance. For

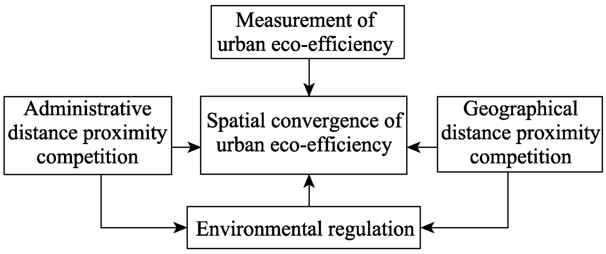

Fig. 1 Research framework

example, Sun et al. (2020) found that the environmental efficiency of 104 countries had increased by an average of 1.3%, and its convergence factors depended on industrial structure, globalization and energy prices. Zhai et al. (2022) empirically found that China's green total factor productivity has achieved significant conditional β-convergence since 2001, and the environmental regulations sped up regional convergence rates of green total factor productivity. Although a variety of factors affect the convergence of regional eco-efficiency, local government competition, as an institutional factor under the Chinese-style environmental decentralization system, cannot be ignored.

There are two hypotheses regarding the mechanism of local government competition, namely, the "yardstick competition" hypothesis and the "resource flow" hypothesis. The former suggests that voters in an information inferior position evaluate government performance by comparing local and non-local taxes and public services, which leads to policy imitation among local governments (Edmark and Ågren, 2008; Tian et al., 2020). The latter suggests that local governments compete to attract investment or tax base income, which usually leads to low effective tax rates and an insufficient supply of public goods (Brueckner, 2003; Qian and Cai, 2017). In terms of yardstick competition, although the decisive performance evaluator of China's local government is not the voters within its jurisdiction but the government at a higher level, local government officials have formed a "top-down" yardstick competition for the purpose of political promotion (Caldeira, 2012), the most typical of which is the "GDP tournament" (Song, 2020).

In recent years, the academic literature has mainly focused on theoretical testing of the hypothesis of "green" yardstick competition, and three conclusions have been drawn. One view is that there is a "green" yardstick competition among regions. For example, Zhang et al. (2010) used the two-regime spatial econometric model to study the spatial interactions of environmental regulation intensity among provincial governments in China, and found that the interprovincial competition in environmental regulation gradually changed from a "race to the bottom" to a "race to the top". Of course, some studies have come to the opposite conclusion. Wang (2015) empirically tested the spatial interaction patterns of different types of pollutants by using the asymmetric reaction model, and found a "free rider" behavior in the treatment of pollutants with strong negative externalities, such as industrial sulfur dioxide and dust, which inhibits the investment of local governments in environmental governance. Other studies have pointed out that both of these two situations exist (Jin and Shen, 2018).

In general, there have been some studies on the convergence of the ecological economy, but some research gaps still exist. Firstly, most studies focus on the empirical testing of the convergence of the ecological economy, and lack any further analysis of the driving factors behind it, especially the institutional factors such as local government competition. Secondly, the existing literature on local government competition is still limited to the field of traditional economic competition and has not been extended to the ecological competition. Finally, most studies still do not go beyond the perspective of the traditional convergence issue and lack an analytical framework to deeply explain how local government competition affects urban eco-efficiency (UEE). Therefore, in this study, we expanded the analysis framework of local government competition from traditional economic competition to ecological competition, and analyzed the mechanism by which local government competition influences UEE. Then, two new quantitative indexes were constructed to evaluate the competitive pressure among local governments, and to empirically test the influence of local government competition on spatial convergence of UEE, in order to provide evidence-based guidance for narrowing the gap of regional sustainable development.

2.2 Research hypotheses

The traditional local government competition theory believes that voters (citizens) often compare the public services in their own regions with those of other regions due to the information asymmetry in principal-agent politics, and require the jurisdictional government to provide higher-quality public service products (Besley and Case, 1995), such as good environmental protection services (Fredriksson and Millimet, 2002). Unlike in western countries, the driving force of Chinese-style local government competition comes from the higher level governments, which (unlike local voters) often reward or punish local officials based on their relative performance in economic development or public services, thus creating a competitive effect among regions (Caldeira, 2012). Since the "ecological civilization construction" was put forward, the central government has significantly increased the proportion of ecological environmental indicators in the performance evaluation of officials. Against this background, two kinds of local government competition strategies have been formed, one is administrative distance proximity competition and the other is geographical distance proximity competition. The former refers to the competition among regions with the same or close administrative affiliations, such as the competition among prefecture-level cities in the same province. Each prefecture-level city which belongs to the same provincial administrative division is subject to performance assessment from the same higher-level government, so its local government competes more fiercely for the relative performance ranking. Geographical distance proximity competition involves different administrative affiliations and has relatively weak competition for performance rankings. In the case of the local government competition effect, the more backward the ecological efficiency of a region is, the more competitive pressure it faces, and the more urgent it is to catch up with the benchmark region.

The regional gap of eco-environmental quality aggravates the urgency of ecological competition in the backward cities, and environmental regulation is an effective tool for forming a competitive advantage. Since the "11th Five-Year Plan", China has defined the target constraints of energy consumption and pollutant emissions, which has been helpful for local governments to turn the pressure of target constraints into the competition of environmental regulation. In order to improve the quality of the ecological environment, local governments often restrict the economic activities of enterprises by formulating a series of environmental protection laws and regulations, and by implementing pollution permits, administrative penalties and emission taxes (Zhang, 2014). For example, Wu et al. (2019) introduced environmental regulation into the local government competition mechanism, and using the statistical data of 30 provinces across the country, they found that there is "imitation" behavior in the formulation and implementation of environmental regulations in various regions under the local government competition mechanism, ultimately affecting regional green development. With the increasing proportion of eco-environmental governance indicators in the performance evaluation of local governments, environmental regulation will play an increasingly important role in the process of regional ecological priority and green development.

