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Does Environmental Protection Tax Reform Enhance Urban Ecological Resilience? Evidence from a Continuous-Intensity Difference-in-Differences Approach in China

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Abstract

Urban ecological resilience is a crucial foundation for sustainable urban development. Based on balanced panel data from 285 prefecture-level and higher cities in China from 2007 to 2023, this paper treats the implementation of the 2018 "Environmental Protection Tax Law of the People's Republic of China" as a quasi-natural experiment and employs a continuous-intensity difference-in-differences model to examine the impact of the environmental protection tax reform on urban ecological resilience. The study finds that the environmental protection tax reform significantly enhances urban ecological resilience, with industrial structure upgrading and green technology innovation serving as key transmission channels. Fiscal pressures weaken the reform's effects, while the level of marketization reinforces its positive impact. Heterogeneity analysis indicates that the reform's effects are more pronounced in non-resource-based cities, coastal cities, and cities in the eastern region. This study expands the research on the ecological effects of environmental protection tax reform and provides empirical evidence for optimizing differentiated environmental tax policies, strengthening incentives for green innovation, and improving regional environmental governance.

Keywords: environmental protection tax reform; urban ecological resilience; continuous-intensity difference-in-differences; industrial structure upgrading; green technological innovation

1. Introduction

The combination of extreme weather, complex pollution, and resource and environmental constraints has exposed urban ecosystems to more frequent and unpredictable external shocks; relying solely on end-of-pipe treatment and short-term emission reductions is no longer sufficient to meet the needs of urban ecological security and sustainable development. Compared to pollution emissions or environmental quality at a specific point in time, urban ecological resilience focuses more on a city's capacity to resist shocks before they occur, adapt during them, and recover and transform afterward [1]. For Chinese cities currently navigating the overlapping phases of industrialization, urbanization, and green transition, how to leverage stable, sustained, and binding institutional arrangements to improve corporate production decisions and local environmental governance practices and thereby enhance cities' ability to respond to ecological risks has become a pressing practical issue that demands an urgent response. On 1 January 2018, the Environmental Protection Tax Law of the People's Republic of China came into force, replacing the pollution discharge

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fee system—which had been in place for nearly 40 years—with a framework based on "rigid tax burden + regional elasticity." This transition is regarded by scholars as a milestone marking China's shift from an administrative regulatory approach to a market-oriented regulatory framework in its green tax system [2]. The environmental protection tax reform has strengthened legal constraints. It has also improved interdepartmental coordination. It also promotes the internalization of pollution costs. These changes have enhanced the normativity of environmental regulations. They have also increased enforcement rigor. At the same time, ecological risks are becoming increasingly complex. Environmental governance is also undergoing a transformation. Its focus is shifting from pollution control to systemic management. It is important to examine the impact of environmental protection tax reform on urban ecological resilience. It can also help evaluate the actual effectiveness of the environmental tax system. It can reveal whether the reform strengthens cities' long-term ecological security. It can also show whether the reform improves their capacity for sustainable development.

From a theoretical perspective, existing research on the environmental protection tax has primarily focused on relatively static environmental performance indicators such as pollution emissions, technological innovation, and green growth while paying insufficient attention to whether it can enhance cities' dynamic capacity to withstand, adapt to, and recover from ecological shocks; although research on ecological resilience has gradually placed greater emphasis on policy factors [3,4], the role of environmental tax systems has yet to be systematically examined. Therefore, incorporating the environmental protection tax and urban ecological resilience into a unified analytical framework helps expand our understanding of the ecological effects of environmental regulation from the perspective of dynamic capacity and further reveals the mechanisms through which it may influence urban ecological resilience via industrial restructuring, green technological progress, and improvements in local governance.

Based on this, this paper takes Chinese prefecture-level and higher-level cities as its research subjects and, against the policy backdrop of the implementation of the Environmental Protection Tax Law in 2018, examines the impact of the environmental protection tax reform on urban ecological resilience. First, we identify the overall impact of the environmental protection tax reform on urban ecological resilience. Building on this, we examine the possible mechanisms through which the environmental protection tax affects urban ecological resilience from the perspectives of industrial upgrading and green innovation. Furthermore, this paper examines the moderating effects of fiscal pressure and the degree of marketization to analyze how local government governance incentives and market mechanisms influence the transmission of environmental policies. At the same time, it conducts a heterogeneity analysis across dimensions such as resource-based versus non-resource-based cities, coastal versus non-coastal cities, and eastern versus central and western cities to reveal differences in the policy effects of the environmental protection tax under varying urban development conditions.

The potential marginal contributions of this paper are primarily reflected in three aspects: First, it expands the scope of research findings on the environmental protection tax by extending the research perspective from relatively static environmental performance indicators such as pollution emissions, green innovation, and green development to a composite measure of urban ecological resilience. Second, it enriches research on the institutional drivers of urban ecological resilience by analyzing, from the perspective of environmental taxation systems, complementing evaluations of water ecological civilization and low-carbon city policies how environmental regulations which feature both legal constraints and price adjustments shape urban ecological resilience. Third, it further elucidates the mechanism of action and boundary conditions of the environmental protection tax. This

study examines the transmission effects of industrial upgrading and green innovation. It also examines differences in fiscal pressures, marketization levels, and urban characteristics. The study explains why environmental protection tax policies produce differentiated ecological effects. It provides empirical evidence for optimizing the environmental protection tax. The study also provides evidence for building resilient cities.

The rest of the paper is organized as follows. Section 2 reviews the relevant literature. Section 3 builds the theoretical framework and hypotheses. Part 4 details the observational approach, parameters, statistics, and illustration. Section 5 presents the primary results and the robustness tests. Section 6 presents the mechanism, moderation, and heterogeneity analyses. Section 7 discusses the findings and their policy implications. Section 8 concludes.

2. Literature Review

2.1. Urban Ecological Resilience: Conceptualization, Measurement, and Policy Drivers

Research on ecological resilience covers three main areas: conceptual development, measurement and assessment, and influencing factors. First, resilience was initially introduced into ecology. It describes the capacity of ecosystems to absorb disturbances while maintaining their basic structure and functions. This concept offers a perspective on system persistence under unstable conditions. Research has since extended from natural ecosystems to urban systems. It now addresses how cities maintain functions, adapt, and transform in response to external shocks. Recovery and development are therefore understood as dynamic processes [5]. Urban ecological research has also examined resilience, eco-efficiency, and their coordination. This reflects a shift from assessing individual capacities to examining system functioning and interrelationships [6].

Second, several frameworks have been developed to measure ecological resilience. The resistance–adaptation–recovery framework distinguishes different capacities for responding to disturbances. It has been used to assess the coupling and coordination between ecological resilience and urbanization [7]. The pressure–state–response framework organizes indicators around environmental pressures, ecological conditions, and societal responses. It provides a conceptual basis for ecological assessment [8]. The driving force–pressure–state–impact–response framework adds drivers and impacts to this structure. It captures the multidimensional characteristics of ecosystem resilience [9]. Some indicator systems adopt an evolutionary perspective and incorporate innovation capacity. This approach reflects the potential of systems to adapt and adjust their development trajectories [10]. Other systems assess environmental pollution generation, pollution management, and ecological protection. They consider both environmental pressures and the capacity for governance and protection [11]. Landscape-based studies measure resilience through scale, density, and morphology. This approach broadens the assessment of urban ecological patterns and functions [12]. Planning-oriented research further integrates resilience with sustainable urbanism. It combines urban design principles, neighborhood-scale metrics, and indicators for evaluating interventions. This framework supports the development of climate-resilient and sustainable neighborhoods [13].

Third, research on influencing factors has expanded beyond natural conditions. It increasingly examines human activities and their interactions with ecosystems. The hydrological environment provides an important starting point. Studies link urban water environments with urban design to develop strategies informed by ecological resilience [14]. Biological abundance and resource endowments are also considered in assessments of ecosystem resilience and its constraints [15]. Studies of human activities focus on the coupling and coordination between urbanization and ecological resilience. They highlight the need to align urban development with ecological carrying and adaptive capacities [16]. Economic development, industrial structure, and technological innovation have

also been examined. This has shifted the analysis from individual factors toward a more integrated assessment [17]. Ecosystem and ecosystem service assessments can also inform land-use planning. They help identify potential ecological risks and service losses associated with development. This evidence can support land protection decisions [18]. Overall, ecological resilience depends on both ecological conditions and human activities. Its assessment therefore requires joint consideration of environmental conditions and socioeconomic processes.

