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Original Research

Network Infrastructure Construction and River Pollution: Evidence from the Broadband China Strategy

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Abstract

To promote high-quality economic development, China continues to strengthen its network infrastructure, but it is unclear how this affects the regional ecosystem. To clarify the impact direction, based on the weekly data of river pollution in China from 2004 to 2018, this paper regards the Broadband China (BC) strategy as a quasi-natural experiment and uses a difference-in-difference (DID) model for empirical analysis. The study found that network infrastructure construction significantly exacerbates river pollution. After a series of robustness tests, such as the placebo test and propensity score matching DID (PSM-DID), this research conclusion still holds. The impact of network infrastructure construction on river pollution is more visible in economically developed regions as well as cities with a higher level of digital economy development. The mechanism analysis confirms that during the sample period, network infrastructure construction led to secondary industry agglomeration but did not have a significant impact on innovation ability or environmental regulation, thus leading to the continuous intensification of river pollution. This paper not only provides empirical evidence for the study of the environmental effects of network infrastructure construction but also provides suggestions on how to better weigh the relationship between economic development and the environment in the digital economy.

Keywords: network infrastructure construction, river pollution, difference-in-difference model, the Broadband China strategy

Introduction

Under the digital wave of globalization, the integration of network infrastructure with economic, environmental, and other fields has become an irresistible trend of the times [1]. From Germany's "Industry 4.0 Plan" to the United States' "Industrial Internet" to China's "National Informatization Development Strategy Outline", network infrastructure construction has become a general trend of world development and an important force to promote economic and social change [2]. As a series of environmental issues including air pollution, water pollution, and global warming occur frequently, the role of network

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infrastructure construction in energy conservation, emission reduction, and other aspects has attracted more and more attention from governments and academic circles. On the one hand, network infrastructure construction can improve resource utilization efficiency by accelerating the sharing and flow of information and reduce environmental pollution by strengthening environmental supervision. On the other hand, some scholars argue that network infrastructure construction can promote secondary industry agglomeration, increase resource and energy consumption, and thus intensify pollution emissions [6]. Based on the controversy at the theoretical level, the empirical examination of the influence of network infrastructure construction on environmental pollution has both a practical necessity and theoretical importance.

At the level of the literature, scholars have studied the influence of network infrastructure construction on environmental pollution from different perspectives. Most scholars believe that network infrastructure construction helps reduce environmental pollution [7, 8] and significantly improves environmental quality [9]. Network infrastructure construction has played a positive role in reducing environmental pollution caused by transportation [10], carbon emissions [11, 12] and air pollution [13, 14]. Whereas, some scholars believe that there is an inverted U-shaped relationship between network infrastructure construction and environmental pollution. Higon et al. believe that the internet can achieve energy saving and emission reduction in industrial process optimization, but the electronic products produced while playing the role of information have a negative impact on the environment [15]. Yang et al. take haze as the research object and point out that when internet development is low, network infrastructure construction will exacerbate the haze concentration [16]. As the degree of internet development increases, the suppression of haze pollution by network infrastructure construction will become stronger and stronger.

The existing literature has extensively explored how network infrastructure construction affects environmental pollution, but no literature has yet provided robust answers. One of the challenges is the endogeneity problem, which is commonly faced in the existing literature. Specifically, most existing studies have used fixed effects models to empirically test the influence of network infrastructure construction on environmental pollution. However, ordinary panel measures are unable to overcome the endogeneity problem. To address this issue, this paper selects the BC strategy as an exogenous policy shock and uses the DID method to assess the influence effect. This method can effectively remove the sample differences before and after the policy implementation to avoid model endogeneity. It is worth pointing out that the BC strategy is implemented by the Chinese government, and several pilot cities have been established in batches. Along with the implementation of the policy in the pilot cities, the broadband access capacity and broadband user penetration rate should reach the national leading level, which will drive the network infrastructure construction in the pilot cities comprehensively and may have an influence on environmental pollution.

Another major challenge comes from the selection of environmental pollution data itself. Scholars have often used air pollution data when assessing how network infrastructure construction affects environmental pollution. However, there are two problems with air pollution data: first, air is too mobile, making it difficult to draw robust conclusions from studies of the influence of network infrastructure construction on environmental pollution. Second, air pollution data have authenticity problems, which can lead to biased estimation results. Air pollution control in China is tied to government performance, and in the early years, local officials had strong incentives to tinker with the data due to the lack of independent monitoring mechanisms [17]. Considering the above, this paper selects river pollution data to further analyze the influence effect. Compared with air, rivers have stronger geographical properties and are relatively less mobile, which makes it easier to monitor river pollution indicators. In addition, river pollution data are managed by the China National Environmental Monitoring Centre[1], which is less likely to be interfered by local governments. The data are real-time monitoring data, and the huge amount of data also leads to huge costs of manual intervention, so the independence and authenticity of water quality data can be guaranteed.

