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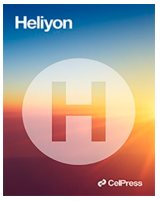

Have government environmental auditing contributed to the green transformation of Chinese cities?

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ABSTRACT

Faced with growing ecological problems, governments around the world are increasingly focusing on improving ecology and the environment. The topic of urban green transformation has attracted a great deal of research. However, not much of it has focused on the effectiveness of government environmental auditing, especially from the perspective of its role in sustainable governance. This article takes 285 cities in China from 2009 to 2020 as the research scale. It innovatively measures government environmental audits with dual indicators and uses System Gaussian Mixture Model (SGMM) to estimate that government environmental audits significantly promote urban green transformation, and the impact of "whether to implement government environmental auditing" is greater than the "intensity of government environmental auditing". The results show that government environmental audit intensity has a stronger impact on urban green transformation in eastern cities. In contrast, environmental audit coverage has a stronger impact in western cities. Moreover, the effect of government environmental auditing on green transformation is more significant in small and medium-sized cities and key environmental protection cities than in large cities and non-key environmental protection cities, respectively. Government environmental auditing could facilitate urban green transformation by restraining local government behavior, forcing green technology innovation, and promoting industrial structural upgrading. In addition, the intensity of government environmental auditing can better act on green transformation through the fore-mentioned mechanisms. It can play a crucial role in green technology innovation.

1. Introduction

China has more than 600 cities of various sizes, with a population exceeding 900 million. Its greenhouse gas emissions account for one-third of the global total, and seven out of the ten most polluted cities in the world are located in China. It is evident that green and low-carbon transformation has become one of the most urgent tasks for Chinese cities. In fact, since the first International Urban Green Environmental Protection Expo in 2001, China has embarked on the journey of urban green construction. However, so far only 15 cities have been selected as global green cities, indicating that progress towards green transformation is still slow. Government environmental auditing is the supervision, evaluation, and certification of the authenticity, legality, and effectiveness of the

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environmental management and related economic activities of audited units by auditing agencies [1], and has become an essential tool for environmental governance and an integral part of the national governance system, promoting economic and social transformation [2]. Meanwhile, government environmental auditing is an effective tool for assessing environmental performance, including emissions and resource consumption. It also helps identify opportunities for mitigating carbon emissions in green governance [3]. In 2009, the Audit Office issued a landmark document, "Opinion on Strengthening Resource and Environmental Audit," marking the formalization and institutionalization of environmental audit in the Chinese government. Since the 18th National Congress of the Communist Party of China, government environmental audits have been placed in a prominent position in the construction of national ecological civilization. A series of audit projects targeting urban sustainable development and pilot audits on natural resource assets for departing leaders have been carried out. However, due to a lack of empirical evidence, whether government environmental audits promote China's urban green transformation still remains unanswered and requires further research [4,5].

Some scholars have examined the connection between environmental auditing and environmental governance in the existing literature. From a managerial standpoint, environmental audits help shape the environmental practices of companies, governments, and institutions [6–8], regulate the use of government environmental protection funds [9], promote institutional and social innovation and development, improve eco-efficiency, and ultimately contribute to socio-economic transformation and development [10–12]. From an auditing perspective, environmental audits help auditees reduce potential environmental violations by fulfilling the governance and defense functions of auditing. This enables companies to mitigate environmental and resource risks, encourage increased investment in environmental protection, and ultimately enhance overall environmental governance [13,14]. From empirical studies, national environmental audits can significantly improve regional energy efficiency and mainly through technological progress [15, 16]; however, the literature also finds that the overall impact of environmental audits on water quality is positive but not significant [17].

Another aspect of the study highlighted the significance of conducting environmental audits for promoting green development in the city. Firstly, embracing environmental audits enhances the transparency of audited areas and boosts the ESG performance of publicly listed companies [18,19], which generates more environmental reputation and economic performance and stimulates public participation in regional green development [20]. Furthermore, environmental audits conducted in special districts have fostered green development within the region. Notably, China's "clean production audit" initiated in 2004 and the "leading cadres' natural resources assets discharge audit" introduced in 2015 have successfully encouraged eco-friendly practices among enterprises and bolstered government investments in environmental protection. Consequently, this has led to a steady enhancement of overall regional green development. The overall level of green development in the region has consistently improved [21]. Finally, environmental audits ultimately contribute to the development of urban ecological civilization and industrial structure [22,23]. Environmental audits, as an external monitoring mechanism, significantly contribute to the development of urban ecological civilization by conducting follow-up audits on environmental policies and performance audits on projects [11,17]. Environmental audits compel enterprises to engage in technological innovation and enforce corrective measures for non-compliance, thereby promoting the upgrading of industrial structure [5].

