

**Balancing environmental protection and economic development: the
role of watershed horizontal ecological compensation policy evidence
from the Yellow River Basin**

Yi-qi WANG¹ and Shen-wei BAO^{1*}

¹School of Economics and Management, Chang'an University, Xi'an, Shaanxi,
China

*Corresponding author: Shen-wei BAO; E-mail: 2296894154@qq.com

Supplementary Appendix

Robustness and Additional Tests

A.1. Parallel trends test

The application of a staggered difference-in-differences approach requires the parallel trends assumption to be satisfied (Jacobson *et al.*, 1993). If the treatment and control groups did not differ significantly before the implementation of the horizontal eco-compensation policy, the estimated coefficients of the interaction terms between yearly dummy variables (pre-policy) and the treatment group dummy should be statistically insignificant. To mitigate potential multicollinearity, the period immediately before policy implementation is excluded. The results, as shown in Figure A1, indicate that after the implementation of the horizontal eco-compensation policy, counties subject to the policy experienced significant improvements in both economic performance and environmental quality.

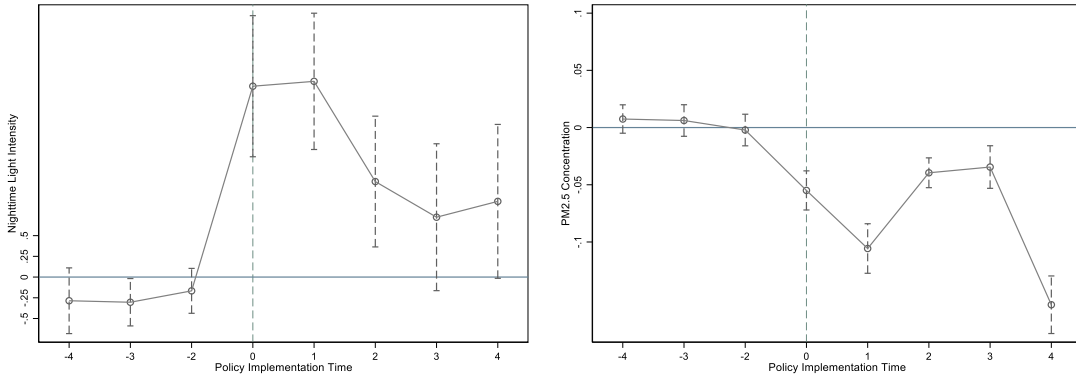


Figure A1. Parallel trend test.

A.2. Placebo test

To rule out the influence of non-policy factors and ensure that the estimated policy effect is genuine rather than driven by unobserved variables or random fluctuations, a placebo test was conducted by randomly selecting the treatment group and assigning random policy shock times. Using Stata, 500 random shocks of a fictitious horizontal eco-compensation policy were generated and applied to counties. Figure A2 displays

the distribution of the estimated coefficients from these 500 iterations for the outcome variables *Light(log)* and *PM2.5(log)*, compared to the baseline estimate.

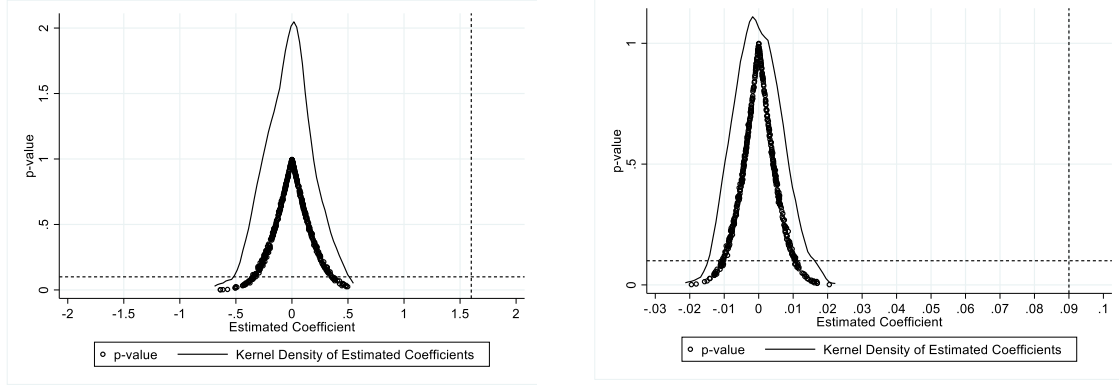


Figure A2. Placebo test.