2.2. Environmental Protection Tax Reform: Ecological Effects and Implications for Urban Ecological Resilience

Research on the ecological effects of environmental protection tax focuses on pollution abatement and coordinated reductions in pollution and carbon emissions. Existing evidence shows that the reform can reduce urban air pollution. Industrial structure upgrading and green technological innovation are important transmission channels [19]. Studies of $PM_{2.5}$ report lower concentrations following the tax reform [20]. Research on ozone pollution also provides evidence of pollution abatement [21]. Environmental taxation can further promote coordinated reductions in pollution and carbon emissions. Process innovation and end-of-pipe innovation mediate this effect. By contrast, the mediating effect of source-oriented technological innovation is not statistically significant [22]. Research has thus expanded from individual pollutants to broader environmental outcomes. These findings provide a basis for understanding the ecological effects of environmental protection tax.

The link between environmental protection tax and ecological resilience may arise from changes in production behavior induced by taxation. Such changes can alter the operating conditions of urban ecosystems. Taxation may reduce environmental pressures through industrial structure upgrading, green innovation, and pollution abatement. Related policy studies provide further evidence. Low-carbon city development can strengthen ecological resilience through green technological innovation, energy-use efficiency, and environmental governance [23]. Green fiscal policies can also improve resilience through central–local government coordination, government–business collaboration, and changes in government behavior [24]. These strands of research offer complementary insights into the relationship between environmental protection tax and ecological resilience. However, lower emissions primarily indicate reduced environmental pressure. They do not, by themselves, demonstrate stronger resistance, adaptation, or recovery capacities. Direct empirical tests of this relationship are therefore needed.

Existing studies provide substantial theoretical and empirical foundations, but several gaps remain. First, ecological resilience research examines a range of policy interventions. Environmental protection tax research focuses mainly on firm behavior, production efficiency, and pollutant emissions. These strands need to be better connected through ecological resilience as an integrated outcome. Second, industrial structure upgrading and green technological innovation are established channels through which the tax affects environmental quality. Whether these behavioral changes also strengthen ecological resilience requires further testing in the context of policy reform. Third, local fiscal pressure is associated with dependence on polluting industries [25]. The innovation effects of environmental protection tax also vary with the level of market development [26]. These findings suggest that local institutional conditions may shape policy outcomes. Their role in the effects on ecological resilience remains to be examined. Accordingly, this study exploits regional variation in the intensity of environmental protection tax reform to examine its effects on ecological resilience. It tests industrial structure upgrading and green technological innovation as transmission mechanisms. It also examines the roles of fiscal pressure and marketization. The analysis aims to clarify the ecological effects of the reform and the conditions under which they arise.

3. Theoretical Framework and Research Hypotheses

3.1. Direct Effect of Environmental Protection Tax Reform on Urban Ecological Resilience

The stability of an ecosystem is reflected in its ability to withstand short-term shocks. It is also reflected in its capacity to maintain core functions following disturbances. Furthermore, structural reorganization can be undertaken and continued adaptation and transformation can be achieved [27]. However, functional redundancy and adaptive capacity within cities' ecosystems are continuously eroded by persistent pollution and resource constraints. Even before ecological thresholds are exceeded, the city's ability to cope with future shocks may be reduced. Therefore, urban ecological resilience can be strengthened through institutional arrangements that alleviate long-term environmental pressures and enhance governance responsiveness [28,29].

Environmental protection tax reform primarily operates by increasing the statutory marginal cost of polluting emissions. The previous pollution discharge fee system has been replaced. Higher emission costs are now imposed on pollution-intensive enterprises. These costs are due to higher environmental protection tax rates. This creates stronger incentives for reducing emissions. Consequently, enterprises may reduce their pollutant emissions. Pollution control facilities may also be improved. They may also adopt cleaner inputs. Highly polluting production activities may also be scaled back. It has been shown by existing research that pollutant emissions can be effectively curbed by environmental price constraints and increased regulatory intensity. Corresponding adjustments in production activities can also be achieved [30,31].

In addition to reducing environmental pressure directly, environmental protection tax reform may also enhance cities' adaptive and responsive capacities. The codification of the tax clarifies the tax base, tax obligations, collection and administration procedures, and liabilities for violations. As a result, environmental costs for enterprises become more stable and predictable. Information sharing and coordinated oversight between tax authorities and ecological and environmental protection departments can also improve the efficiency of pollution data verification and environmental law enforcement. With more stable institutional expectations and binding compliance requirements, there are greater incentives for enterprises to incorporate pollution control into their long-term production and investment decisions. At the same time, enterprises may also be compelled by environmental regulations to improve production processes. They may also be compelled to conserve resources. Enterprises may even be compelled to adopt clean technologies. In this way, compliance costs may be offset to some extent [32,33]. Existing research has found that environmental taxes can significantly reduce fine particulate matter pollution. This offers hands-on proof for the process through which ecological stresses are reduced.

The Porter hypothesis and directed technical change explain how regulation and relative prices may induce innovation. From a social–ecological perspective, such adjustment supports resilience insofar as it helps maintain ecological functions or enables reorganization. Pollution reduction and innovation are therefore possible contributions to resilience rather than sufficient conditions for it.

The effects mentioned are very similar to the three parts of how well a city can deal with problems: the state, pressure, and response. Ecological conditions can be improved by reducing pollution emissions and improving resource utilisation efficiency. Environmental pressure can also be alleviated. Meanwhile, urban response capacity can be enhanced. This can be done through strengthened environmental monitoring. It can also be done through more stable institutional expectations. Increased adaptive investment can also help. Therefore, greater statutory increases in the 'fee-to-tax' conversion are likely to generate a stronger promotional effect on urban ecological resilience. However, improved ecological resilience does not automatically follow from an increase in the statutory tax rate. Its actual

effect depends on the extent to which tax administration, environmental law enforcement, corporate compliance and behavioural adjustments are implemented effectively. Based on the above analysis, the following hypothesis is proposed:

H1. *Greater environmental protection tax reform intensity positively affects urban ecological resilience.*

3.2. Mediating Mechanisms

Urban ecological resilience may be enhanced by environmental protection tax reform through industrial restructuring. The sectoral allocation of economic activities is essentially influenced by environmental taxes through changes in the relative production costs of different industries. Higher emission intensities and pollution control costs are typically faced by pollution-intensive industries. Therefore, their production costs are usually increased more sharply when the environmental protection tax burden rises. Corporate profitability, investment returns, and financing conditions are further affected by the resulting cost differentials. As a result, production factors such as capital and labor may be shifted from high-pollution and low-efficiency sectors toward industries with lower pollution intensity and higher value added [34].

Urban ecological resilience can be enhanced by industrial restructuring in two ways. On the one hand, conventional pollution emissions and resource consumption can be reduced by an increased share of clean and high-value-added industries. The urban economy's dependence on highly polluting and energy-intensive industries can also be lowered. As a result, pressure on the ecological environment can be alleviated. On the other hand, a city's reliance on a single resource or industry can be reduced through industrial diversification. Consequently, the economic system's ability to adapt to stricter environmental regulations, tighter resource constraints, and external shocks can be enhanced. Therefore, the current state of the ecological environment can be improved by industrial upgrading. The adaptability and resilience of the urban system can also be strengthened.