However, the majority of these studies are case studies. Individual empirical studies using DID models have concluded that the implementation of environmental audit policies did not lead to a significant improvement in water quality [5,17]. Based on the above reasons, this article takes 285 prefecture-level cities in China as samples to examine the relationship and underlying mechanism between government environmental audits and urban green transformation through rigorous empirical methods. This article has two main contributions: first, it confirms for the first time the role of government environmental audits in green governance, providing new governance tools for green transformation in developing country cities. Government environmental audits include senior officials and government departments in the audit scope. Its greater mandatory power and deterrent effect are conducive to solving the difficulties of green governance in developing country cities. In addition, a series of heterogeneity analysis and mechanism tests in this article provide references for differentiated and precise implementation of government environmental audits. Second, it creatively measures government environmental audit variables using smaller-scale city samples and more rigorous empirical methods. This article uses text analysis to statistically analyze keywords from the "China Audit Yearbook" published by the Audit Office to observe the implementation and intensity of government environmental audits, solving the problem of how to measure government environmental audits. At the same time, although there is a large amount of data collection work with 285 prefecture-level cities as samples, it can more comprehensively reflect overall urban conditions; using SGMM model estimation can alleviate endogeneity issues.

2. Theoretical analysis and research hypothesis

2.1. The logic of government environmental auditing for urban green transformation

Government environmental audit serves the dual purpose of identifying environmental issues, mitigating environmental risks, enhancing information disclosure quality [24]. It is a crucial institutional component in establishing a contemporary environmental governance system for the nation [2]. Thus, it can promote sustainable urban development by enhancing public environmental performance [15]. At the same time, government environmental auditing helps to promote and guide the proper use and efficient management of funds, policies, and personnel in urban green transformation. This is achieved through project performance audits, policy tracking audits, Officials' Off-Office Accountability Audit of Natural Resource Assets, as well as combining them with economic responsibility audits and internal audits. These efforts contribute to the development of green and low-carbon cities. In this paper, we make the following assumption [25].

H1. Government environmental auditing can contribute to the green transformation of cities.

2.2. Mechanism of government environmental audit affecting urban green transformation

Government environmental auditing influences the green transformation of cities by regulating the actions of local governments. The behavior of the government plays a crucial role in a city's development, and when economic growth becomes the primary objective pursued by the government, the progress towards green development in cities is limited [26]. However, with the strict supervision of centralized and comprehensive government environmental auditing, local governments have been compelled to correct their short-term behavior. This has led them to redirect their efforts towards promoting green development and well-being in cities. For instance, the establishment of a central audit committee in China has empowered government environmental auditing by enhancing its oversight role. As a result, local governments are now encouraged to prioritize sustainable growth instead of solely focusing on GDP achievements [27] and pushing cities toward green development.

Second, government environmental auditing plays a role in driving the green transformation of cities through promoting innovation in green technologies. On one hand, audit reports from environmental auditors expose irregularities and shortcomings, prompting audited entities to allocate more funds towards green technologies and enhance their performance. Additionally, these reports discourage the hasty implementation of high-polluting and high-carbon projects, compelling enterprises to invest more in research and development of green technologies [28]. On the other hand, environmental audits utilize tools such as audit rectification and audit return to identify the parties responsible for environmental issues. They establish a list of green transformation measures and consistently monitor the implementation of these measures by audited entities. This process contributes to the institutionalization and long-term impact of urban green transformation.

Finally, government environmental auditing plays a crucial role in driving green transformation through the promotion of industrial structural upgrades. By exercising supervisory power, environmental audits expedite the elimination of outdated production capacities, such as small projects in chemical, iron and steel, cement, electroplating, printing, and dyeing industries. Additionally, they facilitate faster improvements in projects characterized by high consumption, high pollution levels, high risk factors, low output rates, and low efficiency levels [29]. This promotes the adjustment and optimization of social investment and government expenditure structures. It also effectively guides the supply and consumption of green and low-carbon products, helping to build regional ecological markets. Environmental audits facilitate the transformation of industrial structures into ecological green and advanced rationalization. They form a synergistic pattern of industrial ecology and ecological industrialization, accelerating the green transformation of cities. Accordingly, the following hypothesis is proposed in this paper.

H2. Government environmental audits impact urban green transformation by limiting the actions of local governments.

H3. Government environmental audits hinder the innovation of green technologies, thereby impeding urban green transformation.

H4. Government environmental audits impact urban green transformation by facilitating the upgrading of industrial structures.