The baseline regression coefficients are significantly different from those obtained in the placebo tests. Moreover, the estimated coefficients from the placebo tests follow a normal distribution centered around zero, indicating that the baseline results are unlikely to be driven by unobserved confounding factors.

A.3. Excluding interference from other policies

In the context of basin-wide ecological and environmental governance policies, aside from the eco-compensation policy, certain counties are also subject to influences from other initiatives such as the Eco-Civilization Demonstration Zones and the Low-Carbon City Pilot Policy. To ensure that the regression results are driven by the horizontal eco-compensation policy rather than these overlapping policies, we include two additional policy dummy variables in the baseline model: one for Eco-Civilization Demonstration Zones (*controlpolicy*) and another for Low-Carbon City (*dtcs*).

The estimation results, presented in Table A1, show that the coefficient of the core

explanatory variable remains significantly positive for economic outcomes and significantly negative for environmental outcomes. This indicates that the implementation of Eco-Civilization Demonstration Zones or Low-Carbon City policies does not distort the estimated effects of the horizontal eco-compensation policy. Thus, Hypothesis H₁ is again supported.

Table A1. Controlling for other pilot policy impacts in PES

Variable	Controlling for Eco-Civilization Demonstration Zone Policy		Controlling for Low-Carbon City policy	
	(1)	(2)	(3)	(4)
	<i>PM2.5(log)</i>	<i>Light(log)</i>	<i>PM2.5(log)</i>	<i>Light(log)</i>
<i>policy dummy</i>	-0.098*** (0.29)	1.571*** (-4.54)	-0.098*** (-8.14)	1.600*** (8.36)
<i>controlpolicy</i>	0.004 (-8.15)	-1.179*** (8.16)		
<i>dtcs</i>			0.003 (0.29)	0.676 (1.39)
County fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
Control variables	Yes	Yes	Yes	Yes
N	6,709	6,709	6,709	6,709
R ²	0.951	0.976	0.951	0.976

Notes: T-statistics are reported in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively. The same notation applies to the following tables.

Data source: Compiled by the author.

A.4. Excluding the influence of outliers

To mitigate the potential impact of outliers, the top and bottom 1% of the samples for *PM2.5(log)* and *Light(log)* were winsorized. The regression results, presented in Table A2, show that the estimated coefficients of the outcome variables remain consistent with the baseline regression results after removing outliers, indicating that the findings are robust.

Table A2. Excluding outliers

Variable	(1)	(2)
	<i>Light(log)</i>	<i>PM2.5(log)</i>
<i>policy dummy</i>	1.607*** (8.19)	-0.103*** (-9.09)
County fixed effects	Yes	Yes
Year fixed effects	Yes	Yes
Control variables	Yes	Yes
N	6,709	6,709
R ²	0.976	0.952

A.5. Excluding the influence of the pandemic period

To mitigate external uncertainty arising from the pandemic during 2020–2021, we re-estimate the model by excluding observations in this period. Table A3 shows that the sign and significance of coefficients remain consistent with the baseline, confirming the robustness of our findings.