The impact of environmental regulation on urban eco-efficiency is realized through two measures: economic development and pollutant discharge. The existing literature is less direct in studying the impact of environmental regulation on urban eco-efficiency, but there are many discussions about the impact of environmental regulation on either economic development or pollutant emissions. At present, there are two views on the relationship between environmental regulation and economic development, namely, the "non-benefit theory" and the "benefit theory" (Porter and Van Der Linde, 1995). Compared with the dual impact on economic development, the control of pollutant emissions by environmental regulation is more of a positive impact. Strict environmental regulation can reduce the capital entering high-pollution industries and optimize the industrial structure (Yang et al., 2022), thus contributing to the improvement of environmental quality. Of course, a minority of studies do not support the above views (Sinn, 2008), which are called the "Paradox of green development" (Smulders et al., 2012). Therefore, environmental regulation also has a complex impact on urban eco-efficiency by affecting both economic development and the ecological environment.

In addition, due to the vastness of China's regions, there are significant differences among regions in terms of economic development stages, production technologies, resource endowments, and governance capabilities. On the one hand, local governments have different regional development goals and directions according to their local conditions and comparative advantages, which means that there is a selective competition mechanism among regions (Huang and Xia, 2016). On the other hand, the effect of environmental regulation is heterogeneous, and depends on the local development stage and pathway. In the stage of rapid economic expansion, the strengthened environmental regulations will disrupt the normal operation of enterprises, inhibit the expansion of the production scale of enterprises, and make enterprises pay huge compliance costs to deal with pollutant emission reduction, which will have a negative impact on the improvement of urban eco-efficiency. When the local economy is in a mature stage and the speed of economic expansion is limited, and the local governments will force enterprises to improve their technological innovation capabilities and optimize the industrial structures by increasing environmental regulations, in order to achieve the coordinated development of the economy and the ecological environment, thereby improving the urban eco-efficiency. Based on the above analysis, this study puts forward the following three hypotheses.

Hypothesis 1 (H1): Local government competition accelerates the spatial convergence of urban eco-efficiency, and the effect of administrative distance proximity competition is stronger than geographical distance proximity competition.

Hypothesis 2 (H2): Environmental regulation is the key channel by which local government competition affects urban eco-efficiency.

Hypothesis 3 (H3): Local government competition has a heterogeneous effect on urban eco-efficiency through environmental regulation.

3 Methodology and data

3.1 Measurement of core variables

3.1.1 Urban eco-efficiency

Under the measurement framework of eco-efficiency, data envelopment analysis (DEA) based on non-radial distance function (NDDF) can achieve the flexible expansion and reduction of the desired output and inputs and the undesired outputs, and has been widely used in the calculation of multi-input-output efficiency (Teng et al., 2019). Considering the vast territory of China, the production technologies of different regions are different because of disparities in economic development, resource endowments and governance capabilities. Therefore, regional technological heterogeneity must be considered when constructing the technological frontier, otherwise the measurement results will be biased (Yu et al., 2019). Referring to the practice of Wang et al. (2016), this study applied a modified metafrontier super-efficiency model considering technical heterogeneity to measure the urban eco-efficiency.

Supposing N cities, each city can be regarded as a decision-making unit (DMU). In this study, all DMUs were divided into group H, and the number of cities in group h is N^h , where $\sum_{h=1}^{H} N^h = N$. We defined two production techniques, T^h and T^m, which were assumed to be the production technology set of the h-th group under the group frontier and meta-frontier, respectively, which satisfy $T^m = \{T^1 \cup T^2 \cup \cdots \cup T^H\}$. This study divided all cities in China into four regional groups (East, Central, West and North-east) to distinguish regional technological heterogeneity, and each group has the same production technology. That is, the DMUs in the same group have the same frontier of group technology (Sun et al., 2018). Each DMU inputs K kinds of production materials, $R = [R^1, R^2, \cdots, R^K] \in R_+^K$, obtains M kinds of desired output, $Y = [Y^1, Y^2, \cdots, Y^M] \in R_+^M$, accompanied by S kinds of undesired output, $E = [E^1, E^2, \cdots, E^S] \in R_+^S$, and the production technology (T^m) of the H is defined as follows:

$$T^m = \left\{ (R, Y, E): \sum_{h=1}^{H}\sum_{i=1}^{N^h} \lambda_i^h R_i^h \leqslant R; \sum_{h=1}^{H}\sum_{i=1}^{N^h} \lambda_i^h Y_i^h \geqslant Y; \sum_{h=1}^{H}\sum_{i=1}^{N^h} \lambda_i^h E_i^h = E; \lambda_i^h \geqslant 0, i = 1, 2, \cdots, N^h \right\} \tag{1}$$

where λ_i^h is the weight variable that constructs the production technology into a convex combination, and T^m satisfies weak disposability. Then, combining the pre-defined non-radial distance function with the super-efficiency model and solving the distance function:

$$\begin{aligned} &\overrightarrow{ND^m}(R, Y, E; -g_R, g_Y, -g_E) = \max\{w_R\beta_R^m + w_Y\beta_Y^m + w_E\beta_E^m\} \\ &\text{s.t.} \sum_{h=1}^{H} \sum_{i=1 (i \neq o \text{ if } h=q)}^{N^h} \lambda_{ih} R_{ih}^k \leqslant (1-\beta_R^m)(1-\beta_R^{h*}) R_{qo}^k, \forall k \\ &\sum_{h=1}^{H} \sum_{i=1 (i \neq o \text{ if } h=q)}^{N^h} \lambda_{ih} Y_{ih}^m \geqslant (1+\beta_Y^m)(1+\beta_Y^{h*}) Y_{qo}^m, \forall m \\ &\sum_{h=1}^{H} \sum_{i=1 (i \neq o \text{ if } h=q)}^{N^h} \lambda_{ih} E_{ih}^s = (1-\beta_E^m)(1-\beta_E^{h*}) E_{qo}^s, \forall s \\ &\lambda_{ih} \geqslant 0; \beta_R^m \geqslant 0, \beta_Y^m \geqslant 0, \beta_E^m \geqslant 0; q = 1, \cdots, H; o = 1, \cdots, N^h \end{aligned} \tag{2}$$

