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Assessing the effect of the joint governance of transboundary pollution on water quality: Evidence from China

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The joint governance of transboundary river pollution is an important means to resolve disputes between upstream and downstream, to achieve regional coordinated development and water environment governance. In this paper, dissolved oxygen, chemical oxygen demand and ammonia nitrogen are used to measure water quality. Regarding the joint governance of transboundary water pollution as a quasi-natural experiment, this paper employs a difference-in-differences model of causal judgment to assess the effect of the policy on transboundary water quality based on the water quality monitoring week data from 2004 to 2016 in China. The results show that compared with non-trans-provincial rivers, the joint governance of water pollution at the provincial boundary could significantly promote the rise of dissolved oxygen, while reducing the chemical oxygen demand and ammonia nitrogen emissions. Additionally, the long-term dynamics based on the dynamic trend suggests that the implementation of this policy has fluctuations in the improvement of dissolved oxygen, but has a strong continuous effect on the reduction of chemical oxygen demand and ammonia nitrogen. These results stand up to robustness tests. Moreover, the green promotion pressure of officials and stakeholder supervision are important influence mechanisms of transboundary joint pollution control on improving transboundary water quality. An important implication is to provide a long-term way for collaborative water pollution control and solving transboundary water pollution disputes.

KEYWORDS

transboundary water pollution, joint governance, water quality, difference-in-differences model, China

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1 Introduction

While enjoying rapid economic development, China is also facing more and more serious pressure on the ecological environment with respect to its river's pollution. Rivers provide an important guarantee for the social and economic development of the upstream and downstream areas and for the people to live and work in peace and contentment (Duda and Hume, 2013). However, as the "clear flow becomes turbid water," the important ecological functions of the river are gradually weakened. Due to the nature of rivers as quasi-public goods, negative externalities make upstream areas prone to promoting "beggar-thy-neighbour" pollutant discharge behaviour, whereas positive externalities of pollution control make downstream areas prone to the "free-rider" psychology. A situation that leads to the transboundary pollution of rivers, is an environmental problem commonly faced by the international community (Sigman, 2002). The fact is that not only developing countries have serious transboundary water pollution problems, but developed countries as well (Lipscomb and Mobarak, 2017). Actually, the annual economic loss caused by water pollution in China is as much as 240 billion RMB. More specifically, the central government spent 430 billion RMB in 2016 and 300 billion RMB in 2017 on water pollution control. Approximately 80% of China's oil and chemical projects are along rivers, and as many as 20% of these companies are in trans-provincial areas (Cai et al., 2016). Accordingly, frequent outbreaks of water pollution across river basins have caused serious regional disputes. Since 1995 in China, there have been about 11,000 water environmental emergencies that have resulted in substantial negative impacts on people's lives and productivity. As the issue of transboundary water pollution involves the management boundaries and interest relationships of different administrative divisions, it is difficult to solve the problem solely through negotiations between upstream and downstream local governments. Therefore, the central government urgently needs to introduce some polices to define the responsible subjects, regulate the behaviour of the various subjects, and establish joint governance mechanisms.

Although the environmental protection laws (in 1998 and 2000) stipulated transboundary pollution in China, the effect is not significant. The local protectionism is an important factor in addressing the problem of transboundary pollution in the river basins. However, each administrative region has its own war-style pollution control measures, which are unable to fundamentally reverse the increasingly serious trend of transboundary water pollution. Only by breaking the administrative division and adopting cross-regional joint governance can it be possible to curb this trend. To this end, the State Environmental Protection Administration in China issued the "Notice on Strengthening the Prevention and Control of River Pollution" on 29 December 2007, focusing on solving the serious river water pollution problem in China and proposing to improve the water quality monitoring of transboundary rivers. On this basis, on 7 July 2008, the Ministry of Environmental Protection of the People's Republic of China further issued a policy to solve the transboundary pollution of rivers, that is, the guiding opinions on the prevention and disposal of disputes over trans-provincial water pollution. This policy stipulates the establishment of a cross-provincial joint prevention and control mechanism in key rivers to reduce the level of transboundary water pollution in the basin and resolve regional disputes caused by transboundary water pollution. Therefore, this paper uses a difference-in-differences (DID) model to evaluate the effect of the implementation of the policy on transboundary water pollution in river basins. This is also a test of whether the policy can effectively solve the problem of local environmental pollution. As expected, the results of this paper show that the implementation of this policy has a positive impact on river water pollution, resulting in significant improvements in river water quality in transboundary areas, and the improvement effect is sustainable to a certain extent.

The possible marginal contribution of this paper is as follows. First, this paper takes the implementation of the joint governance policy as a natural experiment, and studies the policy effect of transboundary water pollution control from the water quality of two different watersheds, trans-provincial and non-trans-provincial. This enriches the empirical identification of the relevant literature in the content of water pollution control in transboundary basins. Second, this paper collects the weekly monitoring data of the water quality of the cross-section of the river by the national regulatory authorities, and the time span is long. Most studies use regional or annual data. Therefore, the long-term observation point data in this paper is conducive to using the DID method to evaluate the implementation effect of the policy. This allows for a more accurate assessment of the causality of the policy's impact on transboundary water pollution in the basin, and endogeneity issues are well addressed. Of course, this also provides data support for us to study the long-term dynamic policy effect. Third, few studies have quantitatively analysed the impact mechanism of transboundary governance of water pollution. This paper explores the mechanism from two aspects of official green promotion pressure and stakeholder supervision. This provides effective evidence for the further improvement of upstream and downstream joint governance of river transboundary water pollution.