Overcoming the two major research challenges mentioned above, this paper robustly finds that network infrastructure construction exacerbates river pollution to some extent. Specifically, for every 1% increase in network infrastructure construction, local river pollution levels increase by 8.27%. In particular, the effect of network infrastructure construction on river pollution is more pronounced in economically developed regions and cities with higher levels of digital economy development. Further mechanism analysis shows that network infrastructure construction leads to the agglomeration of secondary industry, but has no significant impact on innovation ability and environmental regulation, thus leading to the continuous intensification of regional river pollution. The above results not only provide further empirical evidence for assessing the environmental governance effects of network infrastructure but also provide useful insights for promoting high-quality economic development in China.

In summary, the possible marginal contributions of this paper are: (1) This paper identifies how network infrastructure construction affects environmental pollution by using the exogenous policy shock of the BC strategy through the DID method. It not

[1] China National Environmental Monitoring Centre, see http://www.cnemc.cn/sssj/szzdjczb/ for details.

Table 1. List of BC pilot cities.

Year	City
2014	Beijing, Tianjin, Shanghai, Shijiazhuang, Yanbian Korean Autonomous Prefecture, Haerbin, Daqing, Nanjing, Suzhou, Anqing, Fuzhou, Nanchang, Shangrao, Linyi, Wuhan, Guangzhou, Zhongshan, Panzhihua, Guiyang, and Wuzhong
2015	Panjin, Baishan, Yangzhou, Jiaxing, Hefei, Yichang, Shiyan, Yueyang, Chongqing, Yibin, Yuxi, Lanzhou and Zhongwei
2016	Wuhai, Baotou, Wuxi, Hangzhou, Suzhou, Zaozhuang, Shangqiu, Nanyang, Ezhou, Yiyang, Haikou, Luzhou, Zunyi, Linzhi, Weinan and Tianshui

Note: The pilot areas only include those with national river monitoring stations.

Table 2. BC Pilot City Standards.

Index number	Index content
1	The broadband access capacity of 20 Mbps and above in urban households reaches 85%
2	More than 4Mbps broadband access capacity of rural households
3	Fixed broadband home penetration rate reaches 55%
4	3G/LTE mobile phone penetration rate reaches 40%
5	The penetration rate of 4Mbps and above broadband users reaches 80%
6	The penetration rate of 8mbps and above broadband users reaches 35%

Note: Mbps is the abbreviation for million bits per second; LTE is the abbreviation of the long-term evolution.

only alleviates the endogeneity problem of ordinary panel econometric models to a certain extent but also enriches the research literature on the influence of government policies on environmental pollution. This paper further focuses on the estimation bias problem caused by the non-randomness of pilot cities and uses the instrumental variables approach to further alleviate the endogeneity problem. (2) This paper collects and organizes river pollution data to study the influence of network infrastructure construction on environmental pollution from the river perspective. The benefit of using this data set is that it avoids the data inaccuracies that can occur when using air data and broadens the study of network infrastructure construction on various types of environmental pollutants. (3) Based on the comprehensive application of agglomeration theory and innovation theory, industrial agglomeration, innovation capability and environmental regulation are incorporated into the same framework, which deeply reveals the influence mechanism and expands the theoretical analysis framework in the fields of network infrastructure, industrial agglomeration, environmental regulation and innovation.

Policy Background and Mechanism Discussion

Policy Background on the Implementation of the BC Strategy

As the "highway" in the information age, network infrastructure provides the underlying support necessary for a digital economy. It is a prominent indicator of comprehensive national strength [18]. Since China connected to internet broadband in 1994, China's network infrastructure construction has continued to develop and made great progress. However, compared with the world's leading broadband networks, China still exhibits many deficiencies. To promote the construction of broadband network infrastructure, the Chinese government issued the Broadband China Strategy and Implementation Plan[2] in 2013. Subsequently, from 2014 to 2016, the Chinese government approved 39 cities annually in a pilot program for BC that totaled 117 cities. From this total, only 49 cities match the data from the China National Environmental Monitoring Centre. A detailed list is shown in Table 1.

According to the construction requirements for these pilot cities, the network development level of BC was set to specific standards (see Table 2). This standard ensured the BC pilot cities' network infrastructure construction level would be significantly higher than that of other cities. This scenario provided an excellent quasi-natural experimental basis for studying how network infrastructure construction affects river pollution.

Mechanism Discussion

This paper summarizes the influence mechanisms of network infrastructure construction on river pollution

[2] Document comes from "The Central People's Government of the People's Republic of China", see http: //www.gov.cn/zwgk/2013-08/17/content_2468348.htm for details.

in three aspects: industrial agglomeration, innovation capability, and environmental regulation.