In equation (2), $w = (w_R, w_Y, w_E)^T$ represents the normalized weight vector corresponding to the input-output variables, $g = (-g_R, g_Y, -g_E)$ is the direction vector, and $\beta = (\beta_R, \beta_Y, \beta_E)^T \geqslant 0$ represents the expansion and contraction ratio of each input-output variable. The specific input variables include capital (K), labor (L), energy (E), land resources (B) and water resources (W), the desirable output is added value (U), and the undesirable outputs are wastewater (D) and waste gas (S). Then, referring to Zhang et al. (2018), we can obtain $(1-\beta_R^{m*})(1-\beta_R^{h*})$, $(1+\beta_Y^{m*})(1+\beta_Y^{h*})$ and $(1-\beta_E^{m*})(1-\beta_E^{h*})$, where, $(1-\beta_R^{h*})$, $(1+\beta_Y^{h*})$ and $(1-\beta_E^{h*})$ are solved in advance based on the group production technology set, and they are then added to equation (2) to obtain $(1-\beta_R^{m*})$, $(1+\beta_Y^{m*})$ and $(1-\beta_E^{m*})$, which represents the improvement space from group production technology to global production technology. The target values of resource inputs, desired outputs and undesired outputs of the oth DMU in group q are $(1-\beta_R^m)(1-\beta_R^{h*})R_{qo}^k$, $(1+\beta_Y^m)$ $(1+\beta_Y^{h*})Y_{qo}^m$ and $(1-\beta_E^m)(1-\beta_E^{h*})E_{qo}^s$, respectively, where k = E, B, W; $m = Y$; $s = D, S$. Finally, the urban eco-efficiency (UEE) can be calculated as follows:

$$UEE(R, Y, E) = \frac{1}{2} \times \left[\frac{1}{K} \sum_{k=1}^{K} \frac{(1-\beta_k^{m*})(1-\beta_k^{h*})}{(1+\beta_Y^{m*})(1+\beta_Y^{h*})} \right] + \frac{1}{2} \times \left[\frac{1}{S} \sum_{s=1}^{S} \frac{(1-\beta_s^{m*})(1-\beta_s^{h*})}{(1+\beta_Y^{m*})(1+\beta_Y^{h*})} \right] \tag{3}$$

The input variables mainly include labor, capital and resources, with resources divided into energy and other natural resources. Since energy consumption data at the prefecture-level city are not available, industrial electricity consumption was used as a proxy indicator. The area of urban construction land and water consumption were regarded as the proxy variables of land and water resources, respectively (Bai et al., 2018). Considering the inconsistent statistical caliber of industrial soot data, this indicator was excluded from the indicator of undesired output, while industrial wastewater and industrial sulfur dioxide emissions were determined as undesired outputs. Finally, real GDP was taken as the proxy variable of desired output. All economic data were converted into 2006 prices in order to eliminate the impact of price factors. The detailed descriptions of the input-output variables are shown in Table 1.

3.1.2 Local government competition

The measurement of local government competition depends on the choice of a reference benchmark. For example, the gap of an economic indicator between a locality and its neighboring benchmark can be used as a measure of local government competition (Huang and Du, 2016; Tian et al., 2020). It should be noted that the governments of different prefecture-level cities within a province belong to the same provincial government, but the prefecture-level government of the same province is different from that of other provinces

Table 1 Input-output variables and data description

Category	Variable	Data and description
Inputs	Capital (K)	The "perpetual inventory method" was used to estimate the capital stock. The calculation formula is: $K_{it} = I_{it} + (1-\delta_t)K_{it-1}$, in which I_{it} is the fixed asset investment of the city i in year t. The capital stock in the initial year was obtained by the method of Young (2003), and the depreciation rate δ_t was derived from Shan (2008)
	Labor (L)	Employed population at the end of the year
	Land resources (B)	Urban construction land area (Bai et al., 2018)
	Water resources (W)	Total urban water supply minus domestic water consumption to obtain water resources input
	Energy (E)	The electricity consumption data automatically recorded by the meter is more accurate, and there is a high correlation between electricity consumption and energy consumption (Li et al., 2013). Referring to Li and Xu (2018), this paper used prefecture-level city power consumption data as proxy variables
Desired output	GDP (U)	Real GDP was considered as the most important desirable output
Undesired outputs	Waste water (D)	Industrial waste water emission
	Waste gas (S)	Industrial sulfur dioxide emission

Note: Due to the inconsistent statistical caliber of industrial (smoke) dust in the sample period, this variable was not used as an unexpected output. To eliminate the influences of price factors, all economic data were adjusted to the corresponding prices in 2006.

in terms of administrative distance. Therefore, under the mechanism of local government competition, it is more appropriate to find an administrative proximity neighbor as the benchmark. For example, Miao et al. (2017) used the ratio of GDP per capita to the highest GDP per capita (benchmark) of prefecture-level cities in the same province as a measure of economic local government competition. Moreover, Zhan et al. (2017) regarded the gap between local agricultural total factor productivity and its frontier as a measurement, which provided inspiration for the selection and construction of indicators in this study. Therefore, the gap between the urban eco-efficiency of a prefecture-level city and its benchmark could be used to measure the competitive pressure among local governments. In order to compare the differences between administrative distance proximity competition and geographical distance proximity competition, two local government competition indicators were constructed as follows:

$$LGC_{it}^{1} = \ln\left(\frac{Y_b}{Y_i}\right)_t \tag{4}$$

$$LGC_{it}^{2} = \ln\left(\frac{Y_g}{Y_i}\right)_t \tag{5}$$

In equations (4) and (5), LGC^1 and LGC^2 represent the intensity of administrative proximity competition and geographical proximity competition, respectively. Y_b stands for maximum eco-efficiency in a province, Y_g stands for maximum eco-efficiency within a 500 km radius, and Y_i is the level of eco-efficiency of other cities. The geographic distance was set to 500 km because that distance happens to include cities in neighboring provinces. Therefore, $\frac{Y_b}{Y_i}$ can be used to measure the gap of eco-efficiency between a local city and the benchmark city in the same province, while Y_g / Y_i can be used to measure the gap of eco-efficiency between a local city and the benchmark city within the distance of 500 km. The difference is that the former reflects the competition among cities based on its administrative distance, while the latter is based on its geographical distance, which represent two kinds of competition mechanisms. The greater the gap between a city and the benchmark city, the greater the competitive pressure. The more backward the urban eco-efficiency, the higher the values of $\ln\left(\frac{Y_b}{Y_i}\right)_t$ and $\ln\left(\frac{Y_g}{Y_i}\right)_t$.

3.2 Empirical model

3.2.1 Convergence model

The purpose of convergence analysis is to test the convergence or divergence of urban eco-efficiency over time, that is, whether the gap of urban eco-efficiency among cities is narrowing or expanding, and achieving long-term convergence is considered to be the realistic basis for green catch-up. This study examined the convergence of urban eco-efficiency through the absolute β-convergence, conditional β-convergence and spatial convergence models. Among them, absolute β-convergence assumes that all cities have the same economic base, and the specific model is as follows:

$$\ln\frac{UEE_{it}}{UEE_{it-1}} = \beta \ln UEE_{it-1} + \mu_i + \varepsilon_{it} \tag{6}$$

In equation (6), UEE_{it} represents the urban eco-efficiency of the i-th city at year t, μ_i represents the city fixed effect, and ε_{it} is the error term. When β is significantly negative, it indicates that there is a long-term convergence trend in urban eco-efficiency. That is, the backward cities are catching up with the advanced cities, to finally achieve balanced growth, and the convergence rate was calculated as $-\ln(1+\beta)$.

The conditional β-convergence model assumes that the economic bases of all cities are different and allows absolute differences among regions. When testing a conditional β-convergence model, some control variables are added to reflect the characteristics of the regional economic foundation. The classical β-convergence model examines the convergence characteristics of economic variables evolving over time, and a lack of spatial factors may lead to bias in the convergence results. Therefore, it is necessary to add a spatial lag term in the model as follows:

$$\ln\frac{UEE_{it}}{UEE_{it-1}} = \beta\ln UEE_{it-1} + \rho W\ln\frac{UEE_{it}}{UEE_{it-1}} + \lambda W\ln UEE_{it-1} + \sum_{k=1}^{m}\gamma_k X_{k,it} + \mu_i + \varepsilon_{it} \tag{7}$$

In equation (7), $X_{k,it}$ is the control variable and γ_k is the coefficient of the corresponding control variable. W is the spatial weight matrix of geographic distance, which was constructed based on the actual highway mileage between every two cities. This model can be estimated using the bias corrected least squares dummy variable method proposed by Yu and Lee (2012), and consistent parameter estimators can be obtained.

3.2.2 Mediation effect model

In order to empirically test the promoting effect of local government competition on urban eco-efficiency, a new dynamic panel model was constructed as follows:

$$\ln UEE_{it} = \beta\ln UEE_{it-1} + \varphi LGC_{it-1} + \sum_{k=1}^{m}\gamma_k X_{k,it} + \mu_i + \varepsilon_{it} \tag{8}$$

In equation (8), *LGC* is the core explanatory variable of this study, and two indicators were used to measure local government competition, namely administrative distance proximity competition (LGC^1) and geographical distance proximity competition (LGC^2). If the coefficient φ is significantly positive, it indicates that local government competition promotes the improvement of urban eco-efficiency. In order to highlight the pertinence of the research objectives, we only compared the two competition mechanisms in the analysis of the direct impact of local government competition on urban eco-efficiency, and the subsequent analysis of the mediation effect is based on the administrative distance proximity competition. In addition, to alleviate the endogeneity problem in the model, we lagged the core explanatory variable *LGC* by one period, and additionally, used a system-GMM to estimate the regression equation. According to the previous theoretical analysis and research hypothesis 2, this study referred to the practice of Baron and Kenny (1986), by adding environmental regulation (*ER*) as a mediation variable into the model to test the mediating pathway of local government competition effect:

$$ER_{it} = \psi ER_{it-1} + \alpha LGC_{it-1} + \sum_{k=1}^{m}\gamma_k X_{k,it} + \mu_i + \varepsilon_{it} \tag{9}$$

$$\ln UEE_{it} = \beta\ln UEE_{it-1} + \varphi LGC_{it-1} + \delta ER_{it} + \sum_{k=1}^{m}\gamma_k X_{k,it} + \mu_i + \varepsilon_{it} \tag{10}$$

In equation (9), the mediation variable is environmental regulation(*ER*), whose lag term is a necessary part of the dynamic panel model, and the coefficient ψ can measure the impact of environmental regulation behavior in the previous period on the later period. Meanwhile, if the coefficient α passes the significance test, local government competition leads to the strengthening of environmental regulation. Note that the mediation variable to equation (8) yields equation (10). In equation (10), φ and δ are the two parameters to be estimated. If they both pass the significance test, and α in equation (9) is also statistically significant, it means that the impact of local government competition on urban eco-efficiency partly comes from the mediation variable. If α in equation (9) and δ in equation (10) are statistically significant, and φ in equation (10) is not statistically significant, then the impact of local government competition on urban eco-efficiency comes completely from the mediation variable. If α in equation (9) is not statistically significant, then there is no corresponding mediating effect.