The rest of this paper is structured as follows. Section 2 reviews the relevant literature. Section 3 expounds the policy background of trans-provincial water pollution control. Section 4 describes the data and empirical strategy used in this paper. Section 5 analyses the empirical results. Mechanistic analysis is in Section 6. Section 7 concludes this paper.

2 Literature review

The prevalence of transboundary pollution indicates the inefficiency of unilateral action. Increasingly more scholars and policy makers have realized that only cooperation between local governments and countries can fundamentally solve the problem of transboundary water pollution (Du et al., 2022). By adding emissions trading and learning-by-doing mechanism to the game model, Chang et al. (2018) used numerical simulation to prove that cooperation is an effective way to solve transboundary pollution. Most literatures only analyse transboundary pollution from the perspective of government governance, and few involve industrial enterprises. Yeung (2007) confirmed that the cooperation between upstream and downstream governments, and between governments and enterprises can achieve a radical cure for transboundary pollution by using game models. The assumption of these studies is that in order to realize cooperative pollution control in the upstream and downstream regions, it is necessary to ensure the ecological environment of the downstream regions without compromising the development opportunities of the upstream regions. However, it is difficult to achieve the symmetrical incentive of joint pollution control in upstream and downstream areas due to the great differences in economic development, pollution control costs and losses caused by pollution. The upstream and downstream regions can effectively solve the problem of transboundary water pollution only by negotiating an agreement on the cost-sharing of pollution control costs (Chander and Tulkens, 1992; Dong et al., 2012; Alcalde-Unzu et al., 2015). Fernandez (2009) took the Tijuana River, a transboundary river between the United States and Mexico as an example, and found that the two governments reached an agreement through negotiation to jointly bear the cost of pollution control such as environmental infrastructure construction. This joint pollution control not only mobilized Mexico's enthusiasm for pollution control, but also effectively reduced the harm of upstream pollution in the United States (Fernandez, 2009).

Addressing transboundary water pollution requires coordinated action by upstream and downstream regions, while the reality is that upstream and downstream regions are often uncooperative due to the indifference of the central government (Duda, 2016). The central government can improve this situation and promote cooperation between upstream and downstream regions by introducing some policies. Hence, it is important for the central government to introduce regional environmental policies to reduce transboundary pollution (Tomkins, 2005). In this regard, it is helpful to investigate the role of these policies in the field of air pollution control in the United States (Greenstone, 2004). The Clean Air Act of 1990 also encourages the building of cooperative governance relationships between and among the federal, state and local governments and actively guides the public to participate in environmental governance, thus achieving obvious improve (Greenstone, 2004; Auffhammer et al., 2009). For the governance of river pollution, Chakraborti (2016) took the clean water act in United States as an example, proved that when the water environment around the factory is improved, the factory could increase the discharge of pollutants, and conversely when the quality of the surrounding water environment is degraded, the discharge of pollutants could be reduced. Schiff (2014) believed that the Clean Water Act in the United States has played an important role in controlling point source pollution from large industrial equipment and sewage treatment plants. However, as river pollution increases on a spatial scale and ocean water quality continues to deteriorate, the policy has not played its role in addressing these two types of pollution. With respect to some policies on air and water pollution in India, Greenstone and Hanna (2014) demonstrated that these policies significantly improve air quality and reduce infant mortality, but water pollution-related policies have not worked. Wunder (2005, 2006) proposed a new direction for marketization to address environmental externalities: payment for environmental services (PES). PES is a market mechanism or public policy to reach a transaction agreement through voluntary negotiation and negotiation on the basis of clarifying the property rights of ecological products (Jing and Du, 2022).

Although the above studies provide useful references for the river transboundary water pollution control and policy evaluation, there are still some deficiencies worth exploring. First, most of the literature is theoretically deduced from the perspective of game theory, proving that upstream and downstream regional cooperation is the best strategy for controlling transboundary water pollution in river basins. However, there is little empirical identification on transboundary water pollution control, especially China's policy effects in addressing transboundary water pollution. Second, some studies have shown that the environmental assessment mechanism for the promotion of officials in China in recent years has had a positive effect on transboundary water pollution control. Water pollution control is a long-term systematic project, and there may be a lag effect. Therefore, after the implementation of the policy, the government implemented environmental assessments on officials. The fact that the level of transboundary water pollution in rivers has decreased since then. Without considering the impact of the joint pollution control policy, it is inevitable that there could be certain policy biases when examining the impact of official promotion assessment on transboundary water pollution alone. Third, the existing evaluations of water environment governance policies rarely use the DID method, and fail to effectively eliminate the impact of other factors on river transboundary water pollution, which may lead to overestimation of regression results. Accordingly, this paper takes the joint governance of transboundary water pollution in China as a quasi-natural experiment, and uses the DID model to empirically evaluate whether the policy has significantly improved the transboundary water quality of rivers.

3 Context of transboundary governance policy

When the level of economic development is low and the degree of water pollution does not exceed the self-purification capacity of the river, the river belongs to the nature of public goods. However, with the rapid development of the economy and the excess of river sewage discharge capacity, the pollution carrying capacity of rivers becomes a scarce resource and gradually evolve into a quasi-public good with competitiveness and non-exclusivity. Moreover, with the aggravation of river pollution, the transboundary water pollution would gradually cause disputes between upstream and downstream regions. Cross-border water pollution not only causes the transboundary transfer of pollutants, but it also has a serious impact on production in the downstream area and on the living conditions of those residing there. Additional issues, such as international disputes, arise if the pollutants cross the national border. Transboundary water pollution poses a new challenge for China's fragmented local governments to control water pollution not only by focusing on their "An acre of three points" but also by promoting collective participation between central and local governments through new regulations.