It should be noted that industrial upgrading is characterized by a gradual process. A certain amount of time is required for capital reallocation, firm entry and exit, inter-sectoral labor mobility, and the expansion of clean industries. Therefore, the policy effects of industrial upgrading are typically manifested more slowly than those of end-of-pipe pollution control measures. As structural adjustments continue to advance, the urban economy's reliance on pollution-intensive industries will gradually be reduced. The constraining effect of the environmental protection tax will then be further translated into enhanced ecological resilience. Based on the above analysis, the following hypothesis is proposed:

H2a. *Urban ecological resilience is enhanced by environmental protection tax reform through the promotion of industrial structure upgrading.*

In addition to changing how industries work, changing taxes to help the environment could also help cities deal with problems. This would happen by getting people to use new technology that is good for the environment. Environmental taxes increase the long-term costs of pollution emissions. Consequently, the relative profitability of different technological choices for enterprises is altered. When pollution costs are expected to rise continuously, greater economic value is placed on clean production processes, energy-saving technologies, pollution control equipment and resource recycling technologies. This is consistent with the theory of directed technological change. According to this theory, the direction of technological innovation can be influenced by changes in relative prices and policy incentives [35].

Through green technological innovation, energy consumption and pollution emissions per unit of output can be reduced. Resource utilization efficiency and clean production standards can also be improved. In addition, pollution monitoring and control capabilities can be enhanced. Long-term environmental pressures on urban ecosystems can therefore be alleviated by the resulting technological progress. The sensitivity of production activities to fluctuations in resource supply and changes in environmental constraints can also be reduced. As a result, the adaptive capacity of urban eco-economic systems can be enhanced. Existing firm-level studies indicate that green technological innovation can be effectively incentivized by environmental protection taxes when environmental regulatory signals are highly credible and firms possess the corresponding adaptive capacity [36,37].

Of course, substantial green innovation is not necessarily induced by environmental taxation. Firms' R&D investment may be squeezed by high environmental compliance costs. Technological upgrading may also be delayed by financing constraints. In addition, end-of-pipe treatment may be chosen by some firms instead of process innovation. However, when stable incentives for innovation are effectively created by environmental taxes, production efficiency can be improved through the research, development, and application of green technologies. Environmental costs can also be reduced. Firms' resilience to external environmental shocks can be further enhanced. Ultimately, urban ecological resilience can be strengthened. Based on the above analysis, the following hypothesis is proposed:

H2b. *Urban ecological resilience is enhanced by environmental protection tax reform through the promotion of green technological innovation.*

3.3. Moderating Mechanisms

Whether enhanced urban ecological resilience can be effectively achieved through environmental protection tax reform depends largely on the fiscal conditions and policy implementation capabilities of local governments. Unlike industrial restructuring and green technological innovation, fiscal pressure is not regarded as a direct channel through which ecological resilience is affected by the reform. Instead, it is treated as a critical institutional boundary condition. Whether the effects of the policy can be fully realized is largely determined by this condition.

On the one hand, local governments' governance incentives are altered by fiscal pressure. Under tight budgetary constraints, greater priority may be given to employment stability, economic growth, and short-term fiscal revenue. As a result, environmental governance objectives may be weakened. A significant share of local tax revenue, industrial output, and employment is typically contributed by pollution-intensive industries. When fiscal pressure rises, stronger incentives may be created for such industries to be maintained in order to alleviate fiscal imbalances. Existing research has also found that local economies' dependence on polluting industries can be reinforced by fiscal pressure. Under such circumstances, the cost constraints imposed by the environmental protection tax may be offset by local growth incentives. Consequently, its ecological effects may be weakened.

On the other hand, local governments' policy implementation capacity is also directly constrained by fiscal pressure. Sustained ecological effects from environmental protection tax reform can only be achieved when sufficient public investment is provided. Such investment is required for environmental monitoring, law enforcement and supervision, ecological restoration, and green infrastructure. When fiscal resources are insufficient, the scope for such expenditures may be reduced. The intensity of environmental monitoring and enforcement may also be weakened. In addition, the credibility of environmental tax signals may be undermined by inadequate or selective enforcement. At the same time, the costs of corporate green transformation, industrial restructuring, and technological upgrad-

ing may be increased by insufficient supporting investment. As a result, the conversion of environmental tax pressure into improvements in ecological resilience may be constrained.

Therefore, stronger fiscal pressure is associated with greater constraints on local governments' environmental governance incentives, policy implementation, and supporting investments. Under such conditions, the positive effect of environmental protection tax reform on urban ecological resilience is more likely to be suppressed. Based on the above analysis, this paper proposes the following hypothesis:

H3a. *Fiscal pressure weakens the positive effect of environmental protection tax reform on urban ecological resilience.*

The degree of marketization is another important institutional factor influencing the effectiveness of environmental protection tax policies. By raising the cost of pollution, the environmental protection tax alters enterprises' relative returns; whether its policy effects can be fully realized depends on whether environmental cost signals can be effectively transmitted to corporate decision-making and further guide the reallocation of production factors such as capital, technology, and labor. Therefore, the degree of marketization primarily modulates the ecological effects of environmental protection tax reform by influencing the transmission of price signals and the efficiency of factor allocation.

In regions with a higher degree of marketization, environmental costs can be more readily reflected in product prices, financing costs, expected returns, and enterprises' entry and exit decisions. As pollution costs rise, capital, labor, and technology can be more smoothly reallocated from high-pollution and low-efficiency sectors to clean and high-efficiency sectors. As a result, industrial restructuring and the adoption of green technologies can be accelerated. The scope for inefficient and polluting enterprises to absorb environmental costs through cost pass-through or the maintenance of existing production methods can also be restricted by well-developed market competition. Consequently, stronger incentives can be created for emission reduction and green transformation.

Furthermore, the uncertainty and financing constraints faced by enterprises in green investment and technological innovation can be reduced by robust property rights protection, relatively unobstructed financing channels, and a regulated competitive market environment. As a result, enterprises' ability to respond to environmental tax signals can be enhanced. Conversely, in regions with a lower degree of marketization, the transmission of environmental price signals may be weakened by strong administrative intervention, fragmented factor markets, and restricted financing channels. Consequently, tax burden adjustments of the same magnitude may be less effectively translated into industrial upgrading and technological progress.

So, it is pretty clear that financial pressures and the level of marketization affect different parts of our institutions. The former primarily affects local governments' policy implementation capacity and public investment, while the latter primarily influences corporate behavioral responses and the allocation of production factors. The higher the degree of marketization, the more fully environmental cost signals are transmitted, the higher the efficiency of resource allocation, and the easier it is to strengthen the ecological effects of environmental protection tax reform. Based on the above analysis, this paper proposes the following hypotheses:

H3b. *Marketization strengthens the positive effect of environmental protection tax reform on urban ecological resilience.*

Figure 1 summarizes the proposed channels and moderating conditions.

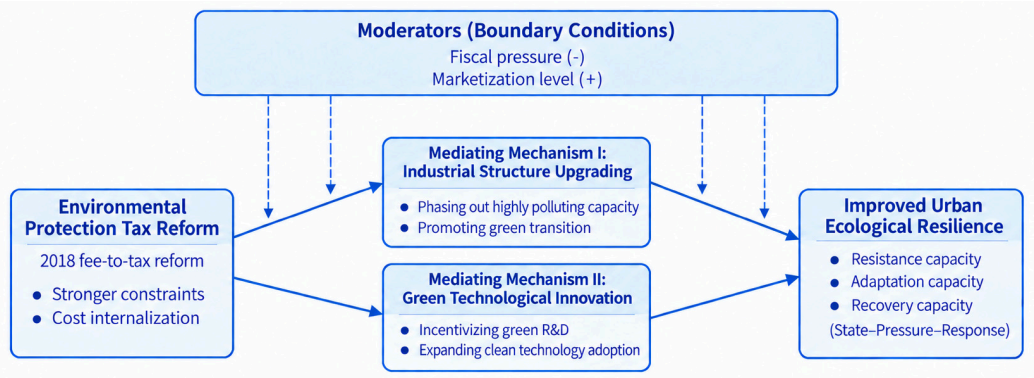


Figure 1. Theoretical framework of the effects of environmental protection tax reform on urban ecological resilience. Solid arrows indicate direct or mediating pathways, whereas dashed arrows indicate moderating effects. The symbols "−" and "+" denote negative and positive moderating effects, respectively.