The Mechanism Analysis of Industrial Agglomeration

Network infrastructure construction can affect river pollution by improving industrial agglomeration. Specifically, three specific features demonstrate how network infrastructure construction affects industrial agglomeration. First is the economy-of-scope effect. Network infrastructure construction breaks time and space constraints between enterprises in an informative way [19]. It enables enterprises to improve resource utilization through synergies, promotes the generation of economies of scope, and expands the market scale. An increase in market size makes upstream and downstream enterprises in the industrial chain agglomerate. This agglomeration is aided by the cumulative cycle of increasing returns to scale [20]. Second is the transaction-cost effect. Hanson proved that transaction cost savings are critical in promoting industrial agglomeration [21]. The construction of network infrastructure relies on digital technology, which can alleviate the fragmentation effect caused by the "digital divide." The subsequent reduction in an enterprise's overall logistical, coordination, and search costs induces industrial agglomeration. The third is the knowledge spillover effect. The internet makes the exchange of information faster and more convenient, with closer interaction. Network infrastructure construction promotes these features between enterprises, allowing them to be conducive to absorbing new knowledge while stimulating innovation, resulting in spillover effects [22]. Knowledge spillovers are particularly favorable to industrial agglomeration. Maximizing access to technology spillovers is an essential motivation for industrial geographic agglomeration [23].

Moreover, improving industrial agglomeration levels also impacts river pollution. The environmental externality of industrial agglomeration has been controversial for a long time. Some scholars have found through empirical analysis that industrial agglomeration has positive environmental externalities [24, 25]. Industrial agglomeration can promote green development by improving technological innovation, strengthening government intervention, and optimizing industrial structure [26]. Conversely, most scholars have shown that industrial agglomeration will bring negative environmental externalities [27, 28]. Whether industrial agglomeration will cause river pollution seems closely related to the degree of actual agglomeration. When the industrial agglomeration level in a country is low, there is an upswing in river pollution. However, river pollution begins to decline as agglomeration increases and reaches a sufficient level [29]. Judging from the reality in China, enterprise agglomeration can also exacerbate river pollution [30]. Most of China's industrial agglomeration is guided by government policies, with industrial parks as the carrier, attracting a large number of enterprises and people in a short period of time. On the one hand, the scale of enterprises and population continues to expand, resulting in increased energy and resource consumption. On the other hand, the entry of enterprises emphasizes economic benefits and technical barriers rather than environmental friendliness. Therefore, industrial agglomeration may lead to more serious environmental pollution.

The Mechanism Analysis of Innovation Capability

Network infrastructure construction can affect river pollution by enhancing innovation capabilities. Network infrastructure construction promotes innovation through knowledge creation effects [31]. As an essential way of disseminating information, it plays a crucial role in forming technological innovation systems [32] and can spur the creation of new technologies. Network infrastructure construction can also facilitate innovation through technological innovation effects. To meet the application department's diversified, high-level, and dynamic innovation needs, R&D departments rely on internet tools or network platforms to continuously carry out technological innovations, thereby improving innovation capabilities [33]. In addition, network infrastructure construction can promote innovation by accelerating the flow of innovation elements. It has the advantages of reducing the cost of information exchange and breaking the spatial barriers, which can accelerate the flow of innovation elements across regions or drive the redistribution of resources in their original environment [34].

At the same time, the academic community believes innovation capability can restrain river pollution. According to existing research, the inhibitory effect of innovation on river pollution is mainly sorted into the following five aspects: The first is product innovation. Traditional product design primarily focuses on a product's practicality without considering its potential harm to the environment, including severe river pollution. Product innovation can reduce the pollution caused by product design [35]. The second is technological innovation. Innovations in green technology can effectively suppress transboundary river pollution [36]. The third is market innovation. Water quality trading is conducive to controlling pollution costs and reducing river pollution [37]. The fourth is resource allocation innovation. The method of coupling the quantity and quality of the water resource allocation model has been applied to Chinese river basins under different scenarios. The results show that innovations in resource allocation can reduce future water scarcity problems and improve river environments [38]. Fifth is organizational innovation. Implementing the river chief system can strengthen the cooperation between government departments and establish a relatively complex and productive management structure that aids in reducing river pollution [39].

The Mechanism Analysis of Environmental Regulation

In terms of environmental regulation effect, network infrastructure construction helps the government implement environmental regulation, which in turn affects river pollution. On the one hand, network infrastructure construction can realize dynamic environmental monitoring. In the traditional environmental regulation process, the government is unable to monitor the enterprises at all times because their discharge behavior is relatively hidden, which makes it more difficult for the government to monitor. By virtue of the characteristics of the internet, such as real-time, interactive, and open [40], combined with modern information technologies, the government can monitor the behavior of enterprises in real time and accurately predict the development trend of ecological environment. On the other hand, network infrastructure construction is conducive to deepening public participation in environmental protection. Network infrastructure construction creates a networked and intelligent governance environment and provides a platform for the public to participate in the supervision of all people. It helps the social public to disclose the behavior of enterprises polluting the environment in a timely manner, which plays a restraining role on polluting behavior to a certain extent [41].