The rivers are being increasingly polluted in China as a result from the extensive economic development mode, unreasonable industrial layout and backward pollution control technology in the past. On 29 December 2007, the state environmental protection administration issued a notice to strengthen river pollution prevention and control clearly stipulates those further efforts should be made to strengthen river pollution prevention and control and accelerate the improvement of river water quality in China. With the aim to improve trans-provincial water quality, the notice proposes to improve the urban sewage treatment rate, strengthen the river water quality supervision, improve early warning mechanisms, increase treatment capacity, and improve the trans-provincial water quality monitoring and assessment system. Furthermore, it was proposed that by the end of 2010, the trans-provincial water quality would be improved significantly and the corresponding guiding measures were put forward. With respect to the local governments' interest disputes regarding upstream and downstream transboundary pollution, the notice puts forward the guideline but is less concerned with the concrete measures.

To manage the increasingly serious cross-border water pollution and the resulting upstream and downstream disputes and to promote the continuous improvement of river water quality across the country, the Ministry of Environmental Protection promulgated a policy on the joint governance of transboundary river pollution, including 13 specific implementation measures in 2008. This policy requires the adjacent areas of the inter provincial boundary basin, especially the upstream areas, to optimize the regional layout, adjust the industrial structure, strictly control the environmental access, strictly control the generation of new pollution sources, and prevent the occurrence of inter provincial water pollution from the source according to the environmental capacity and outbound water quality objectives. In addition, this policy also pointed out that it is necessary to establish a long-term working mechanism for the prevention and disposal of cross-provincial water pollution disputes. These mechanisms include regular joint consultations, information sharing, joint sampling and monitoring, joint law enforcement supervision, early warnings during sensitive periods, coordinated emergency responses, coordinated handling of disputes, and joint rectification supervision.

The policy provides a comprehensive guide to improves the river pollution environment by the upstream and downstream river basin provinces engaging in cooperative governance in China. The goal is to establish cooperative governance regarding pollution between upstream and downstream provinces and the long-term mechanism of resolving disputes, containing transboundary pollution, improving water quality in the cross section of the provinces, improving the river's ecosystem service functions and the welfare level of the coastal residents. If the policy is implemented, it would affect the provincial boundary section's river water quality, but it would not affect the water quality of the provincial non-boundary rivers or areas removed from the boundary transition section. Then, compared with the latter, the water quality of the former provincial boundary section is likely to have a significant improvement. Therefore, it is necessary to use the method of causal judgment to identify the impact of the implementation of this policy on the water quality of the provincial boundary section.

4 Data and empirical strategy

4.1 Data description

The data in this paper were collected from data sources such as China National Environmental Monitoring Centre, China Statistical Yearbook, and China Environmental Statistical Yearbook. The time span is the period 2004–2016. These variables mainly involve water pollution indicators in the weekly water quality monitoring reports of 62 state-controlled sections of China's river basins and other provincial-level data indicators. The name of the station

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provided in the weekly water quality monitoring report of key sections of major river basins in China shows whether the station is located at the junction of administrative divisions. Among them, 24 monitoring stations are located at the provincial boundary, and the administrative division is set as the dummy variable in this paper. If the water quality monitoring point of the national control section is located at the administrative Boundary, the value is 1, otherwise it is 0. The 62 state-controlled sections are mainly located in the Heilongjiang River basin, Liaohe River basin, Haihe River basin, Yellow River basin, Huaihe River Basin, Yangtze River basin, Pearl River basin and Southwest River basin.

The explained variables in this paper are three water pollution indicators that measure water quality (*WQ*), which are derived from the weekly reports on water quality monitoring of key sections in major river basins across the country. The three water quality indicators are dissolved oxygen (DO), chemical oxygen demand (COD) and ammonia nitrogen (NH), respectively. This paper sorts out the monitoring point indicators since 2004 (deleting the revoked Dongsongmen monitoring point in Cangzhou, Hebei), including water pollution indicators at the provincial boundary and non-provincial boundary water pollution indicators. The weekly reports of automatic water quality inspection of 62 state-controlled sections of major river basins in China show whether the monitoring points are monitoring points at provincial boundaries.

The explanatory variable of interest in this paper is treatment, that is, the interaction term between the two variables of *treat* and *post*. This paper uses the year of policy promulgation as the critical point of the period to describe the changes in water quality before and after the policy was promulgated. Specifically, the variable *post* is defined as one for every week in 2008 and later, and 0 otherwise. The variable *treat* is generated according to whether the water quality monitoring points are located at the inter-provincial boundary, and is used to measure the changes in the water quality of the rivers in the treatment group and the control group. To be specific, the rivers of the provincial boundary section are listed as the treatment group, that is, the variable *treat* is defined as 1. While the non-provincial boundary sections are classified as the control group, that is, the variable *treat* is defined as 0.

The control variables cover variables for river, season, and provincial characteristics. The season dummy variable (*Season*) is based on the flood seasons of each river. If the river is in flood season, the value of *Season* is 1, otherwise 0. The variables of river characteristics are dummy variables of the main and tributary stream (*Mainstream*), the upstream and downstream (*Upstream*) and the north-south rivers (*Northstream*). Specifically, the variable *Mainstream* is one if the monitoring point is at the mainstream, otherwise 0. If the monitoring point is located upstream, the variable *Upstream* takes the value of 1, otherwise 0. The variable *Northstream* is defined as one if the monitoring point is located in the northern rivers, otherwise 0. The provincial-level control variables include gross domestic product (*GDP*), industrial structure (*IS*), foreign direct investment (*FDI*), total population (*Pop*), highway mileage (*Road*), and waste water emissions (*Water*). The industrial structure is measured by the ratio of the added value of the tertiary industry to the gross domestic product. Among them, the variables of *GDP*, *FDI*, *Pop*, *Road*, and *Water* are all processed logarithmically in the regressions. The statistical descriptions of these non-dummy variables are presented in Table 1.