4. Research Design

4.1. Model Specification

4.1.1. Baseline Model

To identify the impact of the intensity of environmental protection tax reform on urban ecological resilience, this paper constructs a continuous treatment intensity difference-in-differences model for estimation. The baseline model is specified as follows:

$$ER_{it} = \alpha + \beta_1 EPT_{it} + \gamma' X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (1)$$

ER_{it} represents urban ecological resilience, EPT_{it} is a continuous policy treatment variable, X_{it} is a set of control variables, μ_i and λ_t represent city fixed effects and year fixed effects, respectively, and ε_{it} is the random error term. This paper focuses on the estimated coefficient β_1 of EPT_{it}, which measures the average marginal effect of changes in the intensity of environmental protection tax reform on urban ecological resilience. The optimal specification of the baseline model includes all control variables while controlling for city-specific and year-specific fixed effects.

4.1.2. Mediation Models

To examine the channels through which the reform affects ecological resilience, the following sequential regression models are estimated:

$$M_{it} = \alpha_0 + \alpha_1 EPT_{it} + \gamma' X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (2)$$

$$ER_{it} = \beta_0 + \beta_1 EPT_{it} + \beta_2 M_{it} + \delta' X_{it} + \mu_i + \lambda_t + \nu_{it} \quad (3)$$

M_{it} denotes the mediator. A channel is supported when α_1 and β_2 are both statistically significant and their product has the same sign as the total effect of EPT on ecological resilience. If the coefficient on EPT remains significant after M_{it} is included, the evidence is consistent with partial mediation.

4.1.3. Moderation Models

To test whether the effect of the reform varies with external conditions, the following model is estimated:

$$ER_{it} = \alpha + \beta_1 EPT_{it} + \beta_2 Z_{it} + \beta_3 (EPT_{it} \times Z_{it}) + \gamma' X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (4)$$

Z_{it} denotes the moderator. The interaction coefficient β_3 is the key parameter: a significantly positive value indicates that the moderating factor strengthens the reform's effect on ecological resilience, whereas a significantly negative value indicates an attenuating effect.

4.2. Variable Definitions and Measurement

4.2.1. Dependent Variable: Urban Ecological Resilience

The explained variable is urban ecological resilience (ER). Urban ecological resilience is reflected in the capacity of urban ecosystems to maintain their basic structure and functions under environmental pressure and external disturbances. Recovery, adaptation, and adjustment can also be achieved through internal regulation. Ecological resilience is multidimensional and systemic. Therefore, it cannot be fully represented by a single environmental indicator. Following Chu et al. [38], an evaluation system for urban ecological resilience is constructed in this study. Three dimensions are included: state resilience, stress resilience, and response resilience. A total of 12 indicators are selected. Positive and negative adjustments are first applied to the indicators. The indicator weights are then determined using the entropy weighting method. Based on these weights, the comprehensive urban ecological resilience index is calculated. A higher ER value indicates more favourable measured ecological conditions, lower pressures, and stronger measured responses within the adopted framework. It is an indirect measure of resilience-related attributes rather than observed recovery after a specific disturbance. The specific indicator system is presented in Table 1.

Table 1. Urban ecological resilience indicator system.

Dimension	Secondary Indicator	Unit	Direction
State resilience	Water resources per capita	m^3/person	+
	Green coverage rate of built-up areas	%	+
	Park green space per capita	hectares per 10,000 persons	+
	Built-up area per capita	km^2 per 10,000 persons	+
Pressure resilience	Industrial wastewater discharge per capita	tonnes/person	−
	Industrial smoke and dust emissions per capita	tonnes/person	−
	Carbon emissions per capita	tonnes/person	−
	Annual mean $PM_{2.5}$ concentration	$\mu g/m^3$	−
Response resilience	Industrial smoke and dust removal rate	%	+
	Harmless treatment rate of municipal solid waste	%	+
	Centralized wastewater treatment rate	%	+
	Comprehensive utilization rate of industrial solid waste	%	+

Note: '+' and '−' denote positive and negative indicators, respectively.

State indicators describe ecological resources and urban spatial conditions, pressure indicators capture environmental burdens, and response indicators describe pollution-management capacity. Greenery and water availability may support ecological functioning, while built-up area per capita reflects urban spatial conditions rather than directly measuring recovery. Improvements in pollution and treatment indicators can raise ER without demonstrating stronger shock recovery or improvement in every dimension.

4.2.2. Core Explanatory Variable: Environmental Protection Tax Reform Intensity

The core explanatory variable is environmental protection tax reform intensity (EPT). Because the change in levy standards differed substantially across regions, a binary pre–post indicator cannot capture cross-regional variation in policy stringency. Following Huang and Qi [39], reform intensity is measured as the difference between the sulfur

dioxide environmental protection tax rate applicable to city *i* in 2018 and the corresponding pollution discharge fee standard in 2017:

$$Intensity_{it} = Tax_{i,2018}^{SO_2} - Fee_{i,2017}^{SO_2} \quad (5)$$

The continuous policy-treatment variable is then constructed as:

$$EPT_{it} = Intensity_i \times Post_t \quad (6)$$

$Post_t$ equals one in 2018 and subsequent years and zero otherwise. Accordingly, EPT_{it} is zero for all cities before the reform and equals the city-specific value of $Intensity_i$ after implementation. The measure therefore captures both the timing of the reform and cross-regional differences in its intensity.

The SO_2 differential provides a common statutory price unit for comparing the fee-to-tax change across cities. It measures intensity for this pollutant rather than firms' total environmental tax payments, which also depend on emission quantities, pollutant composition, and the rules applicable to other pollutants. The estimated effect is therefore interpreted with respect to this SO_2-based statutory intensity.

4.2.3. Mediators, Moderators, and Control Variables

The mediating variables are industrial structure upgrading (Sdr) and green technological innovation (GTI). Following Xu [40], Sdr is constructed using an industrial structure advancement index. Specifically, weights of 1, 2, and 3 are assigned to the shares of the primary, secondary, and tertiary sectors in gross domestic product, respectively, and the weighted sectoral shares are then aggregated. A higher value of Sdr indicates a more advanced industrial structure. GTI is measured as the number of green invention patent applications filed in a city in a given year divided by 1000. Accordingly, a one-unit increase in GTI represents an increase of 1000 green invention patent applications.

The moderating variables are fiscal pressure (FP) and marketization (Market). FP is measured as the difference between local general public budget expenditure and local general public budget revenue divided by regional gross domestic product. A higher value indicates a larger fiscal imbalance relative to the size of the local economy and, consequently, greater fiscal pressure. Following Xiong et al. [41], Market is measured as the ratio of regional gross domestic product to local general public budget expenditure. A higher value indicates a smaller fiscal expenditure share relative to regional output. Following this literature, we use the ratio as a limited proxy for the government–market relationship. Before constructing the interaction terms, fiscal pressure and marketization are mean-centered. Consequently, the coefficient on EPT in the moderation models represents the effect of environmental protection tax reform when the corresponding moderator is at its sample mean.

The control variables are economic development (lnGDP), trade openness (Fdi), population density (lnPOP), technological development (Tec), and manufacturing agglomeration (Ind). Economic development is measured as the natural logarithm of GDP per capita. Trade openness is defined as the ratio of total imports and exports to regional GDP. Population density is calculated as the year-end resident population divided by administrative land area and is expressed in logarithmic form. Technological development is measured as local government expenditure on science and technology as a percentage of general public budget expenditure. Manufacturing agglomeration is measured using the location quotient.

4.3. Data Sources and Sample

The sample covers 285 prefecture-level and above cities in China from 2007 to 2023. This yields a balanced panel of 4845 city-year observations. Data on ecological resilience and socioeconomic characteristics are drawn mainly from the China City Statistical Yearbook, China Urban Construction Statistical Yearbook, China Statistical Yearbook, regional statistical yearbooks, and the CNRDS database. Environmental protection tax rates and pre-reform pollution discharge fee standards are collected from official national and provincial policy documents. Sulfur dioxide fee standards reported by mass are converted into CNY per pollution equivalent. They are then matched with the corresponding environmental protection tax rates applied in 2018. Descriptive statistics for the main variables are reported in Table 2.

Table 2. Descriptive statistics.