Environmental regulation can effectively reduce the waste discharge of enterprises and reduce river pollution. China's environmental regulation instruments are mainly of the command and control and market incentive types. Command-and-control environmental regulation refers to the government's legal and administrative means to forcefully regulate the behavior of sewage enterprises, which can effectively control the discharge of pollutants and thus reduce river pollution. Market-incentivized environmental regulation policy refers to the combined use of various economic instruments to adjust the costs and profits of the emitting enterprises so that they take the initiative to reduce the emission of pollutants. The government has effectively reduced river pollution by limiting the amount of emissions that companies can emit during the manufacturing process and implementing an emissions trading system to enforce environmental regulations [42]. Overall, environmental regulation increases the marginal cost of waste discharge for enterprises, and while forcing polluting enterprises to move or shut down, it will also force them to adopt more advanced technologies to achieve industrial transformation and energy conservation, and emission reduction.

Methodology and Measurements

Method

DID Method

The Chinese government formally established the first batch of pilot cities for BC in 2014 and subsequently approved the second and third batches of pilot cities in 2015 and 2016. This paper constructs a quasi-natural experiment using this scenario. After matching cities to their corresponding water-quality monitoring points, the final research sample contained 153 monitoring points and 111 cities. Of these, 49 BC pilot cities comprised the experimental group. The remaining 62 cities formed the control group.

This paper uses the multi-period DID method to assess the effectiveness of the BC strategy. The DID method's central idea is to investigate the double effects of exogenous policy shocks on different individuals before and after a specific time node. It can identify the "net effect" of policies and effectively avoid the estimation bias caused by endogenous problems. The BC strategy adopts a step-by-year approach, while the traditional DID method is only appropriate for assessing policy effects of a single time point. To this end, this paper draws on the practice of Li et al. [43] in constructing a multi-period DID model that sets a virtual variable for the group, assigning a value of 1 to the experimental group (pilot city) and 0 to the control group (non-pilot city). The model also sets a virtual variable for policy implementation time, assigns a value of 1 to the policy implementation year and subsequent years for pilot cities, and 0 to the alternative. The model of multi-period DID is as follows:

$$lncod_{i,j,t} = \alpha_0 + \alpha_1 did_{j,t} + \alpha_2 X_{j,t} + \mu_i + \nu_t + \lambda_{i,j,t} \tag{1}$$

Among them, $lncod_{i,j,t}$ represents the river pollution index of the water quality monitoring point i in city j in the period t; *did* represents the dummy variable for the BC strategy, and its coefficient reflects the impact of the BC strategy on river pollution. X represents the set of control variables, including economic development level, industrial structure, population density, industrial wastewater discharge, and land area covered by the monitoring point; μ_i represents the individual-fixed effect, ν_t represents the time-fixed effect, and $\lambda_{i,j,t}$ represents the random error term.

Endogenous Treatment

The estimation findings of the original model are influenced by the possibility of non-randomness in the selection of pilot cities for the BC strategy. Hence, we further adapted the instrumental variable method to estimate and resolve the problem of estimation error caused by endogeneity. The selection of instrumental variables satisfied two characteristics: first, a strong correlation with endogenous explanatory variables; and second, having no relation to the explained variables. Based on the research of Niu and Cui [14], this paper selects urban terrain relief (UTR) as a tool variable. The higher the UTR, the higher the cost of network infrastructure construction and the worse the network signal, influencing the pilot city selection. In addition, UTR is a geographical factor and is not related to river pollution.

Intermediary Effect Model

In the process of network infrastructure construction affecting river pollution, it may act directly on river pollution or through industrial agglomeration, innovation capability, and environmental regulation. To clarify the influence mechanism, this paper refers to Liu and Mao [44] to construct an intermediary effect model. The following model is used:

$$Mediator_{i,j,t} = \alpha_0 + \alpha_1 did_{j,t} + \alpha_2 X_{i,t} + \mu_i + \nu_t + \lambda_{i,j,t} \tag{3}$$

$$lncod_{i,j,t} = \alpha_0 + \alpha_1 Mediator_{i,t} + \alpha_2 did_{j,t} + \alpha_2 X_{i,t} + \mu_i + \nu_t + \lambda_{i,j,t} \tag{4}$$

Mediator refers to the index of industrial agglomeration, innovation capability, and environmental regulation respectively.

Variable Setting

Explained variable: river pollution. We manually collected and sorted out the weekly water quality monitoring data at the China National Environmental Monitoring Centre, including five water quality indicators. We take the logarithm of COD (lncod) as the explained variable and the logarithm of NPH[3] (lnnph), the logarithm of DO (lndo), the logarithm of NH3-N (lnnh3n), and the comprehensive water quality grade WQ as the surrogate indicators of the explained variable in the robustness test. Due to interruption of monitoring point, power supply, equipment failure, etc., the data is missing in time and site, and there are some writing errors in the weekly report data. We check and correct it as much as possible. In addition, the weekly water quality report on the China National Environmental Monitoring Centre was updated to 2018, so we finally formed the unbalanced panel data of five water quality indicators from 2004 to 2018.