4.2 Empirical strategy

The changes of the transboundary water environment in the basin mainly result from three factors. One is the time effect caused by economic development, improvements in the enterprise's environmental protection, improvements in the agricultural non-point source pollution and improvements in the sewage treatment equipment. A second factor is the cumulative effect of pollution caused by the unidirectional characteristics of the rivers. The third factor is policy effects brought about by law enforcement that the impact of coordinated measures on water pollution by provincial governments. The purpose of this paper is to evaluate the policy effects on the changes in transboundary water pollution in watershed areas. The DID method effectively eliminates the time effect and pollution accumulation effect and identifies the influence of the policy effects. Therefore, this paper constructs the following the difference-in-differences model to evaluate the effect of the joint water pollution control policy on water quality improvement.

$$WQ_{it} = \alpha + \beta treat_i \cdot post_t + \delta treat_i + \gamma post_t + \varphi X_{itp} + \theta_t + \mu_p + \varepsilon \tag{1}$$

Where the subscripts *i*, *t*, and *p* represent the monitoring point, the year-week and the province, respectively. β, the regression coefficient of interest, reflects the net effect of the implementation of the joint governance policy on the transboundary water quality of the basins. With respect to dissolved oxygen, if β is significantly positive, the implementation of the joint governance significantly improves the water quality of the watershed transboundary water. Regarding chemical oxygen demand and ammonia nitrogen, if β is significantly negative, the implementation of the joint governance effectively reduces cross-border water pollution and improves the water quality in the basins. δ is a regression coefficient that denotes that the water qualities of the treatment and control rivers do not change over time. γ is a regression coefficient that reflects the change in water quality of the treatment group over time. X represents a series of control variables, and is logarithmically converted. ε is a random error term.

TABLE 1 Descriptive statistics for non-dummy variables.

Variables	Mean	S.D.	Median	Obs	Data source
DO	7.7780	2.6370	7.7300	39959	China National Environmental Monitoring Centre
COD	4.3680	8.4760	3.0000	39959	
NH	0.7670	2.2070	0.2700	39959	
GDP	19000	15000	15000	299	China Statistical Yearbook, and China Environmental Statistical Yearbook
IS	39.8100	8.0350	38.4000	299	
FDI	1000	1500	428.6000	299	
Pop	5600	2500	5600	299	
Road	140000	70000	140000	299	
Water	260000	160000	240000	299	

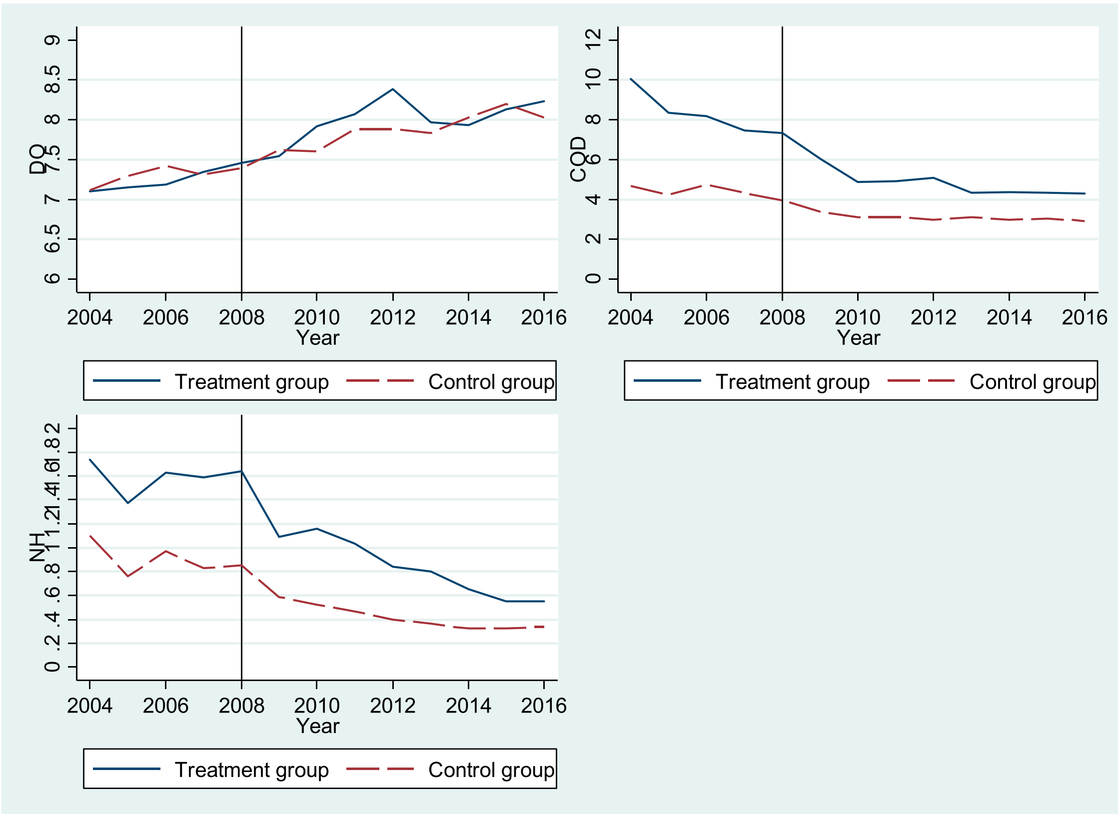

FIGURE 1
Parallel trends for DO, COD, and NH.