VarName	Obs	Mean	SD	Min	Max
ER	4845	0.33	0.06	0.17	0.68
EPT	4845	0.39	0.96	0.00	4.80
Sdr	4845	2.31	0.14	1.83	2.85
GTI	4845	0.27	1.06	0.00	23.94
FP	4845	0.12	0.10	−0.01	0.97
Market	4845	6.18	2.69	0.97	18.14
lnGDP	4845	10.59	0.67	8.17	12.48
Fdi	4845	0.19	0.32	0.00	3.39
lnPOP	4845	5.71	1.01	1.63	9.09
Tec	4845	4.36	1.24	0.69	8.38
Ind	4845	0.86	0.51	0.00	3.17

5. Empirical Results

5.1. Baseline Results

Table 3 reports the baseline estimates. The coefficient on EPT remains positive and statistically significant as control variables and fixed effects are added sequentially. Its magnitude falls from 0.014 in column (1) to 0.002 in column (6). This decline suggests that models without city and year fixed effects may overstate the reform effect. The positive effect nevertheless remains statistically robust in the preferred specification.

In column (6), the coefficient on EPT is 0.002 and is significant at the 1% level. A CNY 1 increase in the environmental protection tax per pollution equivalent, relative to the pre-reform pollution discharge fee, is associated with a 0.002 increase in the ecological resilience index. This corresponds to approximately 0.61% of the sample mean of ER. The results therefore support H1.

Using the rounded coefficient and descriptive statistics, this change is approximately 0.033 standard deviations of ER. The magnitude is modest and refers to a one-unit statutory intensity difference, not to the total effect of nationwide reform.

5.2. Parallel Trends and Dynamic Effects

To examine the parallel trend assumption and the dynamic effects of the reform, the following event-study model is estimated:

$$ER_{it} = \alpha + \sum_{k=-5,\, k\neq -1}^{5} \beta_k (Intensity_i \times D_t^k) + \gamma' X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (7)$$

In Equation (7), 2017 ($k = -1$) is the omitted reference period. Observations from 2007–2012 are retained and pooled with 2013 in the earliest event-time category ($k = -5$), so $D_t{}^{-5} = 1$ for $t \leq 2013$ and zero otherwise. For the remaining reported periods, $D_t{}^{k} = 1$

when $t - 2018 = k$. The first coefficient therefore represents the pooled early pre-reform years rather than 2013 alone. The displayed event-time categories run from $k = -5$ to $k = 5$, while the estimation sample retains the full 2007–2023 panel. The specification uses the same control variables and fixed effects as the baseline model.

Table 3. Baseline regression results.

Variable	(1)	(2)	(3)	(4)	(5)	(6)
	ER	ER	ER	ER	ER	ER
EPT	0.014 ***	0.003 ***	0.006 ***	0.002 ***	0.003 ***	0.002 ***
	(18.326)	(5.843)	(6.651)	(2.951)	(6.559)	(5.438)
lnGDP		0.030 ***		0.029 ***		0.005 **
		(25.103)		(20.799)		(2.438)
Fdi		0.032 ***		0.032 ***		−0.021 ***
		(9.923)		(9.660)		(−4.136)
lnPOP		0.017 ***		0.017 ***		0.066 ***
		(25.472)		(25.607)		(12.353)
Tec		0.013 ***		0.013 ***		0.005 ***
		(18.586)		(18.606)		(8.451)
Ind		−0.003 **		−0.003 **		−0.004 ***
		(−2.201)		(−1.987)		(−2.610)
Constant	0.328 ***	−0.148 ***	0.331 ***	−0.139 ***	0.332 ***	−0.114 ***
	(383.571)	(−12.465)	(387.777)	(−9.883)	(958.545)	(−3.034)
Controls	No	Yes	No	Yes	No	Yes
City fixed effects	No	No	No	No	Yes	Yes
Year fixed effects	No	No	Yes	Yes	Yes	Yes
Observations	4845	4845	4845	4845	4845	4845
R-squared	0.058	0.701	0.161	0.710	0.876	0.888

Note: *t*-statistics are reported in parentheses. *** and ** denote statistical significance at the 1% and 5% levels, respectively.

Figure 2 illustrates the dynamic effects of the environmental protection tax reform. Prior to the implementation of the reform, the estimated coefficients for each period fluctuated around zero, and the corresponding confidence intervals all included zero. A joint test of the coefficients for each period before the reform yielded the result [$F(4, 4529) = 1.24$, $p = 0.2898$], indicating no significant differential pre-trend, which suggests that the parallel trend hypothesis is generally valid. After the reform was implemented, the estimated coefficients for each period were generally positive and exhibited a pattern of gradually increasing over time. The results of the joint test for the coefficients after the reform were [$F(6, 4529) = 4.38$, $p = 0.0002$], which was statistically significant. This suggests that the environmental protection tax reform's promotional effect on urban ecological resilience exhibits a certain degree of lag and is gradually realized following policy implementation.

5.3. Robustness Tests

The robustness analysis considers several alternative specifications. Ecological resilience is reconstructed using equal weighting and principal component analysis. Reform intensity is also transformed as ln(1 + Intensity). Additional tests restrict the sample to 2012–2023, exclude the COVID-19 period of 2020–2022, add province-specific linear trends, and remove cities in the top 5% of the reform-intensity distribution.

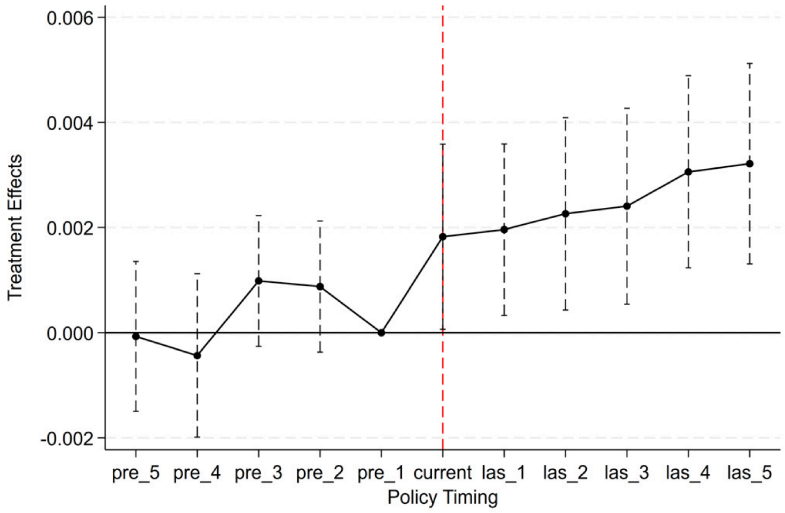


Figure 2. Parallel trends and dynamic effects. The red dashed line marks the policy implementation year (2018), and the black dashed error bars indicate 95% confidence intervals.

Table 4 shows that the estimated policy effect remains positive and statistically significant in all specifications. The coefficients on EPT are 0.001 and 0.002 when ecological resilience is measured using equal weighting and principal component analysis, respectively. Under the logarithmic transformation, the coefficient on lnEPT is 0.005. The EPT coefficient also remains significant at the 1% level after changing the sample period, excluding the pandemic years, controlling for province-specific trends, and removing extreme-intensity cities. These results indicate that the baseline finding is not sensitive to the resilience measure, functional form, sample period, or the presence of high-intensity observations.

Table 4. Robustness tests.