Core explanatory variable: the BC strategic implementation (did). It is set as a dummy variable, indicating whether the BC strategy was implemented that year. For the implementation year and subsequent years of cities whose water quality monitoring points are designated BC pilot cities, the variable value is 1; otherwise, it is 0.

Control variables. It is necessary to set control variables that may affect river pollution, we select four types of control variables. The first type is related to China's economic growth rate and social development level, represented by the GDP growth rate; the second is population data, defined by the density of the urban-resident population; the third is industrial structure, expressed by the proportion of the added value of the primary and secondary industries in GDP; the fourth is environmental data, represented by industrial wastewater discharge; and the fifth is geographic data, represented by the land area of the administrative region.

Data Description

Fig. 1 depicts the broken line chart of the four water quality indicators from 2004 to 2018. We mainly calculate the average value of river pollution degree at different monitoring points to obtain various water quality indicators to reflect the weekly change trend of NPH, DO, COD, and NH_3-N with time. We can see that NPH is relatively stable during the sample period, and the changing trend with time is negligible. The positive water quality index, DO, shows an upward spiral trend, but the increase is not significant. The negative indicators COD and NH_3-N show a fluctuating downward trend. Therefore, it can be preliminarily concluded that the river pollution in China has improved from 2004 to 2018.

Fig. 2(a-d) shows each city's spatial distribution of four water quality indicators from 2004 to 2018. We can see that the distribution of NPH and DO in the South and North regions are not significantly different. However, the distribution of COD and NH_3-N is very different across regions. Overall, the water quality in the South is better than in the North.

This paper's water quality monitoring data comes from China National Environmental Monitoring Centre. The list of BC pilot cities comes from the Ministry of Industry and Information Technology of the People's Republic of China[4]. The data for the control variables are mainly from the China Statistical Yearbook, the China Urban Statistical Yearbook, and the China Environmental Statistical Yearbook. The descriptive statistics of variables in this paper are shown in Table 3.

[3] NPH is the absolute value of the difference between pH and the number 7.

[4] Ministry of Industry and Information Technology of the People's Republic of China, see https://www.miit.gov.cn/ for details.

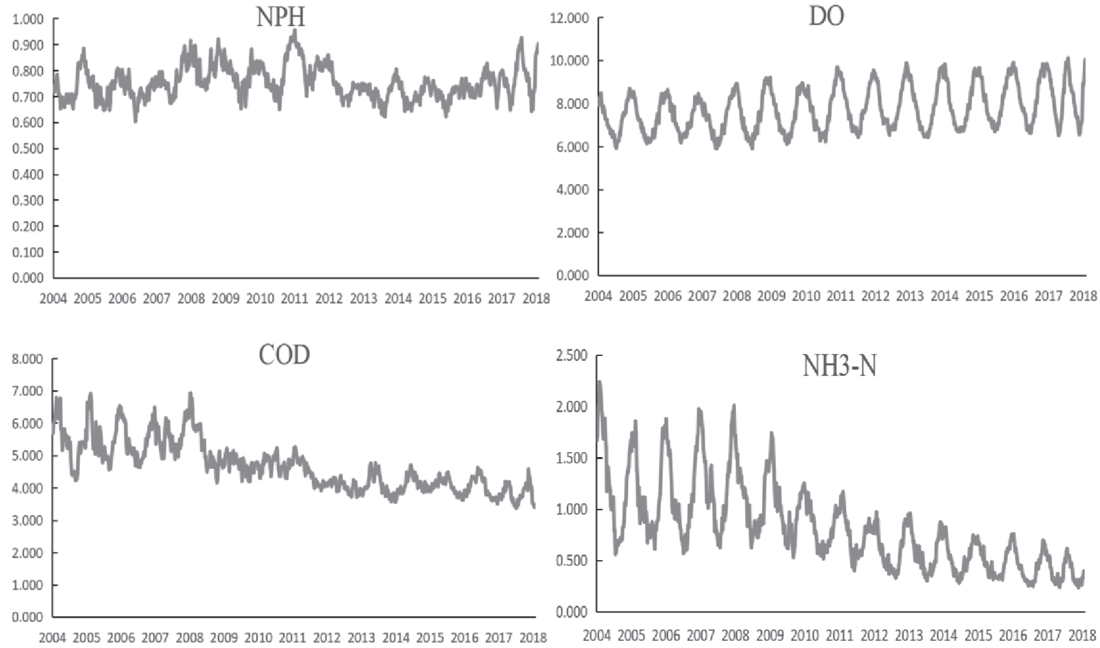

Fig. 1. Variation trends of four water quality indicators from 2004 to 2018.