3. Research design

3.1. Samples and data

This article selects smaller prefecture-level cities as samples, and after excluding cities with missing data, a total of 285 samples (including municipalities directly under the central government) were obtained, covering 97.3 % of the total number of cities in the country. The time span is from 2009 to 2020, which is the stage of development and improvement of China's government environmental audit. It includes various types of routine audits and special audits conducted by audit bureaus across the country on ecological environment. The basic information for government environmental audits comes from the annual "China Audit Yearbook" over the years, while other indicator data are sourced from "China Economic Net Statistical Database" and "China Patent Database". Individual missing values are supplemented or calculated using interpolation method based on relevant provincial statistical yearbooks.

3.2. Model setting

To test the impact of government environmental auditing on urban green transformation, the following dynamic panel model is first constructed in this paper.

$$UGTit = \mu 0 + \alpha 0\ UGTit\text{-}1 + \alpha 1\ GEAit + \beta 1\ EDLit + \beta 2\ FIRit + \beta 3\ EFEit + \beta 4\ MDit + \varepsilon it \quad (1)$$

where i and t are regions and years, respectively, UGTit represents urban green transition, and GEAit is government environmental audit. Drawing on previous studies, economic development level (EDL), financial related rate (FIR), education financial expenditure (EFE), and marketization degree (MD) are used as control variables. α and β are coefficients to be estimated, μ0 is the intercept term, and ε is the random error term.

To test H2-H4, we introduce local government behavior (LGB), green technology innovation (GTI), and industrial structure upgrading (ISU) and their respective interaction terms with government environmental auditing based on model (1).

$$UGTit = \mu 0 + \alpha 0\ UGTit\text{-}1 + \alpha 1\ GEAit + \alpha 2\ GEAit \times LGBit + \alpha 3\ LGBit + \beta 1\ EDLit + \beta 2\ FIRit + \beta 3\ EFEt + \beta 4\ MDit + \varepsilon it \quad (2)$$

$$UGTit = \mu 0 + \alpha 0\ UGTit\text{-}1 + \alpha 1\ GEAit + \alpha 2\ GEAit \times GTIit + \alpha 3\ GTIit + \beta 1\ EDLit + \beta 2\ FIRit + \beta 3\ EFEit + \beta 4\ MDit + \varepsilon it \quad (3)$$

$$UGTit = \mu 0 + \alpha 0\ UGTit\text{-}1 + \alpha 1\ GEAit + \alpha 2\ GEAit \times ISUit + \alpha 3\ ISUit + \beta 1\ EDLit + \beta 2\ FIRit + \beta 3\ EFEit + \beta 4\ MDit + \varepsilon it \quad (4)$$

In this model, the primary focus is on the regression outcome of the interaction term. If it proves significant through testing, it suggests that the government's environmental audit has influenced the city's green transformation using this mechanism. To address concerns about reverse causality and endogeneity resulting from omitted variables, this paper will employ the SGMM method for estimation.

3.3. Variable measurement

(1) Explained variables

At present, there are two main types of measurement methods for urban greening: one is the index method, which constructs the green transformation index by selecting dozens of indicators [30], but the indicator selection criteria and assignment methods are more controversial and require higher data integrity. The second is the efficiency method, which uses the DEA model to solve green total factor productivity, emphasizing higher economic output and less environmental pollution with fewer resource inputs, which is the essence of urban green transformation [31]. Considering the limitations of the exponential method and the reality that there are hundreds of city samples in this paper, we adopt the efficiency method, specifically using the non-radial EBM-Undesirable model proposed by predecessor's research [32], which can better balance the advantages of the traditional radial DEA model and the non-radial SBM model.

The key to this method is constructing a comprehensive green transformation input-output indicator system. Taking into account resource, energy, and environmental constraints, this paper selects five input indicators: labor (number of employees per unit at the end of the year), capital (calculated using the perpetual inventory method proposed by Holz and Sun [33] to determine physical capital stock), land (administrative region's land area), energy (electricity consumption of society as a whole), and water resources (total water supply). Additionally, four output indicators are chosen: desired output (real GDP) and non-desired outputs such as industrial wastewater emissions, industrial sulfur dioxide emissions, and industrial smoke/dust emissions. The UGT can be calculated using MaxDEA Ultra software.

(2) Explanatory variables

Measuring government environmental auditing poses a significant challenge in this study. The approach of this paper is to employ textual statistics, as the linguistic meaning of texts can better capture people's precise attitudes, opinions, values, and interests within the context of high-context communication in China. The China Audit Yearbook serves as an authoritative publication through which Chinese government auditing agencies disclose their annual work. By searching for terms such as "ecological environment," "environmental protection," and "pollution control," relevant information can be obtained.