Variable	(1) Equal-Weight Method	(2) PCA	(3) Log Functional Form	(4) Six Years Before/After Policy	(5) Excluding 2020–2022	(6) Province-Specific Linear Trends	(7) Excluding Top 5% Intensity Cities
EPT	0.001 ***	0.002 ***		0.002 ***	0.002 ***	0.003 ***	0.002 ***
	(2.842)	(3.724)		(5.483)	(3.755)	(4.121)	(4.087)
lnEPT			0.005 ***				
			(4.791)				
lnGDP	0.020 ***	0.020 ***	0.005 **	0.010 ***	0.004	0.002	0.004 **
	(9.077)	(7.940)	(2.164)	(3.778)	(1.433)	(0.731)	(2.034)
Fdi	0.002	0.002	−0.021 ***	−0.011 **	−0.021 ***	−0.019 ***	−0.020 ***
	(0.569)	(0.488)	(−4.115)	(−2.017)	(−3.807)	(−3.720)	(−3.943)
lnPOP	0.022 ***	0.015 **	0.066 ***	0.078 ***	0.058 ***	0.073 ***	0.064 ***
	(4.467)	(2.576)	(12.310)	(10.830)	(9.507)	(12.500)	(11.883)
Tec	0.006 ***	0.006 ***	0.005 ***	0.005 ***	0.006 ***	0.004 ***	0.005 ***
	(9.612)	(8.846)	(8.572)	(7.342)	(7.218)	(5.629)	(8.080)
Ind	−0.006 ***	−0.004 ***	−0.004 ***	−0.000	−0.004 **	−0.006 ***	−0.003 *
	(−3.318)	(−2.763)	(−2.587)	(−0.164)	(−2.394)	(−3.198)	(−1.815)
Constant	0.187 ***	0.205 ***	−0.106 ***	−0.233 ***	−0.057	−0.116 **	−0.095 **
	(4.725)	(5.178)	(−2.828)	(−4.728)	(−1.288)	(−2.453)	(−2.524)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4845	4845	4845	3420	3990	4845	4641
R-squared	0.907	0.870	0.888	0.926	0.882	0.899	0.891

Note: *t*-statistics are reported in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

5.4. Placebo Test

This study conducts a placebo test using random permutation of policy intensity. While keeping the sample, control variables, and city and year fixed effects unchanged, the city-specific policy intensity is randomly reassigned across cities 1000 times to generate placebo treatment intensities. These placebo intensities are then interacted with the post-reform indicator and incorporated into the baseline model. The procedure yields 1000 simulated coefficients and their corresponding *p*-values.

Figure 3 presents the results of the permutation-based placebo test. The horizontal axis represents the estimated placebo coefficients from the 1000 simulations, while the vertical axis shows their corresponding *p*-values. The vertical red dashed line indicates the actual DID coefficient from the baseline regression, and the horizontal red dashed line denotes the 10% significance threshold. These reference lines facilitate a comparison between the actual policy effect and the distribution of placebo estimates.

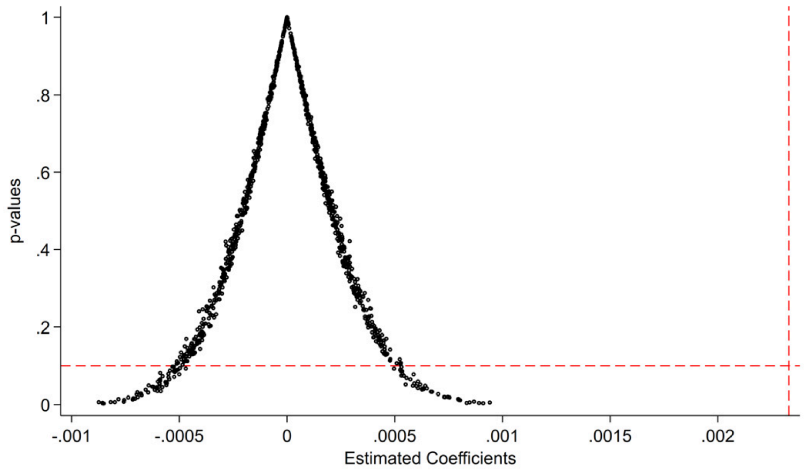


Figure 3. Placebo test. The vertical red dashed line indicates the actual coefficient from the baseline regression, while the horizontal red dashed line denotes the 10% significance threshold.

As shown in Figure 3, the placebo coefficients are concentrated around zero and are clearly separated from the actual DID coefficient. Most simulated estimates are statistically insignificant at the 10% level. Moreover, the empirical *p*-value indicates that only a small proportion of placebo coefficients exceed the absolute magnitude of the actual policy effect. These findings suggest that the estimated effect is unlikely to be driven by random assignment or spurious correlations, providing further support for the robustness of the baseline results.

5.5. Controlling for Other Environmental Policies

Considering that urban ecological resilience may also be affected by other environmental policies implemented during the sample period, this study considers four related policies: central ecological and environmental protection inspections (CEPI), carbon emissions trading pilots (CETP), low-carbon city pilots (LCCP), and green finance reform and innovation pilot zones (GFPZ). To account for their potential confounding effects, the corresponding policy dummy variables are separately incorporated into the baseline model. Each dummy equals one for affected cities in the year of the corresponding policy's implementation and subsequent years, and zero otherwise. The regression results are reported in columns (1)–(4) of Table 5. The coefficient on EPT remains positive and statistically significant across all four specifications, indicating that the estimated positive effect of environmental protection tax reform on urban ecological resilience is robust to separately controlling for these concurrent policies.

Table 5. Controlling for other environmental policies.

Variable	(1) ER	(2) ER	(3) ER	(4) ER
EPT	0.002 ***	0.002 ***	0.003 ***	0.003 ***
	(5.620)	(5.391)	(5.842)	(5.760)
CEPI	−0.003 ***			
	(−3.223)			
CETP		−0.001		
		(−0.627)		
LCCP			0.009 ***	
			(5.804)	
GFPZ				0.027 ***
				(4.214)
lnGDP	0.005 **	0.005 **	0.005 **	0.006 ***
	(2.373)	(2.436)	(2.443)	(2.855)
Fdi	−0.021 ***	−0.021 ***	−0.020 ***	−0.021 ***
	(−4.108)	(−4.225)	(−4.059)	(−4.223)
lnPOP	0.066 ***	0.066 ***	0.060 ***	0.063 ***
	(12.381)	(12.524)	(11.435)	(12.222)
Tec	0.005 ***	0.005 ***	0.005 ***	0.005 ***
	(8.430)	(8.540)	(8.387)	(8.272)
Ind	−0.004 ***	−0.004 **	−0.004 **	−0.004 **
	(−2.602)	(−2.489)	(−2.402)	(−2.465)
Constant	−0.111 ***	−0.116 ***	−0.080 **	−0.109 ***
	(−2.980)	(−3.098)	(−2.141)	(−2.929)
City fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Observations	4845	4845	4845	4845
R-squared	0.889	0.888	0.889	0.889

Note: *t*-statistics are reported in parentheses. *** and ** denote statistical significance at the 1% and 5% levels, respectively.

6. Further Analysis

6.1. Mediating Effect Tests

To further elucidate the underlying mechanisms through which the environmental protection tax reform affects urban ecological resilience, this paper examines mediating effects from the perspectives of industrial structure upgrading and green technology innovation. Table 6 presents the corresponding estimation results. All models include all control variables and account for city-level and year-level fixed effects.

6.1.1. Industrial Structure Upgrading

Columns (1) and (2) of Table 6 report the results of the test for the mediating effect of industrial structure upgrading. In Column (1), the estimated coefficient for EPT is 0.016 and is significant at the 1% level, indicating that an increase in the intensity of environmental protection tax reform can significantly promote industrial structure upgrading. In Column (2), the estimated coefficient for Sdr is 0.032, which is also significant at the 1% level, indicating that industrial structure upgrading can significantly enhance urban ecological resilience. After further incorporating Sdr, the estimated coefficient for EPT remains at 0.002 and stays significantly positive, suggesting that industrial structure upgrading plays a mediating role in the process by which environmental protection tax reform affects urban ecological resilience. A stratified Bootstrap test with 1000 replications is conducted for the Sdr channel. The indirect effect is 0.0005, with a 95% percentile confidence interval of [0.0003, 0.0007]. The confidence interval excludes zero, confirming the mediating effect of Sdr.

Table 6. Mediating effect tests.

