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Efficacy of ecological compensation programs under centralized management: evidence from China

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Watershed ecological compensation programs have emerged as a pivotal instrument for internalizing the externalities associated with watershed ecological protection. In most countries, the direct participants in ecological compensation projects are ordinary persons and enterprises, but in China, the direct participants are local governments and the central government, which to some extent affected the efficacy of the compensation programs. This study used PSM–DID to analyze the efficacy of the Xin'an River Basin Ecological Compensation Project (Xin'an-BECP) and calculated the loss of opportunity developed in the upstream area through EKC (Environmental Kuznets Curve) fitting, which makes the benefit assessment of government-led ecological compensation projects more objective and provides a model that can be used to analyze the benefits of BECP in developing countries. Our results show that (1) the treatment effect of the Xin'an-BECP is not obvious; (2) the compensation funds gained by the upstream area are much lower than the theoretical opportunity loss; and (3) enterprises are not transaction participants in the Xin'an-BECP. Finally, based on the conclusions of the discussion, we propose specific policy recommendations to guide developing countries in increasing the compensatory effects of BECP in the context of growing demand for economic development.

KEYWORDS

river basin ecological compensation, centralized management, PSM-DID, Kuznets curve, benefit assessment

1 Introduction

Statistical analysis indicates that approximately 50% of the world's rivers are contaminated, and there has been a 25% decrease in freshwater resources since 1980 (Mekonnen and Hoekstra, 2017). China's economic growth is predominantly propelled by the advancement of manufacturing and industry, which has caused numerous pressing ecological and environmental concerns, particularly within the Yangtze River Basin

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(Hansen et al., 2018). In recent years, watershed ecological compensation programs have emerged as a pivotal instrument for internalizing the externalities associated with watershed ecological protection (Börner et al., 2017). However, the watershed is frequently divided into different administrative units, which have complex interests in the same basin because of the scarcity and liquidity of water resources (Song et al., 2013). In particular, the implementation of basin ecological compensation programs in China is still mainly based on urban agglomerations, small watersheds, or fragmented areas divided by large-scale watersheds (Chi et al., 2024). Since compensation means balanced interests, it is agreed upon that the subjects of resources development and utilization should pay or provide compensation measures to subjects whose own interests are affected by protecting the resources (Bull et al., 2013). It can be seen that the ultimate goal of ecological compensation of a river basin is inherent in achieving benefit balance by transferring part of the rights and interests under the reasonable division of labor, and the governance of watershed pollution can be seen as the natural result of the balanced benefit.

In most countries, the direct participants in ecological compensation projects are ordinary persons and enterprises. However, in China, the direct participants are local governments and the central government—ecological compensation projects involving only government agencies (ECPioGA). In addition to providing substantial financial support, the central government also assumes the role of adjudicator in the process. Despite improvements in river water pollution in recent years, the problem of water pollution in river basins remains severe. The Xin'an River's main stem measures 373 km in length, with a basin area in excess of 11,000 km^2 (see Figure 1) and a permanent population of 13,838,000. In 2012, China launched the Xin'an-BECP, which operates as follows: if Huangshan City in Anhui Province (upstream area) provides water that meets the standards of Hangzhou City in Zhejiang Province (downstream area), the Hangzhou Municipal Government will compensate the Huangshan Municipal Government; if the water provided by Huangshan City does not meet the quality standards, the Huangshan Municipal Government must compensate the Hangzhou Municipal Government for water pollution damage; the central government provided the main financial support during the initial operation of the project and then withdrew from the project.

However, further discussion is required on the following points: firstly, whether the effectiveness of the ECPioGA was significant, and secondly, whether economic development opportunities that were lost upstream due to water management were fully offset by compensation downstream. Our research found that the effectiveness of the Xin'an-BECP was not significant, and the compensation level downstream did not make up for the development opportunities lost upstream.

2 Literature review and mechanism analysis

2.1 Literature review

With the environmental problems becoming increasingly serious, there are more and more studies on environmental governance. Crossover studies between different disciplines have become mainstream, especially in the field of ecological compensation. However, there have not been much studies done on the benefit evaluation of watershed ecological compensation

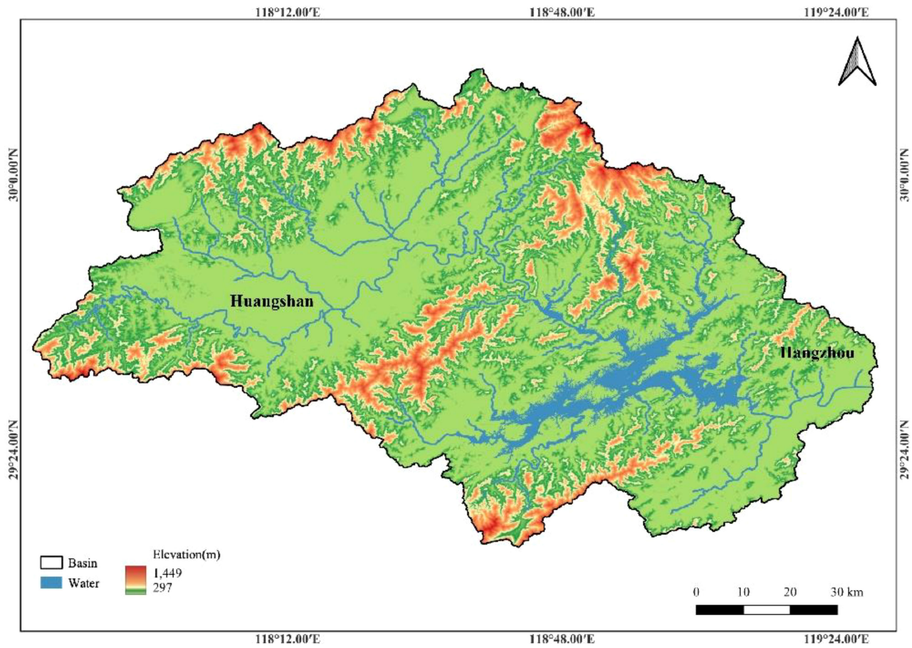

FIGURE 1
The basin of the Xin'an River.

projects, especially relevant explorations on benefit assessment methods of the watershed ECPioGA in China. In the realm of ecological compensation research, it is well-known and widely accepted that the institutional function of the financial ecological appropriation is to compensate local governments for the loss of profits caused by eco-environmental protection, so as to stimulate the supply of ecological services (Liu, 2015). The best form of financial allocation should be matching grants in the light of incentives, but most of the existing policy practices are shown as package grants, which makes it difficult to assess the final benefit of the compensation project. The research related to this issue mainly includes the following aspects:

First and foremost is the definition of the policy objectives for ecological compensation. Corbera et al. (2007) argued that fairness of ecological compensation can be divided into three dimensions, namely, participation fairness, decision-making fairness, and outcome fairness; outcome fairness depends on participation fairness and decision-making fairness. This theory challenged the efficiency-only theory of ecological compensation policy goals advocated by the neoclassical economics (Cox, 2003). There are some scholars who believe that ecological compensation can only be achieved by one of three goals, namely, efficacy, efficiency, and fairness (Mayrand and Paquin, 2004). Others believe that the aim of ecological compensation is inherent in achieving environmental improvement and rural development, and that poor groups are the biggest victims of ecological damage (Nicolas et al., 2008; Barbier, 2008). Holding different opinions, Clements et al. (2010) argued that the balance between efficiency and social inclusion of ecological goals is an important factor that has great influence on the long-term operation and efficacy of ecological compensation. However, what needs to be added is that, in China, socialism and mixed economy are still the dominant principles of the Chinese management model (Fan et al., 2019); in particular, political factors have a great influence on environmental policy (Li et al., 2022), which, in turn, determines the policy goals of BECP to a certain extent.