The one mediator variable and four control variables in the model were selected according to relevant literature. 1) For environmental regulation (*ER*), we used the entropy method to construct a comprehensive index of the removal rate of sulfur dioxide, the comprehensive utilization rate of industrial solid waste, the treatment rate of sewage and the harmless treatment rate of domestic waste as a proxy variable for environmental regulation (Li and Wu, 2016). 2) For industrial structure (*IND*), we used the ratio of the added value of the tertiary industry to that of all industries as a proxy variable (Huang et al., 2018). 3) For foreign direct investment (*FDI*), we used the ratio of the foreign investment to real GDP to represent the level of foreign investment (Shahbaz et al., 2015). 4) For technological progress (*TEC*), we used the real GDP of output per unit of electricity consumption as a proxy variable of technical progress level (Bai et al., 2018), and the higher the GDP of output per unit of electricity consumption, the higher the technical progress level. 5) For economic development (*PERGDP*), we used per capita real GDP as a proxy variable (Lin and Zhu, 2019).

3.3 Sample data

Considering that some statistical data are lacking or unavailable, this study excluded cities in Tibet and Taiwan, as well as Hong Kong and Macau, from the sample. The full sample included 278 prefecture-level cities across the country from 2006 to 2018, and the statistical data came from the

"EPS-China" dataset (http://www.epsnet.com.cn), "China Urban Statistical Yearbook 2007–2019" and the provincial statistical yearbooks over the years. All statistical data were cross-validated to ensure data consistency.

4 Analysis and discussion of empirical results

4.1 Convergence analysis of urban eco-efficiency

In Table 2, columns (1) and (2) report the absolute β-convergence and conditional β-convergence estimated results, respectively; while columns (3) and (4) give the spatial convergence estimated results with fixed effects and two-way fixed effects (equation (7)), respectively. Because of the lag of the explained variables in the model, this study used the system-GMM for parameter estimation based on the method of Chen and Golley (2014).

In the estimated results of all four models (Table 2), the coefficients of the lagged term (Lag(ln*UEE*)) are all negative at the significance level of 1%, which indicates the existence of convergence in the urban eco-efficiency in China from 2006 to 2018. After further calculations, we found that the convergence rate is 0.1450 under the absolute β-convergence model, which is significantly lower than that of the conditional β-convergence model (0.3327), indicating that the regional economic foundation was an important driving force for the convergence of urban eco-efficiency. After adding the spatial lag term into the model, the estimated contemporaneous spatial coefficient ρ and lag spatial coefficient η are both significantly positive, and at the same time, the convergence rate has increased to 0.5763. These results mean that the spatial factor is the key factor affecting the convergence of *UEE*, so as to narrow the regional gap of urban eco-efficiency and realize regional coordinated development.

Table 2 Regression results for the convergence of urban eco-efficiency

Variable	(1) Model Ⅰ	(2) Model Ⅱ	(3) Model Ⅲ	(4) Model Ⅳ
Lag(ln *UEE*)	–0.135***	–0.283***	–0.413***	–0.438***
	(–5.94)	(–7.97)	(–37.19)	(–35.41)
IND		0.018*	0.024***	0.051***
		(1.67)	(3.29)	(7.13)
TEC		0.004***	0.004***	0.004***
		(5.90)	(19.19)	(18.69)
FDI		3.39*	1.001	1.369*
		(1.85)	(1.22)	(1.93)
PERGDP		0.013***	0.027***	0.027***
		(4.47)	(26.40)	(26.47)
η			0.103***	0.051*
			(3.83)	(1.76)
ρ			0.173***	0.122***
			(6.36)	(3.68)
City effect	Yes	Yes	Yes	Yes
Time effect	-	-	No	Yes
Hansen test	0.875	0.343		
AR(2)	0.343	0.478		
R^2			0.679	0.571
F/Log*L*	8.12	11.10	1275.10	1072.32
Obs.	3614	3614	3614	3614
Convergence rate	0.1450	0.3327	0.5327	0.5763

Note: The *t*-statistics for the coefficients are in parentheses; ***, **, and * indicate 1%, 5%, and 10% significance levels, respectively; and the same notation is used in subsequent tables.

4.2 The impact of local government competition on urban eco-efficiency

In this study, regression equation (8) was estimated to examine the relationship between local government competition and urban eco-efficiency, and to compare the difference between administrative distance proximity competition (LGC^1) and geographical distance proximity competition (LGC^2). In Table 3, columns (1) and (2) give the estimated results of the benchmark regression equation (8) by using the system-GMM, and the AR(2) values are 0.881 and 0.867, respectively, indicating that the instrumental variables used meet the assumption of exogenous requirements. The Hansen test values are 0.308 and 0.204, respectively, indicating that there is no over-identification problem. The estimated coefficient of LGC^1 in column (1) is positive at the significance level of 1%, which indicates that the greater the intensity of local government competition, the faster the improvement of eco-efficiency. That is, in a given province, all prefecture-level municipal governments face the pressure of administration performance evaluation from the provincial government. Taking the city with the highest eco-efficiency as the benchmark, the more another city lags behind the benchmark, the stronger the pressure and motivation for that city to catch up. Specifically, when the pressure of local government competition increases by 1 percentage point, the urban eco-efficiency increases by 0.114 percentage points. The coefficient of LGC^2 is positive at the significance level of 5%, but its coefficient is smaller than that of LGC^1, indicating that the impact of geographical distance proximity competition on ecological efficiency is weaker than that of administrative distance proximity competition, thus verifying hypothesis 1. Columns (3) and (4) provide the estimated results of two-way fixed effects which are consistent with columns (1) and (2), indicating that the empirical test results are robust.