Variable	(1) Sdr	(2) ER	(3) GTI	(4) ER
EPT	0.016 ***	0.002 ***	0.042 ***	0.002 ***
	(18.667)	(4.046)	(3.239)	(4.798)
Sdr		0.032 ***		
		(4.054)		
GTI				0.011 ***
				(7.976)
lnGDP	−0.013 **	0.006 ***	−0.129 ***	0.007 ***
	(−2.332)	(2.629)	(−3.122)	(3.212)
Fdi	0.041 ***	−0.022 ***	−1.051 ***	−0.009 **
	(7.305)	(−4.420)	(−5.541)	(−1.964)
lnPOP	−0.038 ***	0.067 ***	2.126 ***	0.042 ***
	(−4.167)	(12.608)	(11.449)	(8.085)
Tec	0.011 ***	0.005 ***	0.063 ***	0.005 ***
	(7.726)	(7.890)	(5.219)	(7.397)
Ind	0.013 ***	−0.005 ***	−0.213 ***	−0.002
	(3.362)	(−2.831)	(−5.757)	(−1.226)
Constant	2.586 ***	−0.196 ***	−10.413 ***	0.004
	(29.854)	(−4.565)	(−10.386)	(0.118)
City fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Observations	4845	4845	4845	4845
R-squared	0.927	0.881	0.716	0.893
Bootstrap Test	Coefficient	95% Percentile Conf. Interval	Coefficient	95% Percentile Conf. Interval
Sdr indirect effect	0.0005	[0.0003, 0.0007]		
GTI indirect effect			0.0004	[0.0002, 0.0006]

Note: *t*-statistics are reported in parentheses. *** and ** denote statistical significance at the 1% and 5% levels, respectively.

These results support the industrial restructuring channel. Higher environmental tax intensity raises the relative cost of pollution-intensive production and encourages resources to shift toward cleaner and higher-value-added activities. This adjustment reduces dependence on resource- and pollution-intensive industries. It also strengthens cities' capacity to respond to environmental constraints and ecological disturbances. The results therefore support H2a.

6.1.2. Green Technological Innovation

Columns (3) and (4) examine the mediating role of green technological innovation. In column (3), the coefficient on EPT is 0.042 and is significant at the 1% level. This result indicates that stronger reform intensity promotes green technological innovation. Column (4) shows that the coefficient on GTI is 0.011 and also significant at the 1% level. A higher level of green technological innovation can significantly enhance urban ecological resilience. A stratified Bootstrap test with 1000 replications is conducted for the GTI channel. The indirect effect is 0.0004, with a 95% percentile confidence interval of [0.0002, 0.0006]. The confidence interval excludes zero, confirming the mediating effect of GTI.

The above results further validate the mediating mechanism of green technology innovation. Environmental protection tax reform, by increasing the cost of pollution emissions, strengthens incentives for firms to adopt clean technologies, improve production processes, and enhance resource utilization efficiency, thereby driving green technology innovation. Green technological progress not only helps alleviate environmental pollution pressures

but also enhances the adaptive capacity of urban eco-economic systems. Hypothesis H2b is supported.

Based on the regression results in Table 6, the environmental protection tax reform enhances urban ecological resilience primarily through two channels: industrial structure upgrading and green technology innovation. The former focuses on the reallocation and structural optimization of economic activities across different industries, while the latter primarily exerts its effect through technological progress and improved production efficiency. These two mechanisms reflect two distinct adaptation pathways: structural adjustment and technological transformation.

6.2. Moderating Effect Tests

6.2.1. Fiscal Pressure

The results in Column (2) of Table 7 show that the estimated coefficient for the interaction term between the EPT and fiscal pressure is −0.014, which is significant at the 1% level. This result indicates that fiscal pressure has a significant negative moderating effect on the ecological resilience effects of the environmental protection tax reform; that is, the greater the fiscal pressure, the weaker the promotional effect of the environmental protection tax reform on urban ecological resilience, thus supporting Hypothesis H3a. A possible reason for this is that higher fiscal pressure reduces local governments' fiscal leeway for expenditures on environmental governance, ecological restoration, and green public services, thereby diminishing their capacity to implement environmental policies and the level of supporting investments, which in turn limits the full realization of the ecological effects of the environmental protection tax reform.

6.2.2. Marketization Level

The results in Column (4) of Table 7 show that the estimated coefficient for the interaction term between the EPT and the level of marketization is 0.0005, which is statistically significant at the 1% level. This result indicates that the level of marketization has a significant positive moderating effect on the ecological resilience effects of the environmental protection tax reform; that is, the higher the level of marketization, the stronger the promotional effect of the environmental protection tax reform on urban ecological resilience, thereby supporting Hypothesis H3b. A possible reason for this is that a more well-developed market mechanism can improve the efficiency of environmental cost signaling and promote the reallocation of production factors such as capital, technology, and labor toward green and low-carbon sectors, thereby enhancing enterprises' ability to respond to environmental tax constraints.

Overall, the implementation outcomes of environmental protection tax reform exhibit marked institutional dependence. Fiscal pressures primarily weaken the reform's effects by restricting local governments' policy implementation space and supporting capacity, whereas a higher level of marketization strengthens the policy's impact by improving the efficiency of price signal transmission and factor allocation, thereby amplifying the ecological benefits of environmental protection tax reform.

6.3. Heterogeneity Analysis

To examine the heterogeneity in the effects of the environmental protection tax reform, this paper groups the sample according to resource endowment, coastal location, and regional development level, and performs separate regression estimates for each subsample. All models control for city fixed effects and year fixed effects. Building on this, the bdiff method is further employed to test, through 1000 Bootstrap resamples, whether the differences in the estimated EPT coefficients across different groups are statistically significant. Table 8 presents the corresponding estimation results.

Table 7. Moderating effect tests.

Variable	(1) ER	(2) ER	(3) ER	(4) ER
EPT	0.002 ***	0.002 ***	0.002 ***	0.002 ***
	(5.163)	(4.724)	(5.592)	(5.714)
FP	−0.013	−0.011		
	(−1.585)	(−1.291)		
EPT × FP		−0.014 ***		
		(−2.880)		
Market			0.001 ***	0.001 ***
			(3.059)	(2.703)
EPT × Market				0.001 ***
				(2.810)
lnGDP	0.004	0.005 **	0.001	0.001
	(1.608)	(1.969)	(0.072)	(0.469)
Fdi	−0.021 ***	−0.020 ***	−0.020 ***	−0.020 ***
	(−4.093)	(−4.059)	(−4.086)	(−4.044)
lnPOP	0.065 ***	0.063 ***	0.065 ***	0.064 ***
	(12.082)	(11.783)	(12.146)	(11.892)
Tec	0.005 ***	0.005 ***	0.006 ***	0.006 ***
	(8.505)	(8.340)	(9.099)	(8.973)
Ind	−0.005 ***	−0.005 ***	−0.004 **	−0.004 **
	(−2.672)	(−2.717)	(−2.409)	(−2.530)
Constant	−0.092 **	−0.095 **	−0.058	−0.062
	(−2.292)	(−2.365)	(−1.405)	(−1.506)
City fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Observations	4845	4845	4845	4845
R-squared	0.8808	0.8810	0.8810	0.8812

Note: *t*-statistics are reported in parentheses. *** and ** denote statistical significance at the 1% and 5% levels, respectively.

6.3.1. Resource-Based vs. Non-Resource-Based Cities

The results of the group-based regression analysis indicate that the impact of the environmental protection tax reform varies significantly across cities with different resource endowments. In non-resource-based cities, the estimated coefficient for the EPT is 0.004 and is statistically significant at the 1% level; in resource-based cities, this coefficient is only 0.001 and does not reach statistical significance. The test for differences in coefficients between groups shows that the policy effects differ significantly between the two types of cities. A possible reason is that the long-standing resource dependence and industrial lock-in in resource-based cities have increased the adjustment costs associated with green industrial transformation and factor reallocation, thereby limiting, to some extent, the full realization of the environmental protection tax's policy effects. In contrast, non-resource-based cities have a relatively diversified industrial structure and their economic activities are less dependent on resource-based industries; therefore, they are better positioned to transform environmental tax constraints into enhanced ecological resilience through industrial restructuring and technological upgrading.

Table 8. Heterogeneity analysis results.