5 Empirical results

5.1 Parallel trend test

The premise of using the DID strategy is that there is no significant difference in the water pollution indicators between the treatment group and the control group before the implementation of the joint governance policy, which means that the two have a parallel trend. As displayed in Figure 1, the three water pollution indicators exhibit the same change trend before the implementation of the policy, while after the implementation of the policy, the changes in the

TABLE 2 Regression results of the policy on the impact of transboundary water pollution in China's river basins.

Variables	(1)	(2)	(3)	(4)
Panel A: DO				
treat·post	0.1336***	0.0792	0.1064**	0.0952*
	(0.0508)	(0.0508)	(0.0509)	(0.0509)
Constant	7.3310***	11.7591***	9.1819***	56.2139***
	(0.2148)	(2.0274)	(0.3024)	(3.5089)
Within R^2	0.0157	0.0328	0.2048	0.2154
Observations	39959	39959	39959	39959
Panel B: COD				
treat·post	−1.2709***	−1.1282***	−0.9045***	−0.7068***
	(0.1321)	(0.1323)	(0.1645)	(0.1604)
Constant	4.3383***	33.7301***	0.9780	−10.3329
	(0.7332)	(5.5945)	(0.9766)	(11.0419)
Within R^2	0.0182	0.0333	0.0361	0.0554
Observations	39925	39925	39925	39925
Panel C: NH				
treat·post	−0.2384***	−0.1558***	−0.1399***	−0.0937**
	(0.0339)	(0.0338)	(0.0421)	(0.0412)
Constant	0.8461***	2.6689*	0.5587**	−21.1439***
	(0.1926)	(1.4654)	(0.2498)	(2.8385)
Within R^2	0.0231	0.0424	0.0881	0.1023
Observations	39975	39975	39975	39975
Control variables	No	Yes	No	Yes
Year-week fixed effect	No	No	Yes	Yes
Province fixed effect	No	No	Yes	Yes

Notes: *, **, and *** denote statistical significance at 10%, 5%, and 1% levels respectively. Standard errors in parentheses.

treatment group were more obvious than that of the control group. The DO in the treatment group rises faster than that in the control group, while the COD and NH indicators in the treatment group decline faster than that in the control group. This indicates that the water quality of the treatment group affected by the policy improves faster than the water quality of the control group. Hence, the implementation of this policy has a positive impact on the improvement of cross-border water quality, and the three water quality monitoring indicators in this paper meet the parallel trend assumption of the DID strategy.

5.2 Benchmark regression results

The benchmark regression results of DID estimation are presented in Table 2. The regression results for column (1) exclude control variables and fixed effects. The results in column (2) add control variables to the regression in column (1). The results in column (3) add the year-week and province fixed effects to the regression in column (1). The regression results in column (4) include both control variables and fixed effects. As can be seen from column (1) of Table 2, all treatment effects are significant at the 1% level. The signs of these coefficients remain the same when the control variables and fixed effects are added to columns (2) and (3), respectively. From column (4), it can be found that the coefficient of *treat·post* in Panel A for DO is statistically significant at 0.0952. This indicates that the joint governance policy helps to improve the dissolved oxygen content in the watersheds along the provincial boundary. In terms of COD in Panel B, the coefficient for *treat·post* is statistically significant at −0.7068. This suggests that this policy is beneficial to reduce the chemical oxygen demand in the trans-provincial watershed. With respect to NH in Panel C, the coefficient for *treat·post* is statistically significant at −0.0937. This implies that this policy helps reduce ammonia nitrogen levels in watersheds across provincial boundaries. In summary, compared with non-transprovincial watersheds, the joint management of water pollution in interprovincial watersheds can indeed improve water quality. These findings are consistent with the results of Fernandez (2009) on transboundary river governance.

TABLE 3 Dynamic trend test results.

Variables	(1)	(2)	(3)
	DO	COD	NH
treat·trend09	−0.0786	−0.2535	−0.1965***
	(0.0919)	(0.2909)	(0.0743)
treat·trend10	0.2608***	−1.0730***	−0.0248
	(0.0911)	(0.2884)	(0.0735)
treat·trend11	0.1363	−1.0372***	−0.1203
	(0.0909)	(0.2881)	(0.0733)
treat·trend12	0.3126***	−0.7117**	−0.2160***
	(0.0913)	(0.2891)	(0.0737)
treat·trend13	0.0307	−1.5535***	−0.2189***
	(0.0907)	(0.2873)	(0.0731)
treat·trend14	−0.0620	−1.2373***	−0.3154***
	(0.0912)	(0.2888)	(0.0736)
treat·trend15	−0.0538	−1.0019***	−0.3770***
	(0.0922)	(0.2921)	(0.0745)
treat·trend16	0.1845*	−1.5011***	−0.5146***
	(0.0950)	(0.3010)	(0.0765)
Constant	56.3927***	−15.3872	−23.7917***
	(3.5069)	(11.1079)	(2.8177)
Control variables	Yes	Yes	Yes
Year-week fixed effect	Yes	Yes	Yes
Province fixed effect	Yes	Yes	Yes
Within R^2	0.2160	0.0575	0.1033
Observations	39959	39925	39975

Notes: *, ** and *** denote statistical significance at 10%, 5%, and 1% levels respectively. Standard errors in parentheses.