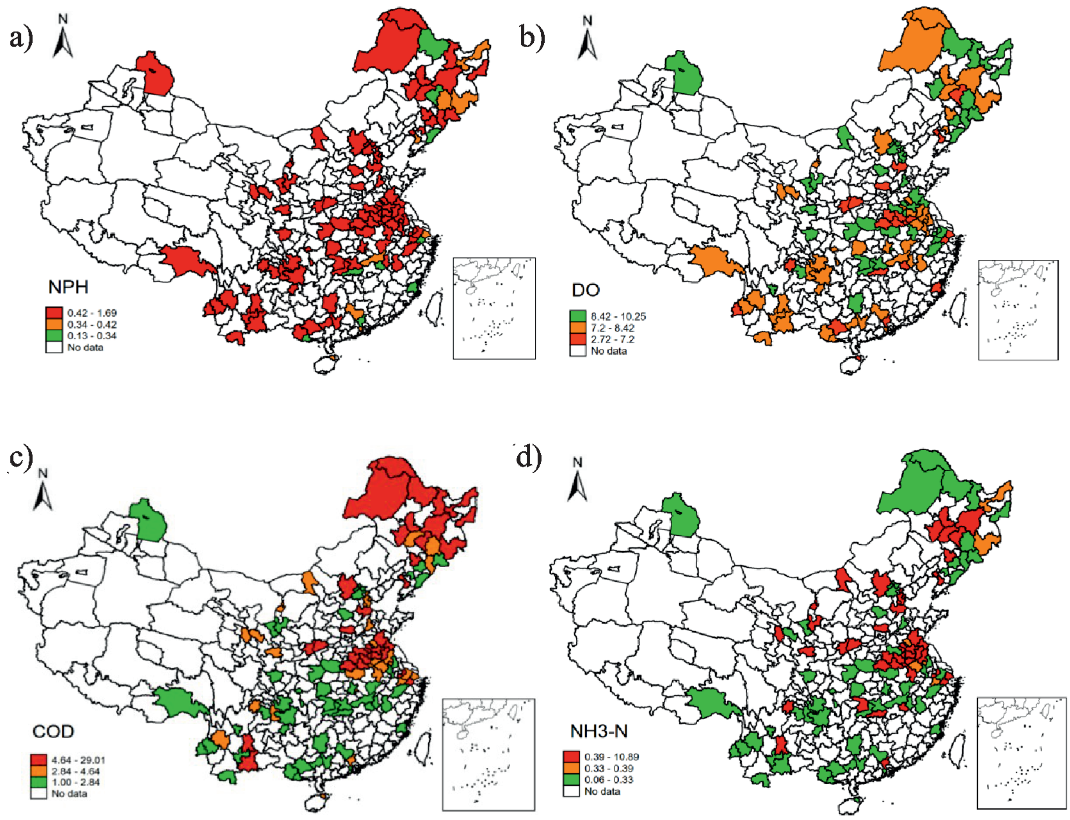

Fig. 2. Distribution of water quality in China from 2004 to 2018.

Results and Discussion

Estimation Results of Multi-Period DID

The samples are estimated according to the above model (1). Table 4 displays the calculated results of network infrastructure construction affecting river pollution. Column (1) is the baseline regression result without the control variable, and columns (2)-(7) are gradually added with the control variable. In columns (1)-(7), we control for the fixed effects of the monitoring points and the fixed effects of time. All regression

Table 3. Descriptive statistics of variables.

Variable name	Variable meaning	Sample size	Average value	Standard deviation	Minimum value	Maximum value
lnnph	Logarithm of NPH	80893	-0.599	0.967	-4.605	0.693
lndo	Logarithm of DO	80775	1.983	0.437	-0.151	2.667
lncod	Logarithm of COD	80853	1.239	0.704	-0.511	3.493
lnnh3n	Logarithm of NH_3-N	80994	-1.207	1.174	-3.912	2.518
WQ	Comprehensive water quality grade	81451	2.966	1.373	1.000	6.000
lnpop_density	Logarithm of population density	79848	7.042	0.794	3.233	9.147
GDPrate	GDP growth rate	71402	11.374	4.097	-9.400	32.900
SGDPpercent	Proportion of added value of secondary industry in GDP	71479	47.043	10.870	14.950	85.920
FGDPpercent	Proportion of added value of primary industry in GDP	71479	13.407	9.460	0.320	49.890
lnIW	Logarithm of industrial wastewater discharge	74724	8.623	1.024	4.868	11.359
lnAlandaera	Logarithm of land area of Administrative Region	76429	9.468	0.805	7.374	12.474

analyses used cluster standard errors at the monitoring point level.