By searching for keywords like "natural resource assets" and "river chief system," we can gain a better understanding of how the government implements environmental auditing. Consequently, we assess the explanatory variables from two different perspectives: first, "whether government environmental audit is implemented" (GEA1) indicates that the city implements government environmental audit when any of the aforementioned keywords appear, GEA1 = 1, otherwise GEA1 = 0; second, "government environmental audit intensity" (GEA2) represents the sum of the frequency of occurrence of any of the aforementioned keywords.

(3) Mediating variables

Local government behavior (LGB) is expressed by "tax revenue as a proportion of local GDP", which is an inverse indicator; green technological innovation (GTI) is expressed by "Ln (1 + number of green patents)"; industrial structure upgrading (ISU) is expressed by ISU is expressed by "the proportion of output value of secondary industry to GDP", which is the inverse indicator. Among them, the number of green patents is expressed in the "China Patent Database" by the six major fields of energy conservation and environmental protection, clean production, clean energy, ecological protection and restoration, urban and rural green infrastructure, ecological agriculture, etc., as specified in the 2019 〞Guidance of the National Development and Reform Commission, Ministry of Science and Technology on Building a Market-oriented Green Technology Innovation System". Classification numbers are used as search criteria, and cities are used as address keywords to gather statistics. Given the various uncertainties in cultivating, applying for, and licensing green patents, along with the significant fluctuations in data each year, this paper employs a 3-year moving average to calculate the number of green patents.

(4) Control variables

Economic development level (EDL) is expressed by "Ln (GDP per capita)"; financial related rate (FIR) is expressed by "RMB deposit and loan balance of financial institutions/GDP"; financial expenditure on education (EFE) is expressed by "The marketization degree (MD) is expressed by "China's marketization index by province", because the marketization degree of cities in the same province is less different, we use the data of the province where the city is located instead, and we also use 2009 as the base period for data caliber

processing.

To sum up, the detailed description of all the variables in this study are listed in Table 1 in the Appendix. The multicollinearity test of Table 2 shows that the Mean VIF is all less than 10, indicating that there is no issue of multicollinearity. As can be seen from Table 1, the mean value of urban green transformation reached 1.046 over the 12-year period, which is greater than unity and represents a favorable trend of green transformation with an average annual growth rate of 4.6 %. It is above the 50 % quantile, showing a right-skewed distribution characteristic, while the standard deviation is modest, indicating that the level of green transformation in most cities is still below the mean, but the internal differences are minor. The mean value of GEA1 is 0.405, indicating that an average of 40.5 % of cities have conducted government environmental auditing, which is inextricably linked to the auditor's constant focus on the ecological environment; However, the large standard deviation again implies a significant disparity among cities. The mean value of GEA2 is 0.775, implying an average of 0.775 government environmental auditing per year per city, and the dispersion coefficient is larger than that of GEA1, indicating a larger inter-city gap.

4. Empirical methodology and results

First, this study uses the Breusch-Pagan Lagrange Multiplier (LM) test proposed by Breusch and Pagan [34] and the Pesaran cross-section dependence (CD) test developed by Baltagi and Hashem Pesaran [35] to examine possible cross-sectional dependence in the panel. These tests are discussed in Section 4.1. Secondly, to verify the stationarity of each variable, this study employs a panel unit root test that takes into account cross-sectional dependence. This is explained in Section 4.2. Thirdly, to avoid the interference of reverse causality and endogeneity issues caused by omitted variables, this paper will use the GMM method for estimation. Compared to Difference-GMM, System-GMM (SGMM) can introduce more instruments to improve efficiency. In the subsequent sections of this paper, SGMM will be used for estimation. This is explained in Section 4.3.

4.1. Cross-sectional dependence tests

When examining the relationships between selected variables in the panel data model, it is important to consider cross-sectional dependence. Ignoring this issue can result in significant estimation bias and size distortions [36]. Therefore, before analyzing the stationary properties of the variables, this study first checks for possible cross-sectional dependence in the panel. The Breusch-Pagan LM test and Pesaran CD test are used for this purpose. Table 3 presents the results of these two tests, which strongly reject the null hypothesis at a significance level of 1 %. This provides strong evidence that there is cross-sectional dependence among China's cities. As a result, when conducting further analysis using this panel sample, we use estimation techniques that take into account cross-sectional dependence.

4.2. Panel unit root tests

Before estimating the parameters in the panel data model, it is necessary to conduct panel unit root tests to avoid spurious regression. Given the presence of cross-sectional dependence in the panel data, traditional first-generation panel unit root tests like Levin-LinChu (LLC), Im, Pesaran, Shin (IPS), augmented Dickey Fuller (ADF), and Phillips-Perron (PP) tests are no longer suitable. Instead, second-generation panel unit root tests proposed by Pesaran [35] that account for cross-sectional dependence are more appropriate for this study. This includes the Pesaran cross-sectionally augmented IPS (CIPS) test.