5.3 Dynamic trend results

The above results indicate that the implementation of the joint governance policy has significantly reduced the cross-provincial water pollution. However, the DID estimation results can only measure the effect of the policy on cross-border water pollution compared with that before the promulgation. This average effect does not reflect the dynamic effect of the implementation of the policy on transboundary water pollution or whether there is a lag effect. Therefore, we rewrite the benchmark regression Eq. 1 as an equation that measures the dynamic effect of the policy on transboundary water pollution:

$$WQ_{it} = \alpha + \beta\sum_{tt=09}^{16} treat_i \cdot trend_{tt} + \delta treat_i + \gamma trend_{tt} + \varphi X_{itp} + \theta_t + \mu_p + \varepsilon \quad (2)$$

where $treat_i \cdot trend_{tt}$ represents the time effect of the implementation of the policy. $trend_{tt}$ represents the dummy variable of the year after the policy is implemented, including *trend09*, *trend10*, . . . , *trend16*. These values are one in a certain year after the promulgation, and 0 in other years.

Table 3 reports dynamic trend results of the implementation effect of this joint governance policy. With regard to DO in column (1), the coefficient of *treat·trend09* in 2009 is negative but not significant. From 2010 to 2013, the regression coefficients are positive and are significant in 2010 and 2012. However, the sign of the regression coefficients gradually changes from positive to negative and there is no significant difference between the period 2014–2015. The regression coefficient is significantly positive in 2016. These results indicate that the implementation of this policy has a certain volatility on the improvement of DO. As for COD in column (2), the regression coefficient is not significantly negative in 2009, but it is significantly negative at 1% level after 2010, which means that the implementation of the policy has a significant continuous effect on the reduction of COD. With respect to NH in column (3), the regression coefficient is negative at the significance level of 1% in 2009, but they are not significant in 2010 and 2011. However, the regression coefficients are negative at the significance level of 1% after 2012. This shows that the improvement of NH in the policy may have a lag of about 3 years. To sum up, the joint governance policy for transboundary water pollution has long-term dynamic effects in improving water quality.

5.4 Robustness tests

To further verify the benchmark regression results, some robustness tests are conducted in this section, including eliminating political cycles, replacing the sample and placebo test.

5.4.1 Eliminating political cycles

Party committees or governments generally change every 5 years in China. In this case, local governments may temporarily shut down water polluters due to political pressure to avoid major environmental pollution incidents. Therefore, political changes may also affect the results of the econometric estimates. The 18th National Congress of the Communist Party of China (CPC) was held in Beijing in November 2012. Thus, this paper conducts a regression analysis again after excluding major national political events in 2012. Column (1) of Table 4 presents the results of eliminating political cycles. These results show that the joint governance of water pollution can promote dissolved oxygen, and effectively reduce chemical oxygen demand and ammonia nitrogen, which are consistent with the benchmark results.

5.4.2 Replacing the sample

Some state-controlled sections are set at sea estuaries and borders, and their water quality is affected by more complex factors. Therefore, this paper deletes the statistical data of monitoring points located at sea estuaries and national

TABLE 4 Robustness test results.

Variables	(1) Eliminating political cycles	(2) Replacing the sample	(3) Placebo test (2006)	(4) Placebo test (2007)
Panel A: DO				
treat·post	0.1425***	0.1596***	0.1078	0.1688
	(0.0523)	(0.0510)	(0.0908)	(0.1137)
Panel B: COD				
treat·post	−1.1327***	−1.1142***	−0.1054	−0.0888
	(0.1750)	(0.1672)	(0.2273)	(0.2822)
Panel C: NH				
treat·post	−0.1105**	−0.1176***	0.0662	−0.0067
	(0.0440)	(0.0425)	(0.0767)	(0.0698)
Control variables	Yes	Yes	Yes	Yes
Year-week fixed effect	Yes	Yes	Yes	Yes
Province fixed effect	Yes	Yes	Yes	Yes

Notes: *, ** and *** denote statistical significance at 10%, 5%, and 1% levels respectively. Standard errors in parentheses.

borders for further testing. As shown in column (2) of Table 4, the results indicate that the impact of this policy on NH is more significant and the benchmark results are generally validated to be robust.

5.4.3 Placebo test

Because there may be missing variables and unobservable data that have a systematic impact on the empirical results, this paper uses a placebo test for the robustness test. Specifically, the implementation time of the policy is advanced to 2006 and 2007, respectively, as the time when the pseudo-policy is implemented. If the pseudo-policy has no significant effect on the improvement of transboundary water quality, then the policy plays a key role in the improvement of cross-border water quality and the empirical results are not affected by systematic errors or missing variables. The results of the placebo test in columns (3)–(4) of Table 4 reveal that the implementation of the pseudo-policy has no significant effect on transboundary water quality.

6 Mechanism identification

The above results suggest that after the implementation of the cross-border joint pollution control by upstream and downstream local governments, the level of water pollution in rivers across provincial boundaries decreases significantly. However, how the implementation of the policy improves the water quality of transboundary rivers requires further discussion. This policy stipulates that the distribution of water quality monitoring sites in cross-provincial cross-sections should be improved and the target accountability system should be implemented for cross-provincial cross-sections. The implementation of the policy is one way to perfect the supervision mechanism and realize water pollution environmental governance. The supervision mechanism is not only needed in the official assessment of the water quality target, but that it is also needed to ensure the diversity of supervision and the compactness of the interest relationship. Accordingly, this paper examines the corresponding mechanism from two aspects of the official green promotion pressure and the stakeholder supervision. Referring to Ruan et al. (2014) and Li et al. (2015), the mechanism identification is presented in Eqs 3, 4.