Secondly, the method of project benefit evaluation is decided by the mode of the ecological compensation project. Research on BECP is chiefly concerned with the establishment and evaluation of water quality control targets for watershed waterbody characteristics. This is done in order to determine ecological compensation values and financial flow strategies, which, in turn, can effectively improve the pollution status of a watershed (Sonter et al., 2020). In this context, the relationship between diverse stakeholders within the same watershed becomes a pivotal aspect. The effective implementation of compensation schemes is contingent upon the existence of appropriate incentives to influence the conservation behavior of stakeholders (Hayes et al., 2019). However, some scholars have summarized 457 relevant documents and found that government agencies have participated in most of the ecological compensation projects, but what differs are their research directions of the ECPioGA (Schomers and Matzdorf, 2013). Liu believed that the institutional function of ecological compensation consists in coordinating interest relations rather than completely "covering" ecological externalities (Liu, 2015). Instead of improving the ecological environment indicators directly, the goal of compensation is to change the ecological behavior of decision-makers that ultimately ended with the mechanism of intergovernmental fiscal ecological compensation. Wang and Li (2015) emphasized the effective integration of the government and market in the progress of compensation. Zheng and Ge (2019) deemed that it is more efficient to construct a diversified ecological compensation model with the coupling of government compensation, market compensation, and social compensation.

The third aspect concerns the evaluation of the compensation projects. In the light of the efficacy of ecological compensation policies, Pagiola assessed the efficacy of compensation policies by measuring the benefits and negative returns of ecological zones brought by resource development and conservation (Pagiola et al., 2007). Sven (2007) considered that the deficiency of the majority of ecological compensation projects can be found in the lack of supervision and evaluation, and the compensation funds are also non-sustainable at the same time (this is consistent with most river basin ecological compensation projects in China); hence, the assessment highlights whether the service providers have changed the traditional methods of production or not. In addition, Corbera et al. (2009) evaluated the acceptability of ecological compensation, the income after compensation, the efficiency of forest management, and its organizational capacity in rural areas of Mexico in quantification. In combination with the variables exemplified by the residents' ability in participating in compensation policies, individual characteristics, environmental awareness, and adaptability to the system, Nicolas et al. (2008) assessed the compensation project of Mexican forests. Recent studies have demonstrated that the evaluation of ecological compensation programs is no longer the ultimate research objective. Liu et al. (2023) constructed an ecological compensation mechanism under the dual control of water quality and water quantity, and the empirical analyses of this mechanism showed that the value of water quantity compensation is likely to be higher than the value of water quality compensation. This indicates that the impact of water quantity on the water environment is greater than that of water quality, and that it is necessary to ensure the river's ecological water demand while strengthening the treatment of water pollution. In a related study, Li et al. (2024) examined the impact of the Xin'an-BECP on the regional economy. Their findings indicated that the implementation of the compensation program led to a shift in the local industrial structure, with an overall negative impact on the county economy. This shift, from secondary to primary and tertiary sectors, resulted in the inhibition of economic growth at the county level.

The last review on the existing research is about their evaluation methods of the compensation project. On the basis of Pagiola's study, Zabel and Roe pointed out that in terms of assessing ecological compensation projects, unobservable factors such as "pollution leakage" and external influences should be highlighted since incomplete information will be produced by these non-objective factors, while Ferraro argues that the incomplete information can be solved by auction or measuring the opportunity cost (Zabel and Roe, 2009). Yu et al. (2024) proposed a tripartite evolutionary game model for two-way ecological compensation to estimate the incentive impact of cross-border horizontal ecological compensation policy on water pollution governance. Liu et al. (2022) quantitatively evaluated China's basin ecological compensation policies based on the PMC index model; however, deficiencies in timeliness, incentive measures, and policy receptors were noted in the compensation policy. The above is a new evaluation method derived from specific issues, but the general evaluation method is roughly a combination of theoretical models and empirical models, such as Liu's systematic evaluation on intergovernmental fiscal ecological compensation projects in six provinces of eastern China, and Wang and Tang's empirical research on land urbanization in mainland China (Liu, 2015; Wang and Tang, 2019).

Though as pioneering and forward-looking as the existing research is, its research methods or results are not fully applicable to the benefit evaluation of the Xin'an-BECP. (1) The Xin'an-BECP is such a typical ECPioGA that the proportion of incomplete information will increase with the absence of micro-interested compensation subjects in the project. In the process of assessing, therefore, it is likely to miss the important variables or to be unable to effectively distinguish the causal relationship between the explanatory variable and the interpreted variable, which results in the significant difference between the OLS estimated value and the IV estimated value, and leads to the difficulty in solving the endogenous problems in the empirical model. (2) The most of the ECPioGAs, indeed, have the motivation to internalise externalities, which is directly reflected in the rigid demand for environmental governance, while the government's anti-pollution actions have not been highlighted by the market-oriented evaluation method of ecological compensation projects.

2.2 Mechanism analysis

(1) The proportion of voluntary transactions is extremely little and the degree of commercialization of ecological services is fairly low. With regard to the supply and demand system of ecosystem services in the Xin'an River, there are rare eco-services transacted voluntarily based on the interests of both parties. The reasons are mainly summarized as follows:

a. It is hard to reach the compensation price that both parties are satisfied with in the market due to the discrepancy of measurement cost for compensation fees. Different calculation methods adopted for different compensation projects bring about various prices of the same compensation volume, which is not conducive to the stability of the compensation price system; that is, the price information loses the credibility supported by market supply and demand.
b. The guidance and support of policies for compensation projects are more economically attractive than private transactions. On the one hand, the government's ability to allocate resources and process information is innately domineering. On the other hand, the opportunity cost of ecological service providers cannot be equivalently replaced by the compensation of the demand side. There is no reason and motivation for compensation even if there is the demand side. In other words, the Xin'an-BECP will not be activated without the leadership of the government.
c. From the micro-level perspective, under the condition that ecological service providers guarantee the supply of ecological services, ecological compensation is a set of ecological environmental protection mechanism based on the purchase of ecological products and services; namely, the pure market-oriented ecological compensation is a voluntary transaction where a beneficiary (at least one) of an ecological service can purchase high-quality ecological services from an (at least one) ecosystem service provider (Sven, 2005). The nihilism of the micro-interests of ecological compensation in the Xin'an River Basin has squeezed the vital space of the voluntary trading market (Sven et al., 2008). In terms of the content of the three-round compensation agreement of the Xin'an River Basin, there are almost no direct compensation objects for residents in the areas where ecological services are provided, collective contractors whose main development capital is cultivated land or water area in the upstream river basin, and enterprises engaged in agricultural production in the river basin. For example, the measures for livestock and poultry collection, the construction of ecological tea gardens, etc. are still insufficient, and the existing compensation projects have limited influence over the involved providers of micro-direct production.

(2) The ecological compensation system of most developing countries is still at the stage of government financing. Sven et al. (2008), who researched on the ecological compensation system of developed and developing countries, divided the market transaction-type compensation system into government financing ecological compensation and beneficiary financing ecological compensation. In the Xin'an River ecological compensation system, the government takes the lead in the implementation and promotion of ecological compensation projects based on its functions and provides high-value financial subsidies to ecological service providers at the same time. The role of the government has changed from administrative regulators to a third-party agent who purchases ecological services collectively from the ecological service providers as a "total demander" (Wang and Li, 2015). This kind of administrative action that is called subsidy but is purchased, in fact, is actually more suitable for the ECPioGA. The destination of its development, undoubtedly, is nothing more than to establish a credit guarantee system, to provide technical assistance services, to promote the upgrading of the basin industry, and to cultivate a market trading mechanism of ecological compensation by means of other measures.