Table 4 displays the results of the panel unit root tests. From this table, not all variables are stationary at levels; however, when differenced once, we can significantly reject the null hypothesis at either a 1 %, 5 %, or 10 % level for all series. This indicates that the selected variables have an integrated order and demonstrate a long-run equilibrium relationship among them. Therefore, we can conclude that our estimation is reliable and effective.

4.3. Baseline regression

The estimation results for the SGMM model are presented in Table 5. From Tables 5 and it can be seen that the p-values of the

Table 1
Descriptive statistics.

Variables	mean	sd	min	max	p25	p50	p75
UGT	1.046	0.128	0.532	2.342	0.993	1.037	1.097
GEA1	0.405	0.361	0.000	1.000	0.000	0.000	1.000
GEA2	0.775	0.976	0.000	10.000	0.000	0.000	1.000
LGB	7.380	1.592	2.245	10.482	3.107	7.468	8.992
GTI	4.788	1.283	0.630	8.093	3.903	4.747	5.767
ISU	0.495	0.102	0.135	0.805	0.430	0.494	0.562
EDL	10.872	0.625	8.995	12.988	10.397	10.902	11.306
FIR	2.937	1.155	0.855	8.921	2.138	2.834	3.638
EFE	7.082	0.559	3.881	9.876	6.821	7.156	7.578
MD	8.654	1.825	4.749	16.240	7.688	8.258	8.977

Table 2
Multicollinearity test.

Variable	VIF	1/VIF	VIF	1/VIF
GEA1	1.09	0.919120		
GEA2			1.14	0.877253
EDL	3.53	0.283114	3.54	0.282682
FIR	1.11	0.897188	1.12	0.894096
EFE	3.82	0.261616	3.83	0.261079
MD	1.69	0.593252	1.68	0.594870
Mean VIF	2.25		2.26	

Table 3
Results of the cross-sectional dependence tests.

Test	Statistics	Prob.
Breusch-Pagan LM test	11.23***	0.0008
Pesaran CD test	315.073***	0.0000

Notes: The null hypothesis is that there is no cross-sectional dependence within the panel data. The t-values in parentheses indicate significance levels: *p < 0.1, **p < 0.05, ***p < 0.01.

Table 4
Results of the panel unit root tests.

Variable	Level		1st difference	
	Intercept	Intercept and trend	Intercept	Intercept and trend
UGT	−1.789	−1.849	−5.166***	−5.141***
GEA1	−1.899	−1.858	−5.620***	−5.633***
GEA2	−1.905	−1.959	−5.756***	−5.751***
EDL	−1.847	−1.903	−4.165***	−4.294***
FIR	−1.330	−1.379	−3.611***	−3.981***
EFE	−1.860	−1.922	−4.596***	−4.634***
MD	−1.704	−1.902	−4.484***	−4.270***

Note ***, **, and * indicate statistical significance at the 1 %, 5 %, and 10 % levels, respectively.

autocorrelation AR(2) for the disturbance terms of each model are relatively large. The P-value is larger than others, implying that there is no second-order autocorrelation in the difference of the disturbance terms. The P-values of the Sargan tests are all above 0.1, which also indicates that all instrumental variables are exogenous, implying that the estimation results are valid. The normalized regression coefficient of GEA1 reaches 0.133 and is significant at the 1 % level, indicating that the implementation of government environmental auditing can contribute to the green transformation of the city. Meanwhile, the standardized regression coefficient of GEA2 in estimation (2) is 0.097, which also passes the significance test, thus supporting Hypothesis H1. Furthermore, when comparing the standardized regression coefficients of the two variables, it becomes evident that "whether or not to implement government environmental auditing" plays a more significant role in driving green transformation. This could be attributed to the fact that current government environmental audits are primarily focused on achieving "wide coverage" and lack a comprehensive incentive and

Table 5
Baseline regression results.

Variables	(1)	(2)	(3)
L. UGT	0.197*** (14.19)	0.201*** (13.66)	0.198*** (13.49)
GEA1	0.133*** (3.15)		
GEA2		0.097*** (4.89)	0.103** (2.67)
GEA2 square item			−0.011 (−0.34)
EDL	0.201*** (2.95)	0.205*** (3.00)	0.193*** (2.82)
FIR	0.177** (2.43)	0.179** (2.48)	0.175** (2.29)
EFE	0.199*** (2.93)	0.211** (3.02)	0.210** (2.94)
MD	0.172*** (2.42)	0.204*** (2.94)	0.200*** (2.73)
_Cons	0.025 (0.63)	0.034 (1.00)	0.032 (0.91)
AR(2)-P	0.862	0.965	0.983
Sargan-P	0.252	0.204	0.227
obs.	3135	3135	3135

Note: The regression coefficients in the table are standardized regression coefficients; standardized regression coefficients = unstandardized regression coefficients × standard deviation of explanatory variables/standard deviation of explained variables. The t-values in parentheses are* p < 0.1,**p < 0.05,***p < 0.01, and the same later.