Table 3 Benchmark estimated results

Variable	Sys-GMM		Two-way FE	
	(1)	(2)	(3)	(4)
LGC^1	0.114*** (3.55)		0.219*** (18.66)	
LGC^2		0.102** (2.19)		0.167*** (3.69)
Lag(ln *UEE*)	0.598*** (7.78)	0.445*** (4.86)		
Control variable	Yes	Yes	Yes	Yes
R^2			0.198	0.168
F	21.380	32.373	46.813	101.81
Hansen test	0.308	0.204		
AR(2)	0.881	0.867		
Obs.	3614	3614	3614	3614

The impact of local government competition on urban eco-efficiency is largely achieved through environmental regulation (Zhang et al., 2020). Taking environmental regulation as a mediation variable, this study examined the mediation effect of the local government competition on urban eco-efficiency. Table 4 shows the estimated results of the mediation effect model (equations (8)–(10)). The coefficient of *LGC* in column (1) is positive at the significance level of 1%, at the same time, the coefficients of *LGC* in column (2) and of *ER* in column (3) are both positive at the significance level of 5%. These results indicate that the local government competition not only has a direct effect on urban eco-efficiency, but it also has a mediation effect on the improvement of urban eco-efficiency by strengthening environmental regulations.

Table 4 Estimated results of the mediation effect

Variable	(1) ln *UEE*	(2) *ER*	(3) ln *UEE*
LGC	0.114*** (3.55)	0.002** (1.99)	0.106*** (3.65)
ER			0.505** (2.20)
Lag(*ER*)		0.769*** (31.67)	
Lag(ln *UEE*)	0.598*** (7.78)		0.643*** (9.48)
Control variable	Yes	Yes	Yes
Hansen test	0.308	0.131	0.896
AR(2)	0.881	0.278	0.773
F	21.380	580.320	22.603
Obs.	3614	3614	3614

5 Heterogeneity analysis

5.1 Heterogeneity analysis of different regions

Table 5 shows the estimated results for the four major regions of the eastern, central, western and northeastern cities. The coefficient of *LGC* in column (1) is positive at the significance level of 1%, indicating that the local government competition of in the eastern cities did indeed lead to the improvement of the environmental regulations. The coefficient of *ER* in column (5) is positive at the significance level of 5%, showing that the urban eco-efficiency was improved by strengthening environmental regulation in the eastern cities, which is consistent with the estimated results of the full sample. The coefficient of *LGC* in column (2) is positive at the significance level of 5%, while the coefficient of *ER* in column (6) is negative at the significance level of 1%, which is completely different from column (5). These results show that local governments in the central region have improved the degree of environmental regulation when facing the competition from other cities, but have not achieved the goal of improving urban eco-efficiency. The above estimated results indicate that there are great regional differences between cities in the eastern region and those in the central region in the process of green transformation and development.

Theoretically, we can understand the impact of environmental regulations on urban eco-efficiency from two aspects. On the one hand, environmental regulations will limit the emissions of enterprise pollutants, which can rapidly reduce the pollution emissions of enterprises in the short term, and improve the urban eco-efficiency by stimulating the innovation ability of enterprises and increasing the application of energy saving and emission reduction technology in the long term. On the other hand, although the strengthening of environmental regulations controls pollution emissions to a certain extent, it also limits the production expansion of enterprises, reduces economic output, and produces compliance costs. When the reduction rate of economic output is

Table 5 Heterogeneity analysis of different regions

Variable	*ER*				ln *UEE*			
	(1) East	(2) Central	(3) West	(4) North-east	(5) East	(6) Central	(7) West	(8) North-east
LGC	0.005***	0.004**	0.006*	0.002	0.103***	0.137***	0.236***	0.156***
	(6.91)	(2.08)	(1.76)	(1.42)	(3.40)	(3.31)	(2.76)	(2.12)
ER					0.755**	–2.056***	1.483*	2.211**
					(1.98)	(–4.30)	(1.68)	(2.41)
Lag(*ER*)	0.658***	0.737***	0.748***	0.881***				
	(132.11)	(25.38)	(31.47)	(16.83)				
Lag(ln *UEE*)					0.553***	0.275***	0.473***	0.227***
					(7.03)	(9.53)	(4.40)	(9.79)
Control variable	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Hansen test	0.232	0.477	0.666	0.827	0.864	0.114	0.999	0.230
AR(2)	0.235	0.329	0.050	0.424	0.368	0.466	0.739	0.207
F	318.121	288.750	166.120	117.269	12.611	37.542	12.314	24.917
Obs.	1313	1157	702	442	1313	1157	702	442

lower than that of the pollution emissions, the level of urban eco-efficiency will decline. The urban economic development in the eastern cities started early, and the production technology is relatively advanced. Cities in the eastern region are economically developed and technologically advanced, and they vigorously implement the central ecological environmental governance resolution as a political priority to achieve high-quality development. The central region is still in the stage of economic expansion and bears the responsibility for undertaking the industrial transfer from the eastern region. Therefore, strict environmental regulations would greatly reduce the willingness of enterprises to invest and reduce the scale of production in the central region, which would lead to a sharp contraction in economic output. When the compliance cost exceeds the technological innovation effect, it is not conducive to the improvement of urban eco-efficiency. The above empirical results are similar to the conclusions of Feng et al. (2020), which are determined by the differences in the development stages and actual conditions of the eastern and central regions, and are also the externalization of the inherent law of regional economy.

Although the coefficient of *LGC* in column (3) satisfies the significance test, the significance level only reaches 10%, while the coefficient of *LGC* in column (4) does not satisfy the significance test. Strictly speaking, cities in the western and northeastern regions do not trigger the linkage between local government competition and environmental regulations, but the coefficients of *ER* in columns (7) and (8) are positive at the significance levels of 10% and 5%, respectively, indicating that the environmental regulations in these regions do not act as a mediation variable but directly promote the improvement of urban eco-efficiency. This situation is mainly due to the fact that most of the cities in these regions are resource-rich cities, with a high proportion of heavy industries such as the oil and coal industries. Environmental regulation has the most significant effects on the reduction of resource consumption and pollutant emissions.

5.2 Heterogeneity analysis in key and non-key environmental protection cities

Table 6 shows the results of the empirical analysis of key and non-key environmental protection cities, in which key environmental protection cities were determined according to the *Eleventh Five-year Plan of National Environmental Protection*, while all other cities were considered non-key cities.