(3) It is difficult to evaluate the environmental benefits of ecological compensation accurately. As far as the object of the environmental benefit evaluation is concerned, although the natural restoration and self-purification function of the environment itself has been generally declining with the development history of human society, the ability of environmental self-restoration remains unstable despite the development of nearly 100 years,

and this instability is even not observable at a certain time. Therefore, the level of environmental self-repair ability is always regarded as a random error term that affects the accuracy of benefit evaluation in the benefit evaluation system of ecological compensation, and the random error summarized by abstraction does not have the stability similar to white noise. The instability of environmental self-healing capabilities is even more true during the nearly 100 years when industry, technology, and information have developed rapidly. On account of this instability, it is difficult for us to distinguish how much improvement of the ecological environment comes from natural restoration and environmental purification, from spillover effects owing to the improvement of the ecological environment in the adjacent space, and from the supply side and the service itself directly (Wang and Li, 2015). As there are profitable business activities, there is a transaction risk associated with it. Based on the psychology of risk aversion, the relative party of the transaction will unconsciously increase the cost and transaction price of ecological services, which is largely affected by the situation of information asymmetry partly induced by the non-stationary and unpredictable self-healing ability of the natural environment. This series of linear conduction market behavior has an urgent need for the government's subsidy funds, because the extra effort made by both sides when the eco-service transaction is finally concluded needs the incentive of subsidy. Therefore, defining the system function of ecological compensation fund with the term "subsidy" has its own meaning, because this kind of subsidy has an incentive effect on the ECPioGA and on market transaction ecological compensation system as well.

(4) Spatial factors have a decisive influence on the choice of different ecological compensation systems. The Xin'an-BECP is the first inter-provincial watershed compensation project with a main stream of 373 km and a drainage area of over 11,000 km^2 in China. On the one hand, it is difficult for commercial institutions to complete the exchange activities of cross-regional ecological service independently in China due to its hugeness. On the other hand, without the participation of the private sector, the government's intervention activities are effective in the project start-up stage, but the incentive effect on the project's middle and late operation is gradually weakened, and the government can neither use the currency vote to evaluate the ecological service like the beneficiaries of the ecological service, nor can it propose the heterogeneous plan to evaluate the ecological service performance for the ecological service provider, which leads to the insufficient incentives for the providers of ecological services they deserve under the government intervention mechanism (Jing and Zhang, 2018).

Based on the reviews and considerations mentioned above, this paper will assess the environmental benefits of the Xin'an-BECP through the following two main steps: (1) Does the compensation project have a significant negative impact on the intensity of environmental pollution? The PSM–DID (Propensity Score Matching and Difference-In-Difference) method is firstly applied to evaluate the policy effects of the BECP; PSM is responsible for selecting control individuals and the individuals who will be treated, and DID is responsible for identifying the impact of policy shocks. (2) Is the compensation project itself in full compensation? Based on the evaluation of the PSM–DID method and the combination with the newly fitted Kuznets curve, this paper will measure the government's theoretical input to the Xin'an River project, and lead to our next analysis. (3) Based on (1) and (2), we will conduct a comprehensive discussion on the Xin'an River compensation project and obtain corresponding policy inspirations, which will provide experience and reference for the formulation and implementation of other types of ecological compensation projects.

3 Research design

3.1 Variable selection and data sources

The explanatory variable selected in this paper is the water pollution intensity, that is, the industrial sewage discharge per 10,000 yuan of GDP. The ecological compensation target should be highlighted in evaluating the effect of ecological compensation (Zhang and Jiang, 2014). The primary purpose of the Xin'an-BECP is to improve the water ecological environment of the basin, and then to provide a clean and stable water source for Zhejiang Province. Hence, it is of certain relevance and rationality to investigate the impact of the ecological compensation project on the water pollution of the basin.

The treated group comprised the entire territories of Hangzhou City and Huangshan City. According to the ecological compensation agreement between Anhui Province and Zhejiang Province, the scope of implementing the Xin'an-BECP is the whole territory of Huangshan City in the upstream and the whole territory of Hangzhou City in the downstream. The DID method requires that the difference between the experimental group and the control group before the implementation of the policy is as small as possible. Considering that the closer the spatial location, the greater the possibility of smaller differences between cities, this paper has selected Xuancheng and Chizhou cities, which are adjacent to Huangshan City, as well as Huzhou and Jinhua cities, which are in the vicinity of Hangzhou City, for the control group.

The explanatory variable is the interaction term between the processing variable and the time variable $du_i \cdot dt_i$ so as to test the change of water pollution intensity caused by the ecological compensation project of the experimental group and the control group.

Taking data availability and data structure balance into consideration, the covariates include infrastructure (Infras), the ratio of added value of tertiary industry to GDP (Struc), technological innovation (Tech), and per-capita drainage system scale (ScaleR), and "Co-governance in Water" (CGW) includes treatment of sewage, flood prevention, dredging water, safeguarding water supply, and conserving water. Among them, the infrastructure of the city, especially the public environmental infrastructure such as sewage network, sewage treatment plant, green park, and garbage disposal facilities, can improve the urban environment through water pollution purification and pollutant degradation, among others. In the general case of infrastructure construction, the per-capita hardened road area is taken as the proxy indicator of infrastructure (Jing and Zhang, 2018). To some extent, the optimization of industrial structure can be reflected by the proportion of the added value of the tertiary industry in GDP, and the optimized industrial structure signifies the elimination of backward production capacity and the transformation of high-energy and high consumption production mode. Technological innovation, indeed, upgrades the technology and improves energy efficiency exemplified by the same output with less energy, thereby reducing pollution emissions (Ryzhenkov, 2016). Therefore, the number of patents granted per thousand people is taken as the proxy index of scientific and technological innovation in this paper. The per-capita drainage system size is measured by the per-capita drainage pipe length, which is selected as the covariate mainly because it measures the balance between the water demand and sewage discharge in the entire production sector to some extent. CGW is the only virtual variable among the covariates, and it has also been the comprehensive treatment policy of Zhejiang Province on sewage, flood, waterlogging, water supply, water conservation, and other issues since 2013. The policy is intended to solve the problems of water environment pollution and water resource shortage, and the ecological problems of the Xin'an River Basin, which is consistent and relevant to the ecological compensation of the Xin'an River Basin in terms of policy objectives and policy implementation. The city implementing "Co-governance in water" is assigned as 1; otherwise, it is 0.

The original data collected in this paper are all derived from *China Urban Statistical Yearbook* from 2008 to 2021, which constitutes the annual panel data of each city during this period, and uses the method of average growth rate to fill in very few missing values. Among them, Huangshan City and Hangzhou City, both of which belong to the experimental group, are located in the Xin'an River Basin. The cities in the control group are Chizhou City and Xuancheng City adjacent to Huangshan City, and Jinhua City, Shaoxing City, and Huzhou City adjacent to Hangzhou City. The year 2012 is the time node before and after the implementation of the compensation project. Descriptive statistics are shown in Table 1.