More specifically, the estimated coefficient of *did* from column (1) is 0.0708, which is significantly positive at 10%, showing that the BC strategy increases river pollution. Columns (2)-(6) show the results of adding the control variables. These demonstrate that the estimated coefficient of *did* increases and is significantly positive at 5%, once again affirming that the BC strategy has exacerbated river pollution to some extent. Column (7) reports the multi-period DID estimation results after controlling all control variables, individual effects, and year effects. After further excluding the selective bias and time trend effects, the coefficient of the core explanatory variable obtained is still significantly positive at the significance level of 5%. The economic significance of this result means that for every 1% increase in network infrastructure construction, the local river pollution levels increased by 8.27%. It is different from the views of Ren et al. [7], Yang et al. [16], who believe that network infrastructure construction has a curbing effect or inverted U-shaped impact on environmental pollution. This may be because they use a panel econometric model, whereas we use the multi-period DID method, which can better alleviate the endogenous problem. This conclusion validates the view of Higón et al. [15] that when network infrastructure construction in developing countries is not perfect, the role of energy conservation and emission reduction cannot be fully utilized. On the contrary, the large-scale construction of internet infrastructure and the rapid growth of internet penetration have caused huge resource and energy consumption, adversely affecting the environment.

Robustness Test

The Parallel Trend Test

Determining the reliability of the policy-effect identification model results is dependent on the critical assumption that before implementing the BC strategy, the river pollution levels of the pilot and non-pilot cities had a similar change trend. This paper thereby uses regression and drawing methods to test the parallel trend.

Firstly, the regression method performed the parallel trend test, the results of which are shown in Table 5. This paper draws on the parallel trend test method that Beck et al. [45] adopted to establish a regression model for river pollution indicators and time-dummy variables. Due to the long period before implementing the BC strategy in the sample, this paper narrows its selection to the five years before and four years after implementation. The results show no discernible difference in river pollution levels between the experimental and control groups before implementing the BC strategy. However, after implementation, the regression coefficient begins to be positive and passes the significance level test, satisfying the parallel trend hypothesis. We further compare the changing trend of river pollution levels before and after implementing the BC strategy through the graphical method, as shown in Fig. 3. The result shows that there are significant differences before and after implementing the BC strategy. We get further confirmation that this study has passed the parallel trend test and that it is appropriate to use the DID method to study the impact of the BC strategy on river pollution.

Table 4. Baseline regression results.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	lncod	*lncod*	*lncod*	*lncod*	*lncod*	*lncod*	*lncod*
did	0.0708*	0.0751**	0.0866**	0.0851**	0.0796**	0.0859**	0.0827**
	(0.0391)	(0.0369)	(0.0360)	(0.0360)	(0.0377)	(0.0374)	(0.0376)
GDPrate		0.0008	-0.0012	-0.0008	-0.0008	0.0003	0.0003
		(0.0046)	(0.0054)	(0.0053)	(0.0053)	(0.0052)	(0.0051)
SGDPpercentage			0.0042	0.0074	0.0078	0.0078	0.0073
			(0.0039)	(0.0046)	(0.0047)	(0.0048)	(0.0047)
FGDPpercentage				0.0094	0.0095	0.0078	0.0060
				(0.0064)	(0.0065)	(0.0063)	(0.0064)
lnpop_density					0.1290	0.0861	0.1850
					(0.2020)	(0.1950)	(0.2300)
lnIW						-0.0460*	-0.0478*
						(0.0259)	(0.0259)
lnAlandaera							0.2430
							(0.1870)
Constant	1.2290***	1.2430***	1.0670***	0.7870***	-0.1500	0.5630	-2.3850
	(0.0050)	(0.0534)	(0.1600)	(0.2510)	(1.5410)	(1.4440)	(3.1470)
Individual effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	80853	69676	69624	69624	69269	67907	67907
R^2	0.7040	0.7190	0.7190	0.7200	0.7200	0.7220	0.7220

Note: Values in parentheses are cluster robust standard errors; *, **, and *** denote 10%, 5%, and 1% significance levels, respectively; the same in the following tables unless otherwise noted.

Table 5. Parallel trend test regression method.

Variables	Coefficient	Variables	Coefficient
Pre_5	-0.0024	Pre_1	0.0780*
	(0.0291)		(0.0394)
Pre_4	-0.0405	Pre_2	0.0602
	(0.0400)		(0.0534)
Pre_3	0.0081	Pre_3	0.1978***
	(0.0459)		(0.0750)
Pre2	-0.0073	Pre_4	0.1384*
	(0.0441)		(0.0701)
Pre_1	0.0503		
	(0.0363)		
Control variables	yes 69624 0.7200		