Table 6
Robustness test results.

	LSDV		Change the sample size				DID		PSM	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
L. UGT	0.235*** (8.33)	0.233*** (8.29)	0.202*** (16.11)	0.207*** (6.28)	0.201*** (12.38)	0.204*** (11.90)	0.195*** (13.83)	0.199*** (13.21)	0.201*** (14.45)	0.207*** (13.49)
GEA1	0.266*** (3.92)		0.156*** (3.87)		0.159*** (3.28)		0.158*** (3.53)		0.135*** (3.16)	
GEA2		0.150*** (4.00)		0.130*** (5.62)		0.103*** (4.12)		0.111*** (4.15)		0.102*** (5.08)
Treat × Post							0.121*** (2.73)	0.084** (2.02)		
Control variables	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

constraint system. Consequently, even with more rigorous environmental audits in place, urban green transformation will not progress significantly.

Government environmental audit is both a state institution and a special environmental regulation method [37]. Considering that studies have confirmed the possible inverted U-shaped relationship between environmental regulation and green development [38], this paper re-estimates (2) by adding the GEA2 squared term to the estimation of (2). The results from (3) show that the regression coefficient of the GEA2 squared term, although negative, does not pass the significance test, indicating that there is not yet an inverted U-shaped relationship between the intensity of government environmental audit and urban green transformation. This also implies that government environmental auditing is currently playing a positive role and there is no hindrance to urban green transformation. This finding not only expands the unique role of existing government environmental auditing but also offers new ideas for promoting future urban green transformation.

4.4. Robustness tests

(1) Replacement of estimation method. The dynamic panel bias-corrected LSDV method, which also allows the first-order lag term of the explanatory variable to be used as the explanatory variable, is used for estimation in this paper. From the results in (1)–(2) of Table 6, the standardized regression coefficients of GEA1 and GEA2 are roughly consistent with the previous ones in terms of direction, tentatively indicating that the previous estimates are reliable.

(2) Change the sample size. There are significant differences between municipalities, provincial capitals, and other cities. This paper excludes and analyzes them separately. The results from (3)–(4) indicate that both GEA1 and GEA2 coefficients pass the significance test. Furthermore, the former coefficient is larger than the latter, similar to the baseline regression. Furthermore, this paper excludes and regresses the data for this year due to the significant impact of the COVID-19 pandemic that devastated the world in 2020.

(3) Double difference method (DID). The Off-Office Accountability Audit of Natural Resource Assets, which is a crucial part of the government's environmental audit, was tested in 2015 and then gradually introduced between 2016 and 2017. It was finally fully implemented in 2018. As a result, we designated the pilot cities as the experimental group and the non-pilot cities as the control group. This paper specifically examines the regression coefficients of GEA and Treat × Post. As shown in (5)–(6) of Table 3, the interaction terms Treat × Post show a significant positive effect, suggesting that the Officials' Off-Office Accountability Audit of Natural Resource Assets positively influences urban green transformation. Additionally, GEA1 and GEA2 remain statistically significant, aligning with the baseline regression results. This indicates that the findings of this paper are robust even when considering external policy effects.

(4) Propensity scores matching method (PSM). To avoid problems such as missing variables due to the use of dummy variables to define explanatory variables, PSM is chosen in this paper to test the robustness of the results while avoiding the endogeneity problem. In this paper, cities with and without government environmental auditing are used as experimental and treatment groups, respectively, and control variables are used as covariates. The regression results for the matched samples are presented in (7)–(8) of Table 6, and GEA1 and GEA2 remain significant, indicating that the baseline regression results are robust.

4.5. Heterogeneity analysis

(1) Different regions

China's eastern, central, and western regions have significant differences in terms of their development bases and economic levels, and it is necessary to test them by region. As shown in Table 7, both GEA1 and GEA2 pass the significance test, indicating that the environmental audit by various regions' governments is beneficial for the green transformation of the city. The coefficient of GEA2 in the eastern region is significantly larger than that of GEA1, which is due to the fact that the green transformation in the eastern cities has been in "deep water," the government environmental audit has started earlier, and the incentive and constraint mechanisms are relatively sound. Therefore, increasing the intensity of the government environmental audit can produce more obvious effects. The GEA1 and GEA2 coefficients are close to each other for the central region, and the slightly larger GEA2 shows convergence with the eastern region in terms of future development paths. The coefficient of GEA1 for the western region is larger than that of GEA2, and the coefficient is the largest among the three regions, indicating that "whether or not to implement government environmental auditing" is crucial for the western region, while its GEA2 is the smallest, indicating that the western region needs to improve the relevant

Table 7
Regression results for different regions.