The coefficients of *LGC* in columns (1) and (4) are positive at the significance levels of 1% and 5% respectively, indicating that local government competition plays a positive role in the growth of ecological efficiency in both types of cities. Comparing the regression coefficients of the two samples shows that the coefficient of key cities is 0.130, and that of non-key cities is 0.085, that is, the local government competition of the former is statistically greater than that of the latter. The coefficient of *LGC* in column (2) is positive at a significance level of 1%, while the coefficient of *LGC* in column (5) is not statistically significant. This indicates that in key cities, local governments promote eco-efficiency by strengthening environmental regulations, while non-key cities do not form this mechanism. The reason this mechanism exists is that the key cities of environmental protection are determined by the central government, so they receive more attention from the central government, and local government officials with a better ecological environment have a greater chance of promotion and are strongly motivated. Therefore, such cities must do something related to environmental protection.

5.3 Heterogeneity analysis in different periods

This study divided the sample period into two periods, 2006–2012 and 2013–2018, to analyze the heterogeneity of the mechanism by which local government competition influences urban eco-efficiency in the two different sample period. This will help to clarify the effectiveness and pathways for the construction of ecological civilization which was first put forward in 2012. In Table 7, columns (1) and (4) report the effects of local government competition on urban eco-efficiency in each period; while columns (2)–(3) and (5)–(6) report their respective estimated results after adding the mediation variables. The coefficients of *LGC* in columns (1) and (4) are positive at significance levels of 1% and 5%, respectively, indicating that the local government competition had a positive effect on the growth of urban eco-efficiency in both sample periods. The coefficient of *LGC* in the former periods is 0.120, and that in the latter period is 0.189. In other words, the local government competition in the latter period had a greater effect on the improvement of urban eco-efficiency, indicating that the construction of ecological civilization has played a positive role in high-quality development.

Table 6 Heterogeneity analysis in the key and non-key environmental protection cities

Variable	Key environmental protection cities			Non-key environmental protection cities		
	(1) ln *UEE*	(2) *ER*	(3) ln *UEE*	(4) ln *UEE*	(5) *ER*	(6) ln *UEE*
LGC	0.130**	0.004***	0.055**	0.085**	0.000	0.058*
	(2.60)	(11.74)	(2.11)	(2.39)	(0.85)	(1.68)
ER			2.387***			0.158
			(3.06)			(1.01)
Lag(ln *UEE*)	0.555***		0.529***	0.491***		0.475***
	(7.61)		(8.32)	(6.90)		(8.12)
Lag(*ER*)		0.340***			0.538***	
		(31.90)			(19.10)	
Control variable	Yes	Yes	Yes	Yes	Yes	Yes
Hansen test	0.235	0.144	0.693	0.136	0.177	0.111
AR(2)	0.894	0.508	0.932	0.899	0.253	0.875
F	15.107	142.392	13.310	25.156	456.452	19.707
Obs.	1417	1417	1417	2197	2197	2197

Table 7 Heterogeneity analysis in different periods

Variable	2006–2012			2013–2018		
	(1) ln *UEE*	(2) *ER*	(3) ln *UEE*	(4) ln *UEE*	(5) *ER*	(6) ln *UEE*
LGC	0.120***	0.006**	0.114***	0.189**	0.003***	0.127***
	(3.72)	(2.34)	(3.65)	(2.44)	(3.18)	(3.85)
ER			–0.546***			1.808***
			(–3.48)			(4.25)
Lag(ln *UEE*)	0.420***		0.162***	0.363***		0.509***
	(8.18)		(9.65)	(7.22)		(8.62)
Lag(*ER*)		0.679***			0.834***	
		(16.18)			(27.15)	
Control variable	Yes	Yes	Yes	Yes	Yes	Yes
Hansen test	0.149	0.051	0.122	0.095	0.301	0.210
AR(2)	0.901	0.261	0.754	0.756	0.861	0.348
F	17.740	99.250	51.955	64.619	124.920	19.134
Obs.	1946	1946	1946	1668	1668	1668

Further analysis found that the coefficient of *LGC* in column (2) is positive at the significance level of 5%, and the coefficient of *ER* in column (3) is negative at a significance level of 1%. These results show that although the local governments have strengthened their environmental regulations in order to control the pollution discharge and ecological damage of enterprises, that effort did not play a role in improving urban eco-efficiency. We noticed that the coefficient of *LGC* in column (5) is significantly positive at a 1% level, and the coefficient of *ER* in column (6) is significantly positive at a 1% level, which indicates that the local governments continued to maintain the enforcement standard of environmental regulations in the later stage of the sample period. In order to gain a competitive advantage in performance appraisal against the background of ecological civilization construction, local governments have formulated strict environmental regulation policies and significantly improved the level of ecological environmental governance. Obviously, the effects of environmental regulation in the two periods are not the same. In the short term, the government has disrupted the normal production and business activities of enterprises through strict environmental regulations, such as closing high-polluting enterprises and "pulling the gates and limiting electricity". As a result, enterprises have incurred huge economic losses in the process of evading environmental regulations, which is not conducive to the improvement of urban eco-efficiency. In the long term, environmental regulations force enterprises to increase their technological research and development efforts. Through technological upgrading, especially the use of green and environmental protection technologies for production, the efficiency of resource utilization has been improved, pollution emissions have been reduced, and a win-win situation has been achieved between economic output and improvement of the ecological environment.

6 Robustness analysis

There are many robustness analysis methods. In this study, the robustness analysis was carried out by changing the measurement method of urban eco-efficiency (Table 8). Here, the conventional super-efficiency DEA model was used to re-measure the urban eco-efficiency, and after re-regression, it was compared with the original estimated results. The results show that the coefficient of *LGC* is consistent with the results in column (1) in Table 4, indicating that the relationship between the local government competition and urban eco-efficiency is robust. The coefficient of *LGC* in column (2) is consistent with the estimated results of column (2) in Table 3 in terms of both sign and significance. The coefficients of the core explanatory variables *LGC* and environmental regulation in column (3) are also consistent with the previous estimated results, all of which indicate that the results of this study are robust.