Table A3. Excluding the influence of the pandemic period

	(1)	(2)
	<i>Light(log)</i>	<i>PM2.5(log)</i>
<i>policy dummy</i>	2.424*** (8.96)	-0.147*** (-8.56)
County fixed effects	Yes	Yes
Year fixed effects	Yes	Yes
Control variables	Yes	Yes
N	5,819	5,819
R ²	0.976	0.952

A.6. Instrumental variable test

To address potential endogeneity bias in the horizontal eco-compensation policy, this study employs an instrumental variable (IV) approach. Per capita daily domestic water

consumption at the county level is employed as the instrumental variable. The choice of this instrument is justified on two grounds. First, higher per capita daily water consumption indicates greater local resource use and richer water resources. Increased resource consumption may pressure local governments to implement environmental regulations, while abundant water resources – a key indicator of ecological service capacity – enhance the ability to provide downstream regions with services such as water conservation and purification, thereby facilitating cross-county eco-compensation agreements. Thus, per capita water consumption is positively correlated with the likelihood of adopting horizontal eco-compensation, satisfying the relevance condition.

Second, per capita daily water consumption reflects residents' daily water demand, which is primarily determined by exogenous geographical factors such as natural precipitation and terrain-related water retention capacity. It lacks a direct causal relationship with environmental protection efforts or economic development levels, satisfying the exogeneity requirement. The test results are presented in Table A4. In the first stage, per capita daily water consumption shows a significant positive correlation with the policy variable, indicating that regions with higher water consumption are more likely to implement the horizontal eco-compensation policy, consistent with theoretical expectations. The instrument passes tests for underidentification and weak identification, confirming its validity and strength. In the second stage, the core explanatory variable remains significantly negative for environmental pollution ($PM_{2.5}(\log)$) and significantly positive for economic outcomes ($Light(\log)$),

indicating that the baseline results hold even after accounting for endogeneity.

Table A4. Instrumental variable tests

	(1)	(2)	(3)
	First stage	Second stage	Second stage
		<i>PM2.5(log)</i>	<i>Light(log)</i>
Instrumental variable (%)	0.039*** (7.55)		
<i>policy dummy</i>		-0.521*** (-6.36)	17.850*** (5.94)
Cragg-Donald Wald F statistic	127.577		
Kleibergen-Paaprk LM statistic	37.216***		
County fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
Control variables	Yes	Yes	Yes
N	6,709	6,709	6,709

A.7. Propensity score matching

As a quasi-natural experiment relies on non-randomly selected samples, propensity score matching (PSM) is employed to mitigate potential endogeneity bias arising from sample selection. For each treated county (i.e., a compensation-receiving area), a control county with the most similar observable characteristics is identified and matched. Matching is performed annually using a 1:1 nearest-neighbor algorithm, with covariates including population size, industrial structure, natural conditions, fiscal status, and agricultural development level. Regression results based on the matched sample remain consistent with the baseline estimates, with the test results shown in Table A5, providing further support for the empirical conclusion that the horizontal eco-compensation policy generates significant economic and environmental benefits.

Table A5. Propensity score matching for PES policy

Variable	(1)	(2)
	<i>Light(log)</i>	<i>PM2.5(log)</i>
<i>policy dummy</i>	0.484* (2.36)	-0.030** (-2.62)
County fixed effects	Yes	Yes
Year fixed effects	Yes	Yes
Control variables	Yes	Yes
N	3,746	3,746
R ²	0.526	0.837

A.8. Moderating effect of fiscal transfers

Fiscal transfers, as an intergovernmental fiscal coordination mechanism, achieve structural balance between financial power and administrative responsibilities across government levels through vertical and horizontal allocation of fiscal resources. This ensures equalization of public services and coordination of fiscal revenues and expenditures. The core logic of how fiscal transfers moderate the relationship between economic development and environmental protection lies in their use of fiscal redistribution to correct the structural conflict between the externality of environmental governance and local development rights.

The public good nature of ecological environments leads to a spatial mismatch between the costs and benefits of governance. Local pollution often spills over to neighboring areas, and accountability is difficult to assign, resulting in short-sighted decision-making by local governments when balancing economic growth and environmental protection. Fiscal transfers address this through fund allocation: on one hand, general transfers compensate for funding gaps in local economic development, alleviating fiscal pressure that crowds out environmental spending, thereby providing

buffer space for local governments to balance economic performance and ecological responsibilities. On the other hand, specific transfers guide local government behavior by earmarking funds for environmental governance. This reconfigures the cost-sharing and benefit-sharing mechanisms of environmental governance, compensates for local environmental costs, and shifts environmental regulation from a passive constraint to an active value-added process, ultimately balancing environmental protection and economic development.