Variables	East		Middle		West	
L. UGT	0.101** (2.42)	0.109*** (2.73)	0.284*** (71.19)	0.283*** (60.70)	0.199*** (9.71)	0.201*** (11.85)
GEA1	0.052* (1.90)		0.142*** (9.75)		0.407*** (8.94)	
GEA2		0.283*** (4.50)		0.165*** (19.18)		0.141*** (7.17)
Control variables	YES	YES	YES	YES	YES	YES
AR(2)-P	0.427	0.284	0.264	0.253	0.743	0.834
Sargan-P	0.999	0.998	0.745	0.642	0.996	0.989
obs.	1111	1111	1067	1067	957	957

supporting system. In conclusion, the coverage rate of government environmental auditing should be of concern for the green transformation of cities in economically backward regions, while for the green transformation of cities in economically developed regions, the intensity of government environmental auditing should be increased.

(2) Different types of cities

In this paper, we further analyze the impact of government environmental auditing on green transformation under different conditions, such as the size of the city and whether it is included in the list of key cities for environmental protection. The estimation results in Table 8 are consistent in that the GEA1 coefficient is larger than the GEA2 coefficient for both large, small, and medium-sized cities, as well as key and non-key environment cities. Government environmental auditing is more effective for promoting green transformation in small and medium-sized cities and key environmental cities compared to large cities and non-key environmental cities. This is because the challenges of green transformation are less complex and difficult in smaller cities [31], allowing government environmental auditing to have a greater impact. Key environmental cities are included in national development plans and have a series of incentive policies to support them (the coefficient of GEA2 is larger than all other regressions as an example), and government environmental auditing is more conducive to the formation of a powerful audit supervision system, thus accelerating the green transformation of cities.

4.6. Impact mechanism test

Based on the above assumptions, we also examine the three main mechanisms by which government environmental auditing affects urban green transformation. From the estimates (1)–(2) in Table 9, it can be seen that the standardized regression coefficients of LGB all pass the 5 % significance test, indicating that constraining local government behavior is conducive to enhancing urban green transformation. Combining the coefficients of the interaction terms shows that government environmental auditing can promote urban green transformation by constraining local government behavior, and Assumption H2 holds. The GTI in estimates (3)–(4) is all significantly positive, indicating that green technology innovation is conducive to urban green transformation. Combined with the statistically significant positive normalized regression coefficients across products, we can see that the governmental environment contributes to urban green transformation by enhancing green technology innovation, and assumption H3 holds. Estimates (5)–(6) present a similar conclusion that government environmental auditing can contribute to green transformation by promoting industrial structure upgrades, and hypothesis H4 also holds.

From the lateral comparison in Table 6, the normalized regression coefficients of across product of GEA2 with local government behavior, green technological innovation and industrial structure upgrading are all larger than those of GEA1, indicating that increasing the intensity of government environmental auditing can better restrain the short-term behavior of local governments, force economic agents to implement green technological innovation and promote industrial structure transformation, thus producing a stronger green governance effect. This clearly shows the significance of enhancing government environmental auditing and emphasizing the audit focus, aligning with the proposal in the "Fourteenth Five-Year" National Audit Development Plan to "increase resource and environmental audits". Additionally, the standardized regression coefficients for the interaction terms between local government behavior, green technology innovation, and industrial structure upgrading with GEA2 are −0.318, 0.391, and 0.209 respectively. This indicates that the green technology innovation mechanism has a greater impact, followed by the local government behavior mechanism, and finally the industrial structure upgrading mechanism. Therefore, to enhance the effectiveness of government environmental auditing in promoting green governance, the primary focus should be on fostering green technological innovation. The secondary focus should involve regulating local government actions and optimizing industrial structure upgrades. This will ensure a systematic approach that overcomes transmission barriers and collectively drives urban green transformation.

Table 8
Regression results for different types of cities.