Table 8 Estimated results of the robustness analysis

Variable	(1) ln *UEE*	(2) *ER*	(3) ln *UEE*
LGC	0.127**	0.003**	0.069**
	(2.11)	(2.24)	(2.25)
ER			0.760**
			(2.18)
Lag(ln *UEE*)	0.512***		0.493***
	(5.56)		(7.57)
Lag(*ER*)		0.731***	
		(25.04)	
Control variable	Yes	Yes	Yes
Hansen test	0.101	0.116	0.630
AR(2)	0.256	0.272	0.242
F	22.978	264.394	14.517
Obs.	3614	3614	3614

7 Conclusions and implications

7.1 Conclusions

This study theoretically established the logical link between local government competition and the spatial convergence of urban eco-efficiency, then brought environmental regulation as a mediated pathway into the analysis framework, and explained how local government competition promotes the sustainable catch-up of urban eco-efficiency to narrow the development gaps between regions. In terms of empirical strategies, this study calculated the urban eco-efficiency through the metafrontier super efficiency model based on NDDF, and analyzed the convergence characteristics of urban eco-efficiency by using the spatial convergence regression model. On this basis, two indexes of administrative distance proximity competition and geographical distance proximity competition were constructed, and their impacts on urban eco-efficiency were analyzed and compared. This analysis led to several specific conclusions.

First, there is a convergence phenomenon in urban eco-efficiency, and the regional gap is gradually narrowing. Compared with the traditional β-convergence model, the convergence rate based on the spatial convergence model reached a maximum of 0.5763, indicating that spatial interaction plays an important role in the convergence process of urban eco-efficiency. Second, both administrative distance proximity competition and geographical distance proximity competition promote the improvement of urban eco-efficiency, and the estimated coefficient of the former is greater than that of the latter. This difference indicates that the local government competition caused by ecological administrative performance assessment is an important driving force for narrowing the regional gap of urban eco-efficiency. Third, the pressure of local government competition will strengthen environmental regulations to control pollution and reduce ecological damage, and ultimately improve urban eco-efficiency. Fourth, the impact of local government competition on urban eco-efficiency has regional and temporal heterogeneity. The eastern regions and key environmental protection cities have improved their urban eco-efficiency by implementing strict environmental regulation policies, while the central region and non-key environmental protection cities have lowered their urban eco-efficiency. In terms of time periods, the strengthening of environmental regulation actually inhibited the improvement of urban eco-efficiency in the early sample period (2006–2012), while it was the opposite in the later sample period (2013–2018), which reflects the differences between the short-term and long-term effects of environmental regulations.

7.2 Implications

Based on the above research conclusions, we can offer three points of implications. 1) The reasonable division of environment supervision and control powers between central and local governments should be promoted under China's current environmental decentralization system. The central government needs to increase its environmental supervision to guide local governments in forming a new development pattern, and give full play to the leading ecological role of benchmarking cities. 2) The administrative performance evaluation index system of local government officials should continue to be optimized and perfected. The promotion of local government officials should be transformed from a "GDP tournament" into a comprehensive competitive ability that accounts for both economic development and environmental governance, and a new administrative performance evaluation system based on the improvement of ecological effects should be established. 3) The "top-down" and "bottom-up" ecological incentives should be combined to enhance the public's participation in local ecological and environmental governance, so that the superior government incentives and public environmental pressure can jointly encourage the local government to improve the ecological efficiency of the region. 4) The "one-size-fits-all" approach in the field of environmental governance should be avoided. The resource endowment, technical conditions and management level of each region need to be considered, and local governments need to be given more independence and flexibility in formulating environmental regulatory policies. Local governments should properly handle the relationships between short-term interests and long-term development in ecological environment governance on the basis of respecting the inherent law of economic development, clarify the phased goals of economic development and ecological environment governance, seek green development pathways that are suitable for local conditions, and finally realize the regional coordinated improvement of urban eco-efficiency. Of course, there are still many deficiencies in this study. For example, in the analysis of the mechanism of influence between local government competition and the convergence of urban eco-efficiency, only the most key environmental regulations are discussed in general terms, and some specific policy approaches, such as the policy of industrial structure upgrading and rationalization, public research funding policy, etc., are not thoroughly examined. In addition, there are also some defects in the construction of the local government competition index, which leads to some endogenous problems that are not well resolved in this study. These shortcomings should be improved in future research.

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中国城市生态效率的空间收敛性分析：基于地方政府竞争的视角

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摘　要：生态环境区域协同治理是促进区域可持续发展的重要途径，而地方政府竞争是中国区域生态环境治理过程中容易被忽视的体制性因素。选取 2006–2018 年中国 278 个地级市的面板数据，运用空间收敛回归模型和中介效应模型，从地方政府竞争的角度分析城市生态效率的空间收敛性及其影响机制。结果表明：首先，城市生态效率呈现收敛趋势，空间因素是影响城市生态效率收敛的关键因素；其次，地方政府竞争作为一种制度因素，在促进城市生态效率空间收敛的过程中发挥着重要作用，并且行政距离邻近竞争比地理距离邻近竞争的效应更强，其竞争压力程度每增加 1 个百分点，城市生态效率就增加 0.114 个百分点。再次，地方政府竞争导致了严格的环境规制政策，这些规制政策整体上促进了城市生态效率的改善，从而缩小了落后城市与先进城市的差距。最后，地方政府通过环境规制政策对城市生态效率产生异质性影响。具体而言，在地方政府间的竞争压力下，东部和环保重点地区城市的环境规制改善了生态效率，而中部和非环保重点地区城市的效果则相反。本研究的上述结果表明，如果进一步将城市生态效率引入地方官员行政绩效评价指标体系，可以通过生态竞争缩小地区之间的区域差距。

关键词：空间收敛; 城市生态效率; 地方政府竞争; 环境规制