3.2 Model setting

At the end of 2012, an agreement on the Xin'an-BECP was formally signed by the Ministry of Finance and the Ministry of Environmental Protection, Zhejiang Province and Anhui Province, which implies the start of the implementation of the ecological compensation project. In this paper, the pilot policy of inter-provincial ecological compensation is regarded as a quasi-natural experiment, and the double difference method is used to evaluate the project performance. The year 2012 is taken as the first year of the formal implementation of the project based on the consideration of the overall implementation time of the project. According to the basic steps established by the DID model, two groups of virtual variables are constructed: (1) construct the treatment variable $du_i \in \{0,1\}$, where $du_i = 0$ means that the individual i belongs to the control group, and $du_i = 1$ means that the individual i belongs to the experimental group. The experimental group is the implementation city of the Xin'an-BECP, and the control group consists of the cities that do not participate in the Xin'an-BECP. (2) Construct time variable $dt_i \in \{0,1\}$, where $dt_i = 0$ means that an individual i belongs to the Xin'an River Basin before the implementation of the ecological compensation project, and $dt_i = 1$ indicates that an individual i belongs to the Xin'an River Basin after the implementation of the ecological compensation project. Next, Y_i is the observable result of individual i, Y_i^N is the potential result when the individual i is not affected by the compensation item, and Y_i^I is the potential result of the individual i being affected by the compensation item, then the observable result of individual i in the processing variable $I_i = du_i dt_i$ can be expressed as (Hu and Lin, 2018):

$$Y_i = I_i Y_i^I + (1 - I_i) Y_i^N \quad (1)$$

Assuming that the effect of policy impact on individual i is a fixed constant:

$$\tau = E[Y_i^I | du_i = 1, dt_i = 1] - E[Y_i^N | du_i = 1, dt_i = 1] \quad (2)$$

In this formula, $Y_i^N | du_i = 1, dt_i = 1$ indicates the state when the individual i is not affected by the policy. This state is unobservable and generally refers to counterfactual, which will be used later for counterfactual testing. Now, assuming that Y_i^N has a linear form, there are:

$$Y_i^N = c + \alpha dt_i + \beta du_i + \sum_{i=1}^{n} \gamma_j X_{it} + \varepsilon_{it} \quad (3)$$

In Equations 3, 4, ε is the disturbance term, and its mean is 0 and independent of the processing variable and the time variable:

TABLE 1 Descriptive statistics.

Variable	All			Treated			Controls		
	Obs.	Mean	Std. Dev.	Obs.	Mean	Std. Dev.	Obs.	Mean	Std. Dev.
Pollution	78	5.3836	3.2044	26	4.2517	2.5052	52	3.9765	2.0043
Infras	78	10.0597	13.6645	26	15.1214	3.6984	52	9.5016	6.2819
ScaleR	78	0.8459	1.3602	26	1.2306	0.2408	52	0.7761	0.4943
Struc	78	0.4684	0.0806	26	0.4564	0.0741	52	0.4328	0.0611
Tech	78	3.4338	8.5390	26	3.9901	1.9090	52	2.3379	2.1604
CGW	78	0.3077	0.4645	26	0.6154	0.4961	52	0.3077	0.4660

$$\varepsilon_{it} \perp du_i, dt_i \tag{4}$$

j is the number of sections, and X is a covariate and also an observable characteristic of i. According to Equation 3, the expression of the expectation of the potential outcome of individual i not being affected by the policy is Equation 5:

$$E[Y_i^N | du_i = 1, dt_i = 1] = c + \alpha + \beta + \gamma_j X_{it} \tag{5}$$

Combining Equations 2, 3, the expression for the expectation of the potential outcome when individual i is affected by the policy is Equation 6:

$$E[Y_i^I | du_i = 1, dt_i = 1] = \tau + c + \alpha + \beta + \gamma_j X_{it} \tag{6}$$

Recalling Equation 1, the linear regression model containing policy effect τ is obtained as follows:

$$\begin{aligned} E[Y_I | du_i, dt_i] &= du_i dt_i (\tau + \alpha dt_i + \beta du_i + \gamma_j X_{it}) + (1 - du_i dt_i) \cdot (\alpha dt_i + \beta du_i + \gamma_j X_{it}) \\ &= \alpha dt_i + \beta du_i + \tau du_i dt_i + \gamma_j X_{it} \end{aligned} \tag{7}$$

Estimates of different combinations of Y_i can be obtained from Equation 7 (See Table 2).

However, there is a high heterogeneity of development in different cities in China, and it is difficult for different cities to meet the conditions of consistent time effects. Therefore, we adopt the tendency score matching method (PSM) of Heckman to eliminate the bias of sample selection as much as possible. In terms of PSM and DID, PSM can eliminate the deviation of sample selection to some extent, but it cannot solve the endogenous problem caused by missing covariates. Though DID can effectively solve the endogenous problem, it cannot avoid the deviation of sample selection. Based on this, the paper finally uses the PSM–DID method by combining PSM and DID to evaluate the project (Hirano et al., 2003). Among them, the regression model based on DID is Equation 8:

$$pollution_{it} = c + \alpha dt_i du_i + \sum_{i=1}^{n} \gamma_j X_{it} + \varepsilon_{it} \tag{8}$$

The model of DID regression after matching the control group with the experimental group via the PSM method is Equation 9:

$$pollution_{it}^{PSM} = c + \alpha dt_i du_i + \sum_{i=1}^{n} \gamma_j X_{it} + \varepsilon_{it} \tag{9}$$

Among them, the treatment effect of individual i in the experimental group is:

$$\tau^{PSM} = (Y_{i+1}^I - Y_i^I) - \sum_{j \in N} \omega(i,j)(Y_{i+1}^N - Y_i^N) \tag{10}$$

TABLE 2 Estimate of Y_i.

	$du_i = 0$	$du_i = 1$
$dt_i = 0$	$\gamma_j X_{it}$	$\beta + \gamma_j X_{it}$
$dt_i = 1$	$\alpha + \gamma_j X_{it}$	$\alpha + \beta + \tau + \gamma_j X_{it}$

In Equation 10, ω(i,j) is the propensity score weight of an observation value.

4 Analysis

4.1 Impact of compensation projects on water pollution

The parallel trend test should be carried out for the experimental and control groups before using the double difference method to evaluate the efficacy of the compensation project. The hypothesis of parallel trend states that changes with time of the explained variables of the experimental group and the control group are generally parallel to each other before the implementation of the policy. Except for the experimental impact, the influence of the unrelated factors on the individual is identical, and the samples of the experimental group and the control group are of the same variance statistically. The samples of the treated group and the control group sample present the same trend before the implementation of the policy (Su and Song, 2019). It can be seen from Figure 2 that the time trend of water pollution intensity of the experimental group and the control group is relatively consistent before the implementation of the Xin'an-BECP, which conforms to the parallel trend test. From the distribution of confidence intervals in Figure 3, it can be seen that prior to the introduction of the Xin'an-BECP, there were cases where the coefficient of the interaction term was not significantly different from 0; after the introduction of the Xin'an-BECP, there were at least three periods where the coefficient of the interaction term was significantly different from 0, which indicates that the parallel trend test is passed.

Furthermore, Figure 4 illustrates the distribution of the estimated coefficients of 800 pseudo-policy dummy variables and the corresponding p-values. The x-axis denotes the magnitude of the estimated coefficients of the pseudo-policy dummy variables, while the y-axis indicates the density value and the magnitude of the p-value. The curve represents the kernel density distribution of the estimated coefficients. The blue dots correspond to the p-values corresponding to the estimated coefficients. The vertical dashed line indicates the true estimated value (−1.165) of the DID model, and the horizontal dashed line signifies the significance level of 0.1. This figure reveals several key insights. Firstly, the estimated coefficients are found to be normally distributed. Secondly, the majority of the estimated values possess a p-value greater than 0.1, indicating that they are not significant at the 10% level. Finally, it is observed that only two of the estimated coefficients of the pseudo-policy dummy variables are located to the left of the true policy dummy variable. This finding suggests that our estimation results are unlikely to be an accident.