Variable	(1) Non-Resource-Based Cities	(2) Resource-Based Cities	(3) Inland Cities	(4) Coastal Cities	(5) Central and Western Cities	(6) Eastern Cities
EPT	0.004 ***	0.001	0.001	0.004 **	0.001	0.003 **
	(3.506)	(0.263)	(1.292)	(2.489)	(1.002)	(2.284)
Bootstrap test *p*-value	[0.001 ***]		[0.002 ***]		[0.006 ***]	
lnGDP	0.008	0.011 *	0.005	0.012	0.001	−0.008
	(1.047)	(1.813)	(0.987)	(1.101)	(0.052)	(−1.022)
Fdi	−0.029 **	0.020	0.012	−0.024 **	0.001	−0.024 *
	(−2.254)	(1.307)	(0.779)	(−2.024)	(0.149)	(−1.714)
lnPOP	0.081 ***	0.029 **	0.039 ***	0.127 ***	0.038 ***	0.116 ***
	(5.060)	(1.985)	(3.624)	(4.696)	(3.455)	(4.422)
Tec	0.006 ***	0.004	0.003 *	0.004 *	0.003 **	0.005 ***
	(3.811)	(1.562)	(1.918)	(1.774)	(2.047)	(2.667)
Ind	−0.008 *	0.000	0.003	−0.015 **	−0.001	−0.013 **
	(−1.780)	(0.086)	(0.577)	(−2.497)	(−0.190)	(−2.195)
Constant	−0.232 *	0.033	0.041	−0.557 ***	0.094	−0.261 *
	(−1.726)	(0.342)	(0.515)	(−2.696)	(0.934)	(−1.736)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
City fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2924	1921	2941	1904	2805	2040
R-squared	0.904	0.780	0.800	0.915	0.817	0.904

Note: *t*-statistics based on city-clustered standard errors are reported in parentheses. The *p*-values in square brackets come from bootstrap tests of differences in the (EPT) coefficients across groups, based on 1000 replications. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

6.3.2. Coastal vs. Inland Cities

The results of the heterogeneity test indicate that the environmental protection tax reform has a more significant positive effect on the ecological resilience of coastal cities. Specifically, the estimated coefficient for EPT in coastal cities is 0.004 and is significant at the 5% level; in inland cities, this coefficient is 0.001 and does not pass the significance test, and the difference between the coefficients of the two groups is significant. This difference may stem from coastal cities' higher degree of market openness, stronger innovation capabilities, and relatively well-developed environmental governance systems. These conditions help promote technological upgrading and the optimal allocation of production factors, thereby reinforcing the role of the environmental protection tax reform in enhancing urban ecological resilience.

6.3.3. Eastern vs. Central and Western Cities

For eastern cities, the EPT coefficient is 0.003 and is significant at the 5% level. For central and western cities, the coefficient is 0.001 and is not statistically significant. The difference between the two groups is significant. Stronger fiscal capacity, more developed markets, greater technological capability, and more effective environmental regulation may help eastern cities translate the reform into stronger ecological outcomes.

Taken together, the heterogeneity results show that the reform effect is stronger in non-resource-based, coastal, and eastern cities. By contrast, resource dependence, locational constraints, and a weaker foundation for green transition may limit the response to environmental taxation. In such cities, environmental tax incentives may need to be complemented by fiscal support, green innovation policies, and measures that facilitate industrial restructuring.

7. Discussion

7.1. Main Findings

The findings indicate that environmental protection tax reform significantly improves urban ecological resilience. Environmental taxation may generate cumulative ecological benefits through industrial adjustment and improved environmental governance. The findings extend the understanding of environmental taxation beyond conventional pollution control to broader ecological outcomes.

Industrial structure upgrading and green technological innovation are identified as two important transmission channels. Higher environmental tax intensity encourages the reallocation of production factors toward cleaner industries. It also promotes the development and adoption of green technologies. These adjustments reduce environmental pressures and improve the adaptability of urban eco-economic systems. Environmental taxation can therefore contribute to ecological resilience through both structural transformation and technological progress.

The effectiveness of environmental protection tax reform also depends on local institutional conditions. Fiscal pressure weakens the reform effect, whereas marketization strengthens it. Fiscal capacity and market mechanisms therefore play important roles in translating environmental tax incentives into ecological improvements.

The heterogeneity results further show that the reform has stronger effects in non-resource-based, coastal, and eastern cities. These findings highlight the importance of local economic and institutional conditions in determining the ecological effects of environmental taxation.

7.2. Policy Implications

Based on the empirical findings, several policy implications can be drawn.

First, the environmental protection tax system should be further refined to improve policy effectiveness and stability. The positive and gradually increasing effects of the reform highlight the importance of policy continuity for long-term ecological improvement. Tax rates and administration arrangements should reflect regional pollution characteristics, environmental carrying capacity, and economic development conditions. Information sharing and coordinated supervision between tax authorities and environmental departments should also be strengthened. More effective pollution monitoring and tax administration can reinforce incentives for enterprises to reduce pollution.

Second, environmental taxation should be better coordinated with industrial and technological policies. Industrial structure upgrading and green technological innovation are important channels through which environmental taxation improves ecological resilience. Environmental tax incentives should therefore be combined with measures supporting industrial restructuring and green technological development. Green R&D subsidies, green finance, and technology commercialization can reduce the costs of green transformation. These measures can facilitate the reallocation of production factors toward cleaner and higher-value-added industries. They may also strengthen the long-term ecological effects of environmental taxation.

Third, fiscal support and market-oriented reforms should be strengthened to improve policy effectiveness. Fiscal pressure may constrain environmental governance and green transformation. Fiscal support for environmental monitoring, ecological restoration, and green infrastructure should therefore be increased in regions with limited fiscal capacity. Market competition and factor mobility should also be improved. Reducing local protectionism and barriers to factor allocation can enhance the transmission of environmental cost signals. These measures can help enterprises respond more effectively to environmental tax incentives and promote green industrial transformation.

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Fourth, differentiated environmental tax policies should reflect regional development conditions. The reform has stronger effects in non-resource-based, coastal, and eastern cities. Environmental taxation in these regions can be further integrated with green innovation and industrial upgrading policies. Resource-based, inland, and central and western cities may require additional fiscal support and technological assistance. Such support can help reduce industrial dependence and overcome transformation constraints. Cross-regional coordination in environmental governance should also be strengthened. This can help narrow differences in policy implementation capacity and promote more balanced improvements in urban ecological resilience.

7.3. Limitations and Future Research

Several limitations should be considered. First, the composite ER index captures selected ecological conditions, pressures, and responses rather than recovery following a specified shock. Indicators directly affected by pollution control can contribute to its improvement, and alternative weighting does not resolve this measurement limitation. Second, provincial tax changes may reflect prior conditions. The separate controls for four concurrent policies strengthen robustness, but do not account for every policy or unobserved regional development.

Third, spatial spillovers are not explicitly modelled. Pollution transport or relocation of pollution-intensive firms toward neighbouring cities with lower tax intensity could shift environmental pressure rather than generate net regional gains. The estimates therefore cannot distinguish local improvement from wider ecological benefits. Finally, the Chinese institutional setting and the post-reform period ending in 2023 limit generalization and the assessment of long-term transformation.

Future research could examine recovery under observed climate disturbances, multilevel governance, territorial inequalities, and spatial interactions in environmental tax effects. These extensions could clarify how environmental fiscal instruments interact with planning and ecosystem management.

8. Conclusions

This study examines the effect of China's 2018 environmental protection tax reform on urban ecological resilience. A continuous-intensity difference-in-differences model is employed using panel data from 285 Chinese cities over the period 2007–2023. The results show that greater reform intensity significantly improves urban ecological resilience. The effect becomes more pronounced over time. Industrial structure upgrading and green technological innovation are identified as two important transmission channels. Fiscal pressure weakens the reform effect, whereas marketization strengthens it. The effect is also more pronounced in non-resource-based, coastal, and eastern cities.

The findings extend the evaluation of environmental protection tax reform from conventional pollution control to urban ecological resilience. They also provide evidence on the transmission channels and institutional conditions underlying the reform's ecological effects. The continuous-intensity DID approach captures regional differences in statutory tax changes under a nationwide reform.

Overall, environmental taxation can support urban ecological resilience through industrial transformation and technological progress. Its effectiveness depends on local fiscal, economic, and institutional conditions. Stable environmental tax policies, complementary green development measures, and differentiated regional support are important for improving the ecological benefits of environmental taxation.

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