The amount of transfers received by each county is determined using a methodology designed for estimating fiscal transfer payments at the county level. The results in columns (1) and (2) of Table A6 show that the interaction term between fiscal transfers and the horizontal eco-compensation policy is statistically significant at the 1% level, with the same sign as the baseline regression coefficients. This indicates that fiscal transfers help achieve a win-win outcome for both economic development and environmental protection in counties implementing the horizontal eco-compensation policy. This is primarily because the horizontal eco-compensation policy, through fiscal transfers, provides financial compensation and institutional incentives. It directly supports ecological restoration and pollution control, links environmental quality to fund allocation, influences government performance evaluation mechanisms, and compels local governments to shift from “prioritizing economic growth” to “competing on environmental performance.” Consequently, local governments are guided to phase out highly polluting industries, raise entry standards for green industries, and indirectly optimize the regional industrial structure. Meanwhile, dedicated eco-compensation

funds promote the development of low-pollution industries such as eco-agriculture and eco-tourism, forming an environmentally friendly economic model.

Table A6. Moderating effect tests

	(1) <i>Light(log)</i>	(2) <i>PM2.5(log)</i>	(3) <i>Light(log)</i>	(4) <i>PM2.5(log)</i>
Variable	Fiscal transfers	Fiscal transfers	Human capital	Human capital
<i>policy dummy</i>	-0.711 (-1.54)	-0.028 (-1.33)	0.853* (1.73)	-0.032* (-1.78)
<i>policy dummy</i> *Moderator	0.479*** (5.20)	-0.013*** (-3.57)	5.730* (1.72)	-0.476*** (-4.79)
Moderator	-0.189** (-2.12)	0.013*** (6.75)	7.963*** (2.68)	0.161 (1.40)
County Fixed Effects	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes
Control Variables	Yes	Yes	Yes	Yes
R ²	0.591	0.842	0.593	0.844
N	6,709	6,709	6,317	6,317

A.9. Moderating effect of human capital

human capital links economic growth momentum with ecological governance efficacy through knowledge spillovers and technology adaptation, enabling regions to balance economic development and environmental protection. On one hand, high human capital implies a pool of highly educated, skilled, and qualified talent. This enhances the capacity for innovation in key areas such as green technology R&D and clean production process transformation. It strengthens the ability of the horizontal eco-compensation policy to channel production factors toward low-carbon sectors, reducing resource and environmental costs per unit of output.

On the other hand, human capital ensures the implementation of environmental

concepts and enhances public participation in regional environmental protection. It drives the horizontal eco-compensation policy to improve the efficiency of environmental regulation enforcement and accelerates the internalization of ecological value into the economic system. Moreover, human capital helps raise the level of regional specialization, incentivizes environmental innovation and green industry incubation, and improves the practical application of pollution control technologies. These enhancements amplify the effect of the horizontal eco-compensation policy in promoting both economic development and environmental protection, providing endogenous momentum for high-quality regional growth.

Human capital is measured as the proportion of students enrolled in regular institutions of higher education relative to the total population. The results in columns (3) and (4) of Table A6 show that the interaction term between human capital and the horizontal eco-compensation policy is statistically significant at the 10% level, with the same sign as the baseline regression coefficients. This indicates that human capital facilitates a win-win outcome for economic development and environmental protection in countries implementing the horizontal eco-compensation policy. This is mainly because human capital enhances the implementation effectiveness of the horizontal eco-compensation policy through knowledge spillovers. It reduces the cost of clean technology R&D, allowing eco-compensation funds to be more efficiently converted into investments in clean technology development. It also helps transform ecological value into economic value, breaking through the traditional dilemma of “environmental protection inhibiting growth.”

References

Jacobson LS, LaLonde RJ and Sullivan DG (1993) Earnings losses of displaced workers. *American Economic Review* **83**, 685–709.