Next, benchmark regression (Table 3) reveals the following: (1) when no covariates are added, whether it is a random effect or a fixed effect, the compensation project has a significant negative impact on the water pollution intensity; (2) after adding covariates, the significant negative impact of compensation projects on water pollution intensity is only reflected in the fixed effects.

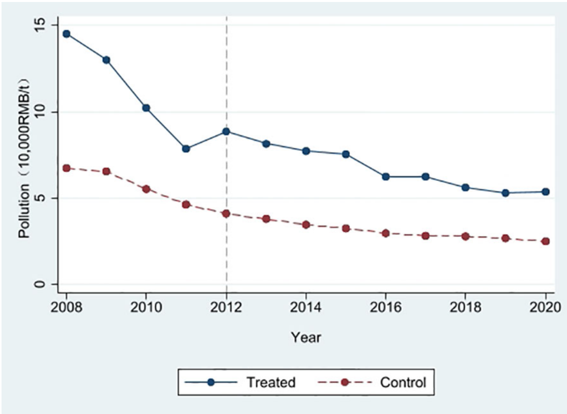

FIGURE 2
Pollution in the treated and control groups.

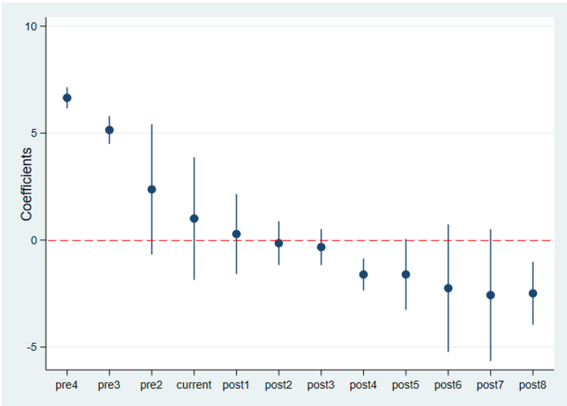

FIGURE 3
The estimated effects of coefficients.

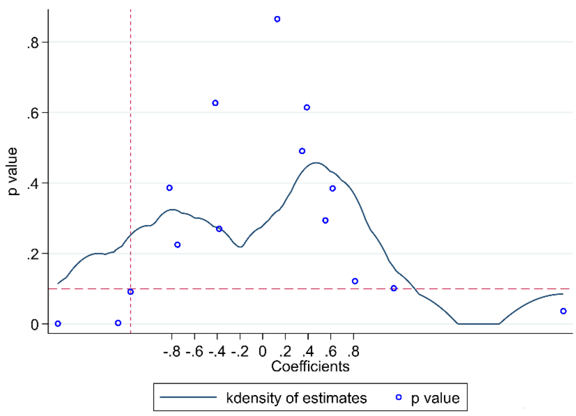

FIGURE 4
The placebo test.

TABLE 3 The benchmark regression.

		I pollution	II pollution	III pollution	IV pollution
dudt		−3.0623*** (0.4813)	−4.6207*** (0.7859)	1.4980 (2.1159)	−2.1944*** (0.6684)
Infras				−0.5034* (0.2933)	−0.7523*** (0.2113)
ScaleR				−5.8452 (4.3007)	6.0459*** (2.1535)
Struc				7.0220 (12.9054)	−22.1901*** (4.0382)
Tech				0.1362 (0.4035)	0.2366 (0.2028)
CGW				−3.6020*** (0.8058)	−1.2793** (0.5655)
C		6.0903*** (1.5676)	6.4499*** (0.2770)	2.2708 (6.2168)	18.3179*** (1.9095)
Time fixed effect		No	Yes	No	Yes
Individual fixed effect		No	Yes	No	Yes
Obs.		78	78	78	78
R^2	Within	0.3275	0.3275	0.0140	0.6617
	Between	0.7192	0.7192	0.7034	0.4371
	Overall	0.0574	0.0574	0.2758	0.0025

***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

4.2 Inspection based on the PSM–DID method

In order to minimize the systematic differences in the level of environmental pollution in different cities, it is necessary to use du_i to make logit regression for each covariate so as to get the score of propensity, and the city which is the closest to the score of propensity can be selected into the control group. Therefore, after the PSM matching, it is also necessary to examine whether there is a significant difference between the experimental group and the control group. If the significant difference between the experimental group and the control group is present as high, the PSM–DID regression is not applicable, and *vice versa*. In Table 4, only pollution has significant difference after matching, so that PSM–DID regression can be carried out.

However, Table 5 shows that the compensation project did not significantly reduce the water pollution intensity in the Xin'an River Basin.

4.3 Robustness test

In order to verify the validity of this conclusion, a robustness test was conducted. When estimating the pollution reduction effect of Xin'an-BECP, it is possible that other policies may also be a factor, which could result in an overestimation or underestimation of the estimated results. To address this issue, a national environmental policy event was added to verify the robustness of the conclusion. In 2013, following the advent of a new Chinese government, significant emphasis was placed on environmental concerns, resulting in the promulgation and implementation of a series of environmental protection policies and laws. It is hypothesized that the environmental protection measures implemented by the new government have led to a reduction in pollution. To identify this effect, a dummy variable for the 2013 policy (var_2013) was incorporated into the baseline regression model. If the effect of the var_2013 policy is not significant, it can at least show that the Xin'an-BECP has a pollution reduction effect. In contrast, it shows that the preliminary conclusions of this article may have been affected by similar policies in a wider context, thereby affirming the robustness of the estimation results. The addition of var_2013 to the model in Table 6 indicates a highly significant effect of the 2013 policy, suggesting that the enhancement in the quality of the Xin'anjiang River is not attributable to Xin'an-BECP alone.

Furthermore, in order to further test the robustness of the estimation results of this paper in the time dimension, the sensitivity of Xin'an-BECP to time change is identified by altering the time interval. To this end, the year 2012 was selected as the intermediate time point, and samples of 1, 2 and 3 years before and after this time point were taken. The samples were then regressed. If a significant change in the coefficients and significance was observed, it was indicated that the estimation results of this paper were robust. As illustrated in Table 7, the pollution reduction effect of stage (1) is found to be significant, while the pollution reduction effects of stages (2) and (3) are not significant. This observation indicates that the sensitivity of Xin'an-BECP to temporal variations

TABLE 4 Applicability test results.

Variable	Mean treated	Mean controls	Diff.	|t|	Pr(|T|>|t|)
Pollution	6.243	3.965	−2.277	3.23	0.0840*
Infras	5.221	7.938	2.716	0.47	0.6823
ScaleR	0.383	0.712	0.329	0.60	0.6120
Struc	0.423	0.427	0.004	0.06	0.9559
Tech	0.533	2.136	1.603	0.73	0.5413
CGW	0.000	0.500	0.500	0.82	0.5000

***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

is high, thereby providing indirect evidence that substantiates the robustness of the estimation results presented in this article.