	Large Cities		Small and medium-sized cities		Key Environmental Cities		Non-Key Environmental Cities	
L. UGT	0.193***	0.188***	0.242***	0.236***	0.111***	0.101***	0.242***	0.243***
	(21.88)	(22.50)	(41.30)	(42.22)	(7.37)	(7.86)	(33.91)	(29.99)
GEA1	0.178***		0.237***		0.369***		0.184***	
	(5.46)		(11.29)		(9.32)		(5.85)	
GEA2		0.101***		0.187***		0.297***		0.123***
		(6.32)		(22.37)		(8.99)		(6.03)
Control variables	YES	YES	YES	YES	YES	YES	YES	YES
AR(2)-P	0.418	0.459	0.279	0.209	0.373	0.346	0.326	0.421
Sargan-P	0.374	0.431	0.514	0.379	0.966	0.979	0.994	0.830
obs.	1595	1595	1540	1540	1243	1243	1892	1892

Note: Large cities and small and medium-sized cities are classified according to whether the municipality has a population of more than 1 million in 2020; The list of key environmental protection cities is derived from the National Environmental Protection Eleventh Five-Year Plan, which is already widely used.

Table 9
Results of impact mechanism test.

	LGB		GTI		ISU	
	(1)	(2)	(3)	(4)	(5)	(6)
L. UGT	0.191*** (14.18)	0.192*** (13.41)	0.195*** (14.10)	0.197*** (13.71)	0.201*** (14.18)	0.202*** (14.38)
GEA1	0.643*** (5.94)		0.668*** (4.29)		0.524*** (4.15)	
GEA2		0.403*** (5.99)		0.477*** (4.82)		0.249*** (3.25)
LGB	−0.090** (−1.98)	−0.093** (−2.01)				
GEA1 × LGB	−0.278*** (−4.93)					
GEA2 × LGB		−0.318*** (−4.71)				
GTI			0.161*** (2.66)	0.173*** (2.65)		
GEA1 × GTI			0.281*** (3.73)			
GEA2 × GTI				0.391*** (4.03)		
ISU					−0.088* (−1.87)	−0.081* (−1.85)
GEA1 × ISU					−0.204*** (−2.90)	
GEA2 × ISU						−0.209*** (−2.96)
Control variables	YES	YES	YES	YES	YES	YES

5. Conclusion

This article examines the impact and heterogeneity of government environmental audits on urban green transformation in China. It uses a dual-index measurement for the audits, analyzes data from 285 cities, and establishes a dynamic panel model to reveal the underlying mechanisms. The study finds that.

(1) Government environmental auditing plays a significant role in urban green transformation. The impact of deciding whether or not to implement government environmental auditing is greater than the effect of the intensity of such audits. However, there is no inverted U-shaped relationship between government environmental audit intensity and green transformation.
(2) Increasing the intensity of government environmental audits in the eastern region can have a more significant impact on green transformation, while increasing the coverage rate of environmental audits in the western region enhances green governance effects. The role of government environmental audits is greater in small and medium-sized cities and key environmental protection cities compared to large cities and non-key environmental protection cities.
(3) Government environmental audits constrain local government behavior, drive innovation in green technology, and promote the upgrading of industrial structures to facilitate urban green transformation. The intensity of government environmental audits can have a greater impact on green transformation through these mechanisms. Among them, the role played by innovation in green technology is the most significant, followed by local government behavior, and finally industrial structural upgrading.

The significance of the above findings is as follows: First, to enhance the role of government environmental auditing in urban green transformation. The government should integrate environmental audits into the city's green governance system, develop audit plans specifically for urban green transformation, and regularly announce the results of these audits. Second, while expanding the coverage of government environmental auditing, we should also increase its intensity. Depending on the stage of urban green transformation, we will gradually intensify environmental audits by expanding their scope and improving coordination mechanisms and supporting systems. This will fully leverage the unique role that intense government environmental auditing plays in urban green transformation. Third, our priority is to promote enterprise innovation in green technology through government environmental auditing to support cities' green transformations. We will also strengthen performance assessments focused on sustainability and discourage short-term behavior from local governments to drive industry-wide green transformations. By combining these efforts, we can effectively promote cities' transition towards sustainability.

Due to the limitations of municipal-level statistical data, there are not enough available control variables in this study, which may result in imprecise estimation results. Additionally, the lack of third-party audit data at the city level makes it difficult to evaluate the impact of audit coordination on green transformation. In future research, more manual data can be added to address the deficiencies in existing urban statistical yearbooks.

Data availability statement

Question 1. Has data associated with your study been deposited into a publicly available repository?
Response 1: No.

Question 2. Please select why. Please note that this statement will be available alongside your article upon publication.as follow-up to "**Data Availability**. Has data associated with your study been deposited into a publicly available repository? "
Response 2: Data will be made available on request.

CRediT authorship contribution statement

Wei Wang: Writing - review & editing, Writing - original draft, Funding acquisition. **Zhidan Wang:** Writing - original draft, Software, Resources, Methodology, Investigation. **Yuanfei Mei:** Writing - review & editing, Writing - original draft, Supervision, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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