$$pressure_{it} = \alpha + \beta treat_i \cdot post_t + \delta treat_i + \gamma post_t + \varphi X_{itp} + \theta_t + \mu_p + \varepsilon \tag{3}$$

$$stakehol_{it} = \alpha + \beta treat_i \cdot post_t + \delta treat_i + \gamma post_t + \varphi X_{itp} + \theta_t + \mu_p + \varepsilon \tag{4}$$

Where *pressure* denotes a green promotion pressure on officials, and *stakehol* stands for the stakeholder supervision. This paper constructs the green promotion pressure by sulphur dioxide emissions, dust emissions, total waste water emissions, solid waste emissions and environmental emergencies. The annual sub-indexes of each province are compared with the annual averages of the corresponding indexes at the provincial level. If the sub-indexes of each province are greater than the mean value, the value is 1, otherwise 0. Five indexes are then added together to obtain the promotion pressure of the environmental protection assessment. The higher the value, the greater the green promotion pressure on local officials. The stakeholder supervision indicator is obtained through principal component analyses of the number of suggestions from National People's

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TABLE 5 Mechanism identification results.

Variables	(1) Green promotion pressure	(2) Stakeholder supervision
treat·post	0.3652***	0.0819***
	(0.0153)	(0.0126)
post	5.5471***	−3.3571***
	(0.1689)	(0.1399)
treat	−0.2483***	−0.0554***
	(0.0212)	(0.0175)
Constant	−0.3956	27.8154***
	(1.1190)	(0.9269)
Control variables	Yes	Yes
Year-week fixed effect	Yes	Yes
Province fixed effect	Yes	Yes
Within R^2	0.2459	0.6946
Observations	37386	37386

Notes: *, ** and *** denote statistical significance at 10%, 5%, and 1% levels respectively. Standard errors in parentheses.

Congress (NPC), proposals proffered by the Chinese People's Political Consultative Conference (CPPCC), letters, visiting batches and the total number of public complaints and proposals in the field of environmental protection as counted by provinces between 2004 and 2016. Table 5 reports the regression results for mechanism identification.

6.1 Green promotion pressure

Political tournaments centered on GDP have caused officials to only pay attention to economic growth while ignoring environmental protection in the process of pursuing promotion, resulting in serious environmental pollution (Qian and Roland, 1998; Jin et al., 2016). Therefore, scholars propose to improve the performance evaluation system of officials, increase the weight of indicators such as environmental protection, and gradually realize the transition from the GDP tournament to the environmental protection tournament. The central government first introduced a "one vote vote" system for evaluating officials in 2005. In 2009, targets for environmental protection and ecological improvement were added to the evaluation system for officials. In 2012, it was made clear that officials should not be judged solely on GDP. Since then, the environmental protection assessment system for officials has been gradually improved. The 11th Five-Year plan included chemical oxygen demand, which involves water pollution indicators, in the assessment set for officials, and the 12th Five-Year Plan included ammonia nitrogen in the assessment set. The GDP championship is gradually transitioning to the environmental protection championship. By increasing the assessment weight of environmental protection, the baton role of the environmental protection championship can be played to influence the behavioural preferences of officials. Only by increasing the investment in environmental protection can we get more promotion opportunities.

Based on the promotion pressure (Qian et al., 2011), this paper constructs the promotion pressure of environmental protection assessment, including five indicators of sulfur dioxide emission, dust emission, total wastewater discharge, solid waste discharge and emergency environmental events. The annual sub-indicators of each province are compared with the average of corresponding indicators at the provincial level. If the corresponding indicators are greater than the mean, the value is 1, otherwise, it is 0. Then, the promotion pressure of environmental protection assessment is obtained by adding up the five indicators. The higher the number, the greater the pressure on local officials to assess environmental protection. From column (1) of Table 5, it can be seen that the coefficient of official green promotion pressure is 0.3652 at the significance level of 1%, indicating that this policy promotes the increase of the green promotion pressure of officials and then improves the transboundary water quality of the river basins. This is mainly due to the fact that through the pressure of the downstream local government on the upstream local government, the upstream government is encouraged to actively implement source treatment and adjust the industrial structure to improve the water environment quality and reduce the pollution of the cross-section water. Therefore, the implementation of the joint governance further encourages local officials to actively participate in environmental governance through official assessment indicators and gradually develops the environmental protection championship pattern of official promotion, finally improves the river water environment.

6.2 Stakeholder supervision

The failure of the government in environmental governance is usually due to the form of environmental decentralization adopted by the government, which will lead to serious information asymmetry between the central government and local governments, and then lead to the "principal-agent" problem in environmental governance. The objective function of the central government includes ecological environmental protection. However, the behaviour preference of local governments, especially the "top leaders" of local governments, may prefer "personal promotion caused by economic growth," and the supervision cost of the central government to local governments is relatively high, leading to the failure of the government in environmental governance. On the other hand, fiscal decentralization leads to the tendency of local governments to obtain their own fiscal revenue, which is more likely to lead to the collusion between government and enterprises under local protectionism, and environmental governance becomes more "an armchair strategy". The resulting environmental pollution is ultimately paid by residents. Therefore, improving public appeal channels can effectively reduce the degree of information asymmetry between the central government and local governments and play a good supervisory role (Nie et al., 2013). First, the central government holds the key to the promotion of local officials, so this form of political centralization provides more powerful support for public demands. The public demand for environmental protection is more manifested in major environmental pollution incidents, and the central government's assessment of local governments has implemented the "one vote veto" system in the field of environmental protection (Lin and Shen, 2021), which puts a "restraint" on the environmental protection behaviour of local officials through the public demand. Secondly, the public's demand for good water quality and environment can improve the local government's efforts to control water pollution and strengthen the enforcement of relevant laws (Zheng et al., 2014). Finally, public demand data is a mirror reflecting local officials' efforts in environmental governance. If public environmental demand is high, it indirectly indicates that officials do not implement policies to improve the environmental level in the process of local environmental governance, thus lowering the assessment scores of officials. On the premise that the mechanisms of "voting with hands" (Harsman and Quigley, 2010) and "voting with feet" (Tiebout, 1956) are not perfect, the establishment and improvement of public appeal channels can bring citizens into the environmental governance process of governments and enterprises, and truly realize the "triangle" of environmental governance. And it can change the top-down "unidirectional" of China's environmental governance, realize the "responsibility from below" of China's environmental governance, and improve the ecological environment.