Concomitantly, counterfactual tests are imperative to eliminate the possibility that policy estimates are erroneous due to selection bias in the time dimension. The basic principle of the counterfactual test is the regressions or tests based on the actual implementation year of the project, which has been illustrated above, and the counterfactual test needs to reset the implementation year of the compensation project; that is, we can imagine that the compensation project was officially implemented in 2009, 2010, or 2011 in order to take the hypothetical project implementation year as the base period to re-estimate the processing effects of the compensation project. Under the premise of the implementation time and interval of the artificial simulation project, the processing effect of each time interval showing insignificant results can be regarded as the most ideal result; thus, it can be said that the pollution reduction effect of the compensation project is significant. Unfortunately, only stage (1) is insignificant in Table 8, and the other stages are significant at different confidence levels, which means that the Xin'an-BECP does not have a significant pollution reduction effect in time scale. In general, there are two reasons for this result: (1) people have already expected the policy to be implemented before the policy occurs, and (2) there is no parallel trend between the experimental group and the control group. Obviously, the above two points are not the real reason for the failure of the compensation project to pass the counterfactual test.

TABLE 5 PSM–DID regression results.

	Before	After	Diff-in-Diff
	Pollution		
Diff (Treated − Control)	−1.198	−1.610	−0.412
Std. Err.	0.940	1.580	1.839
t	−1.27	1.02	0.22
p>|*t*|	0.243	0.342	0.829

4.4 Heterogeneity analysis

Cities with a population size greater than 1 million have been shown to experience an economic agglomeration effect, resulting in enhanced efficiency of resource allocation and utilization, which can contribute to a reduction in environmental pollution (Shi et al., 2018). This article therefore seeks to ascertain whether there are differences in the pollution reduction effect depending on the population size. The population sizes of the cities observed in this paper are all at least 1 million. Table 9 indicates that the pollution reduction effect is more pronounced in cities with a population size of less than 3 million. However, when controlling for variables is not taken into account, the pollution reduction effect is marginally weaker in cities with a population size of more than 3 million compared to cities with a population size of less than 3 million. This finding suggests that cities with a population of more than 1 million may be able to achieve wastewater reduction through their own endowment, provided that the impact of the Xin'an-BECP is not taken into account. It is highly probable that the pollution reduction effect observed in the Xin'anjiang River is not attributable to the Xin'an-BECP.

In Table 10, the present study analyzes the influence of geographical factors on the pollution reduction effects of the treated and control groups. It is well established that the economic agglomeration effect of cities on the southeast coast of China is higher than that of cities not located there. Therefore, the following question is posed: does a significant pollution reduction effect exist when the observed cities are located on the southeast coast, or when they are not located there? To this end, a dummy variable i_coastal is introduced, with i_coastal = 1 when the observed city is located on the southeast coast, and i_coastal = 0 otherwise. Subsequently, the independent variables are multiplied by i_coastal to obtain an interaction term, which is then incorporated into the benchmark regression. Should the coefficients of the core independent variable and the original core independent variable be the same positive value, it would indicate that the pollution reduction effect of the Xin'an River may be attributable to the inherent endowment of the coastal cities in the watershed, as opposed to the Xin'an-BECP.

TABLE 6 Effectiveness of other policies.

	V pollution	VI pollution
dudt	−2.4323*** (0.730)	−1.9524***
var_2013	−2.4620*** (0.400)	−1.1269** (0.514)
Infras		−0.6890*** (0.209)
ScaleR		6.4397*** (2.062)
Struc		−16.6772*** (4.809)
Tech		0.0670 (0.197)
CGW		−0.5452 (0.694)
C		15.7599*** (2.208)
Control	No	Yes
Obs.	78	78

***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

5 Measurement of theoretical ecological compensation quota

Based on the above analysis, we also need to take the compensation project itself as the point of contact to further investigate the balance of compensation. Therefore, the calculation of the theoretical ecological compensation amount becomes the next issue to be discussed in this paper. With regard to the calculation of the theoretical ecological compensation limit, the expectation of this paper is that when the compensation amount is close to the loss amount in the upstream of the river basin, that is, when the environmental rights and development rights of the upstream and downstream regions reach equilibrium, the implementation of the compensation project will have the possibility of significant treatment effect.

TABLE 7 Pollution reduction effects after changing the width of the time window.

No. stage	(1)	(2)	(3)
Simulated stage	2012 (2011–2013)	2012 (2010–2014)	2012 (2009–2015)
dudt	2.1026*** (0.393)	0.6559 (0.536)	−0.7536 (0.545)
Infras	−0.6331 (0.963)	−0.0894 (0.435)	−0.1325 (0.361)
ScaleR	8.6473 (5.570)	−11.9147** (5.039)	−12.2720*** (4.295)
Struc	−29.9683* (14.073)	6.5806 (12.742)	25.2004** (9.680)
Tech	−0.8832* (0.370)	−0.4481 (0.330)	−0.5874** (0.286)
CGW	−0.3168 (0.345)	−0.1478 (0.525)	−0.2312 (0.590)
C	19.6220** (6.827)	11.6182** (4.833)	4.8624 (3.953)
Control	Yes	Yes	Yes
Obs.	18	30	42

***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

The output price of sewage in the current year is represented by P_t, and the functional relationship between the GDP_{PC} (yuan/person) and per-capita sewage discharge $Water_p$ is set as follows:

$$Water_p = f(GDP_{PC}) \tag{11}$$

Then, according to Equation 11, the theoretical per-capita sewage discharge per year under the normal economic development level is calculated (tons/person) as Equation 12:

$$Water^*_{p,t} = f(GDP_{PC,t}) \tag{12}$$

The annual pollution rights lost in the upstream watershed due to environmental governance environmental governance is Equation 13:

$$\Delta Water_{p,t} = Water^*_{p,t} - Water_{p,t} \tag{13}$$

The total loss of pollution rights in the upstream basin is Equation 14:

$$Q_{water,t} = POP_t \times \Delta Water_{p,t} \tag{14}$$

According to Equation 14, the total value of pollution loss in the upstream basin (i.e., the portion of the downstream basin that needs to be compensated to the upstream basin) is:

$$V = P_t \times Q_{water,t} = P_t \times POP_t \times (Water^*_{p,t} - Water_{p,t}) \tag{15}$$

The EKC hypothesis posits that the ecological environment deteriorates during the initial stage of economic development, but will improve to a certain extent once the economy has reached a certain level of development (Kılıç et al., 2024; Golpîra et al., 2023). Based on this hypothesis, if we only observe the relationship between GDP and water pollution, then their quantity curve is inverted U-shaped (Equation 16):

$$Water_p = \varphi_0 + \varphi_1 \times GDP_{PC} + \varphi_2 \times (GDP_{PC})^2 + \xi \quad (\varphi_2 < 0, \varphi_1 > 0) \tag{16}$$

However, studies related to EKC show that the GDP_{PC} and environmental pollution in some regions of China have an N-shaped curve (Shen and Xu, 2000). Taking the above into consideration, when there is an N-type curve relationship, the relationship between the GDP_{PC} and $Water_p$ should also satisfy the Equation 17:

$$Water_p = \delta_0 + \delta_1 \times GDP_{PC} + \delta_2 \times (GDP_{PC})^2 + \delta_3 \times (GDP_{PC})^3 + \xi \quad (\delta_1, \delta_3 > 0, \delta_2 < 0) \tag{17}$$

TABLE 8 Counterfactual test.

No. stage	(1)	(2)	(3)	(4)	(5)
Simulated stage	2009 (2008–2010)	2010 (2008–2011)	2010 (2008–2012)	2011 (2008–2012)	2011 (2009–2012)
Pollution	−3.5256 (−1.42)	−4.1103** (−2.61)	−3.2785** (−2.35)	−3.6373*** (−6.05)	−2.9528*** (−4.80)

The year in the first line is the base period of the simulation, and the years in parentheses are the time interval of the simulated project. ***p < 0.01; **p < 0.05; *p < 0.1.