According to Yu (2014), this paper calculates the number of people's congresses' suggestions, CPPCC proposals, total number of letters, batches of visitors and total number of visitors in the field of environmental protection from 2004 to 2016 in provinces (autonomous regions and municipalities directly under the Central Government) through principal component analysis, and obtains the public environmental demand index. As shown in column (2) of Table 5, the regression coefficient of *treat·post* is 0.0819 at a significance level of 1%, indicating that stakeholder supervision effectively reduces the degree of river transboundary water pollution and improves water quality. On the one hand, the petition work of the NPC, the CPPCC and related personnel can promote local governments to strengthen the implementation of cross-border joint law enforcement and information sharing. The proposals of the NPC and the CPPCC represent the requirements of a good water environment. This kind of supervision can standardize and institutionalize a good way of cross-border joint pollution control, thereby strengthening the effect of cross-border joint pollution control. On the other hand, the public's demands for environmental protection are more manifested in major environmental pollution incidents. Through the supervision mechanism of petition, the environmental protection behaviour of local officials is put on a "curse." If the number of petitions is frequent, it indirectly indicates that officials do not effectively implement the policy of improving the environmental level in the process of local environmental governance, thus lowering the evaluation scores of officials. Therefore, under the premise that the mechanisms of "voting with your hands" and "voting with your feet" are not sound, incorporating stakeholder supervision into the environmental governance process of the government and enterprises could truly realize the "triangle" of environmental governance, which is conducive to improving river water quality.

7 Conclusion

Only the cooperation between upstream and downstream can better solve the problem of river transboundary water pollution. The key to the effect of joint water pollution control is whether it can promote cooperation between upstream and downstream. To this end in this paper, the weekly monitoring data of 62 state-controlled sections between the period 2004–2016 are used to assess the policy effect of the joint governance on transboundary water pollution by using a difference-in-differences strategy in China. Further, this paper examines the dynamic effect of the implementation of the joint governance on the improvement of transboundary water pollution in watersheds and proves the robustness of the results by deleting the political cycle, replacing the control group and placebo test. The Ministry of Environmental Protection hopes to improve the target of transboundary water pollution in the basins through joint prevention and control of upstream and downstream areas in China. Only when both upstream and downstream regions adopt a cooperative attitude can they avoid the free-rider problem of public goods to the greatest extent. Therefore, this paper also provides evidence from China for the theory of cooperative governance of environmental pollution.

Based on empirical results, in general, it has a significant impact on the reduction of transboundary water pollution in the basins since the promulgation of the joint governance policy. Also, as long as the upstream and downstream areas continue to deepen the cooperation between the two sides, the level of transboundary water pollution in the basins can be significantly reduced. What's more, official green promotion pressure and stakeholder supervision play an important role in promoting this policy in transboundary governance of water pollution. To solve the problem of motivation, we should build a market-oriented environmental governance mechanism. First, at present, the joint governance of transboundary pollution is mainly used for water quality improvement, and does not involve the treatment of forests, grasslands and wetlands. This will not systematically achieve stable improvement of water quality. Forests and grasslands can better fulfil ecological functions such as soil and water conservation, flood prevention, climate regulation and biodiversity maintenance. The management of "mountains, rivers, forests, fields, lakes and grasses" and the unified management of cities, villages, industries and agriculture can improve and maintain river water quality more effectively.

Second, choosing the water quality breakpoint of the provincial boundary section for monitoring can promote better joint monitoring of the upstream and downstream provinces, so as to achieve fair and transparent water quality monitoring. In addition, a third-party independent institution can be introduced to follow up the implementation of water quality, improve the water quality evaluation index system and upgrade the evaluation technology. Since the joint prevention and control measures promulgated by the Ministry of Environmental Protection have played a certain role in reducing river transboundary water pollution, but a long-term mechanism for joint prevention and control of transboundary water pollution has not yet been formed. The regular joint prevention and control system can not only effectively prevent transboundary water pollution, but also reduce disputes caused by water pollution in upstream and downstream areas.

Third, when assessing the environmental protection performance of officials, it is not only necessary to establish a "one vote veto" system, but also to establish a set of scientific green evaluation index system. As China is still a large developing country with uneven regional development and arduous task of poverty alleviation, it also needs a certain economic growth rate to improve people's living standards, so economic development and environmental protection should not be neglected. Different assessment indicators are set according to different regions and different development stages, so as to not only adapt measures to local conditions, but also achieve the goal of environmental protection. For example, China has implemented the ecological function zoning system, which can increase the proportion of environmental assessment in the promotion assessment index of officials in key ecological function zones and restricted development zones, and reduce or cancel the proportion of GDP assessment, so as to provide important indicator guidance for officials to implement ecological and environmental protection.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Author contributions

SJ: Software, validation, data curation, writing—original draft. LL: Formal analysis, conceptualization, supervision, visualization. MD: Methodology, writing—review and editing, project administration, funding acquisition. ES: Conceptualization, writing—review and editing, funding acquisition.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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