We made use of the data from *Huangshan Statistical Yearbook* and the *Hangzhou Statistical Yearbook* (2008–2020) (Tables 11, 12) to test the matching degree of EKC with model (16) and model (17), and obtained the results in Table 13. It can be found that the coefficients in model (16) do not satisfy the inverted U-shaped curve relationship and are not significant as well, by which it is eliminated as a result; all coefficients in the model (17) are significant, but the sign is completely opposite to the requirement of the N-type curve; thus, it is an inverted N-type curve.

Therefore, from model (17), it can be known that the quantitative relationship between GDP_{PC} and $Water_p$ is Equation 18 (ξ is the random error term):

$$Water_p = 59.7089 - 8.0278 \times GDP_{PC} + 0.9546 * (GDP_{PC})^2 - 0.0236 * (GDP_{PC})^3 + \xi \quad (18)$$

In Figure 5, the theoretical $Water_p$ of Huangshan City and Hangzhou City is calculated by model (18). We can find out that the theoretical $Water_p$ of Huangshan City in the upper reaches of the Xin'an River is between 40.49 and 43.91 t from 2012 to 2020, while the actual $Water_p$ is between 28.35 and 35.17 t, and approximately 23% of the pollution right has not been exercised. In addition, the actual wastewater discharge of Huangshan River basin takes only from 28.23% to 49.87% of the actual wastewater discharge of Hangzhou River Basin. Even though the proportion is decreasing year by year with the improvement of the economic development level, there is still a large gap between these two. Taking the adjacent areas and similar ecological environment and equivalent economic volume as reference values, we choose Wei Chu and other people's calculation results of the industrial wastewater unit output value (the average value is t/280 yuan) of the Shanxi Reservoir Watershed in Wenzhou City—the adjacent area of the Xin'an River (Wei and Shen, 2011), and calculated that the loss of potential output caused by emission reduction and control in the Huangshan watershed of the Xin'an River in the window period is at least from 2.264 billion yuan and 5.050 billion yuan while the annual average is 3.980 billion yuan, which is far from the compensation fund of 500 million yuan in the first round of the Xin'an-BECP led by the government (the annual average compensation fund of 700 million yuan for the second round of compensation project), and it is twice as high as the amount of all funds of the three rounds of

TABLE 9 Heterogeneity analysis of city scale.

	(1)	(2)	(3)	(4)
	Population <3 million		Population ≥3 million	
dudt	−2.31383*** (0.71)	−5.27413*** (1.14)	−1.67981 (1.12)	−3.96731*** (1.05)
Infras	−0.77990*** (0.22)		1.56025** (0.67)	
ScaleR	−6.23011* (3.23)		−1.1e+01* (6.12)	
Struc	7.16097 (5.83)		4.48221 (9.75)	
Tech	0.44875 (0.35)		−0.66507** (0.23)	
CGW	−0.16941 (0.90)		−1.50582 (0.89)	
C	11.60991*** (1.99)	6.52083*** (0.33)	1.71887 (5.40)	6.30816*** (0.50)
Control	Yes	No	Yes	No
Obs.	52	52	26	26

***p < 0.01; **p < 0.05; *p < 0.1.

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TABLE 10 Heterogeneity analysis of geographical distribution.

Pollution	Coefficient	Std. err.	*t*	*p*>|*t*|
dudt	−2.0045	0.5924	−3.38	0.001
i_coastal*Infras	−0.4065	0.2038	−1.99	0.051
i_coastal* ScaleR	5.0944	1.9929	2.56	0.013
i_coastal* Struc	3.9928	6.4435	0.62	0.538
i_coastal* Tech	−0.1608	0.2258	−0.71	0.479
i_coastal* CGW	−1.7002	0.7985	−2.13	0.038
C		1.6038	3.51	0.001

***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

compensation agreement between Zhejiang and Anhui Province. Moreover, 200 million of the 500 million yuan compensation fund was bet on each other by Zhejiang Province and Anhui Province with the chips of the Xin'an River environmental quality meeting the agreed standards. Although the compensation funds were eventually used for environmental pollution control, the comparative calculation result is still a drop in the bucket according to the result (Du and Che, 2019).

6 Discussion

6.1 Discussion on compensation policy

As mentioned above, the Xin'an-BECP does not have a significant pollution reduction effect. Firstly, according to the analyses in this paper, it is possible that the reduction in the intensity of water pollution in the Xin'an River after 2012 can be attributed to other reasons, such as the new government's emphasis on environmental pollution, the city's own endowment, or the different geographic distribution of upstream and downstream. In addition, if the ECPioGA continues to increase compensation inputs to keep the environmental and development rights of both upstream and downstream parties in equilibrium as much as possible, it will be difficult for this government-led compensation model to internalize all the externalities if the involvement of market players is neglected: either the pollution reduction effect is not significant or the right to development of the upstream area is diminished.

Secondly, there is a huge gap between the fund of the Xin'an River Ecological Compensation Project provided by the government and the calculation of the opportunity cost of economic development in the upstream basin. We have calculated that the potential output loss caused by emission reduction and control in Huangshan basin of the Xin'an River during the window period is at least from 2.264 billion yuan to 5.050 billion yuan, with an average annual loss of 3.980 billion yuan; from a certain point of view, the government is purchasing ecological services at low prices. Although Huangshan City has made extra efforts for environmental protection in the upper reaches of the Xin'an River that need to be realized, the extent of such incentives is far from enough. Moreover, in the light of more macroscopic policy, the government's purchase of ecological services does not mean that the government is a direct consumer of ecological services. Although it promotes environmental protection for the purpose of providing its own public service functions, for the private sector that does not directly pay the compensation price in the downstream, the acquisition of free positive externalities is not conducive to the voluntary

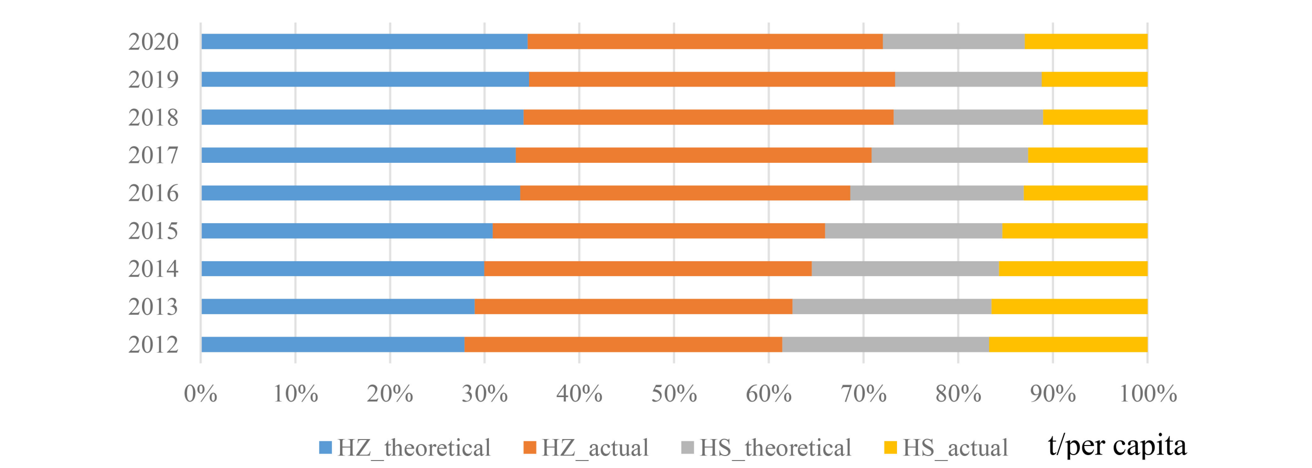

FIGURE 5
Per-capita industrial wastewater discharge of Hangzhou and Huangshan.

TABLE 11 Per-capita industrial wastewater discharge (unit: ton).

Year	Tunxi District	Huangshan District	Huizhou District	She County	Xiuning County	Yi County	Qimen County	Hangzhou urban area	Hangzhou non-urban area
2012	2.46	1.51	14.56	4.23	4.20	1.21	1.99	30.06	97.49
2013	3.11	1.06	14.53	4.90	4.42	1.96	1.64	25.20	65.98
2014	2.82	1.69	13.91	4.58	4.28	1.53	1.89	43.39	32.20
2015	2.89	1.80	15.20	6.36	4.52	0.94	2.22	41.48	28.38
2016	2.54	1.77	15.05	4.87	3.74	0.94	2.21	36.26	18.07
2017	1.12	1.27	14.48	4.79	3.78	0.67	2.00	31.00	10.46
2018	1.14	1.25	14.49	6.39	3.75	0.62	2.01	35.32	8.47
2019	1.13	1.25	14.42	6.39	3.75	0.62	2.01	29.00	9.39
2020	4.76	0.66	15.48	6.03	4.45	3.43	1.61	19.47	7.77

downstream of the Xin'an River. Although it is shown from the data that the actual per-capita sewage discharge of Hangzhou is decreasing year by year, it can be largely attributed to the rigid provisions of environmental protection policy.

Thirdly, the nihilism of the micro-interests of ecological compensation in the Xin'an River Basin has led to the absence of a protection system for substantive interest groups. Being confined to the appearance of management practice, the research and discussion on the subject of social relations of ecological compensation only linger at the macro level of the regional government rather than trace the micro level and the private subjects restricted by the development and utilization of environmental resources (Du and Che, 2019). For example, the implementation of compensation projects reduces the agricultural land of some farmers in Huangshan City due to return farmland to forests, which brings about the effect on the income of upstream residents whose livelihood is tea, forestry, and fish farming as their main source of income was suddenly reduced. However, most of the compensation project funds are used for environmental governance, and the people's livelihood project has not been constructed at the same time due to the virtualization of micro-interests.

6.2 Policy implications

The policy implications are derived as follows by means of the above analysis:

1. Improve the legal rights and interests of the micro-interests of Xin'an River Basin Ecological Compensation, and ensure that the private sector pays directly for the ecological services. Even in the middle and later stages of the operation of the ecological compensation projects, it is also necessary to provide strong livelihood security for the micro-benefiters whose living environment has been changed. Effective livelihood security should be the basis for optimizing the space for ecological development.
2. With due regard to the interests of private actors, the government should continue to increase funding for compensation programs. There are reasons to believe that the upstream region needs to be fully compensated for sacrificing the right to development. At the same time, we believe that the shadow value of pollution control has a higher probability of premium in the whole system. Although the direct purpose of the ecological compensation project of the

TABLE 12 Per-capita GDP (unit: yuan).

Year	Tunxi District	Huangshan District	Huizhou District	She County	Xiuning County	Yi County	Qimen County	Hangzhou urban area	Hangzhou non-urban area
2012	29,631.58	38,333.33	32,755.10	18,782.61	20,966.54	22,127.66	23,262.03	99,538.61	64,637.92
2013	53,220.34	42,484.47	44,607.84	25,271.97	22,763.64	24,210.53	25,721.93	106,374.5,6	69,308.38
2014	56,648.04	45,308.64	48,039.22	27,379.45	24,565.22	26,382.98	27,967.91	116,288.63	70,620.69
2015	57,577.32	46,583.85	53,829.79	28,147.37	26,802.97	27,872.34	28,930.48	125,316.09	76,333.33
2016	62,436.55	50,000.00	57,789.47	29,979.04	29,074.07	30,212.77	31,010.64	141,314.66	84,954.02
2017	66,237.62	50,802.47	66,000.00	32,063.16	30,780.67	30,851.06	32,553.19	154,418.02	83,637.14
2018	71,899.55	56,525.43	73,247.06	35,657.34	33,646.52	34,417.41	36,546.23	196,852.98	72,266.81
2019	94,667.73	71,255.24	85,238.10	40,848.18	40,797.61	45,873.24	40,618.85	218,547.94	73,775.30
2020	95,916.69	74,163.57	89,958.17	42,486.31	43,491.21	49,274.58	41,588.64	223,560.06	72,820.34

TABLE 13 Results of the econometric model.

Item	(16)	(17)
Prob > *F*	0.0083	0.0056
Constant	43.5939*** (3.91)	59.7089*** (7.66)
GDP_PC	0.0090 (0.00)	−8.0278*** (−3.86)
$(GDP\_pc)^2$	0.1061* (1.77)	0.9546*** (5.22)
$(GDP\_pc)^3$		−0.0236*** (−4.74)
R^2_overall	0.9065	0.9653

***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

Xin'an River Basin is merely to adjust the institutional arrangement of benefiters' interests mainly by economic means, pollution prevention and control are the bottom line of its direct purpose instead. Only when pollution prevention and control are guaranteed by the economy and system will the government's economic adjustment means be more efficient. On the other hand, it can also establish an independent system such as a third-party organization running ecological compensation projects with the participation of the government and the private sector. Third-party organizations have a considerable influence on the operation of ecological compensation projects, such as setting trading conditions, affecting the transaction price, and controlling the transfer of resources between the two parties of the eco-service transaction (Vatn, 2010; Kosoy and Corbera, 2010). Nevertheless, the aim of the third-party organization in our proposal is to solve the gap between existing funds and actual funds: the funds used by the government to purchase ecological services directly should be allocated to third-party institutions, which provide financial institutions with guarantees for ecological service demanders. The credit can be granted from the financial institutions to the eco-service demanders according to their own qualifications and guarantee quotas. They can purchase eco-services from the eco-service providers indirectly through third-party institutions right after the eco-service demanders receive the corresponding level of credit. Such a system design proposal actually introduces a tool of trading leverage in which the lower the margin ratio is, the greater the leverage ratio is, and the third-party agencies can provide guarantees in a larger scope. At the same time, the financial pressure of the government will also be correspondingly reduced, which opens the door for private capital to enter the ECPioGA.

7 Conclusion and future recommendations

This article provides a reference model and enriches the research on the benefit analysis of river basin ecological compensation projects, and we believe that (1) the one-way purchase price should be replaced by the two-way transaction price, which brings about a higher premium on the shadow value of pollution control; (2) the government agencies gradually withdraw from the compensation system, and the micro-interest will become the compensated subject of the ecological service and resource-intensive industries will become the main purchasing force of ecological services, through which the ecological compensation projects will return to the authentic *who benefits and who compensates* model in the hope of achieving higher project returns.

In addition, two research directions merit further exploration in future studies: (1) the theoretical ecological compensation amount of BECP can be measured directly by calculating the unit output value of water resources in the watershed, as opposed to the current practice of calculating the unit output value of industrial wastewater in the cities in the watershed (Chen et al., 2022); (2) the methodology of this paper and its associated recommendations may also be applicable to the study of marine ecological compensation projects (Wang, 2023), especially in the national system of centralized government management; the issue of the effectiveness of marine ecological compensation projects that lack the participation of market players deserves further study.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Author contributions

XX: Writing – review & editing, Validation. WT: Writing – original draft, Software, Methodology. YW: Conceptualization, Investigation, Writing – review & editing.

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Conflict of interest

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2025.1514149/full#supplementary-material

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