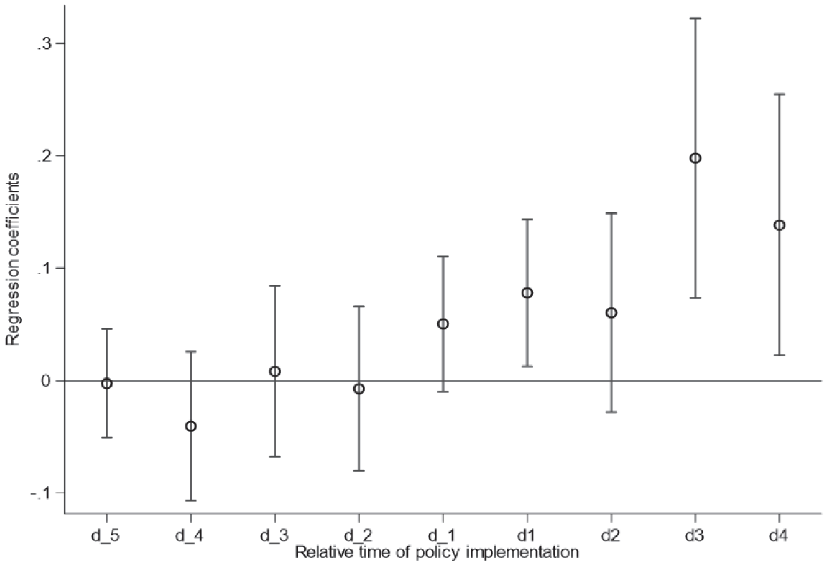

Fig. 3. Parallel trend test - drawing method.

The Placebo Test

Although the control variables have been added to the benchmark regression, there may still be some unobserved variables that impact the estimation results. To further exclude the influence of missing variables on the validity of the experimental results, we will randomly select the experimental and control groups from all samples and conduct a placebo test. The expression obtained from formula (1) is:

$$\widehat{\alpha_1} = \alpha_1 + \gamma \frac{cov(location_{i,t},\ \varepsilon_{it}|control_{i,t})}{var(location_{i,t}|control_{i,t})}$$

Among them, *control*$_{i,t}$ represents all other control variables and fixed effects, γ is the influence of other unobservable factors on river pollution. To make the estimation result of α_1 unbiased, γ needs to be 0, but it cannot directly verify whether γ is 0. Therefore, we adopted the method of an indirect placebo test to find the wrong *location*$_{i,t}$ variable (that would not theoretically have an impact on river pollution) using a computer simulation to replace the real *location*$_{i,t}$ variable.

If $\widehat{\alpha_1} = 0$, it can be pushed out to γ = 0; if $\widehat{\alpha_1} \neq 0$, it means γ≠0, the estimation result of the article is biased, and the unobserved factors will indeed affect the estimation result. Improving the identifiability of the placebo test was done by conducting the above process randomly, 500 times to obtain the estimated nuclear density, with results shown in Fig. 4, in which the vertical line is the real coefficient α_1. The estimated results of random grouping are concentrated around zero, and basically conform to the normal distribution, the mean value is close to 0, and most of the P values are greater than 0.1. Therefore, the BC strategy does not significantly promote the randomly selected experimental group. In addition, α_1 (vertical solid line) is not in the main distribution range, indicating that the impact of the strategy on river pollution is real.

Estimation Based on PSM-DID Method

The pilot cities selected for the BC strategy may not have been random. Cities with higher economic development levels may be more likely to become pilot cities, leading to a deviation in the benchmark regression results. In an attempt to minimize any significant differences in economic variables between the treatment group and the control group, which may lead to biased results from the multi-period DID model, this paper adopted the PSM-DID model for empirical analysis. After completing the matching work using the nearest neighbor matching method, the results are shown in Table 6. Column (1) is the result of adding individual effects, and column (2) is the result of adding both individual effects and year effects. The coefficients of the core explanatory variables are all positive and significant at 5%. Because there is no significant

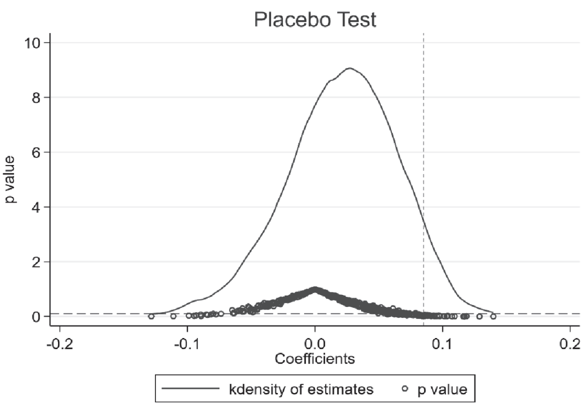

Fig. 4. Placebo test results.

Table 6. PSM-DID model regression results.

	(1)	(2)
	lncod	*lncod*
did	0.0753**	0.0767**
	(0.0320)	(0.0365)
Constant	0.6800***	0.8110***
	(0.2150)	(0.2730)
Control variables	Yes	Yes
Individual effects	Yes	Yes
Year effects	No	Yes
Observations	68323	68323
R^2	0.7130	0.7220

Table 8. Endogenous treatment.

	Results of the first stage regression	Results of the second stage regression
	did	*lncod*
UTR	12.1241***	
	(1.5347)	
did		0.2517*
		(0.1420)
Control variables	Yes	Yes
Individual effects	Yes	Yes
Year effects	Yes	Yes
Observations	69141	69141

difference between the coefficients and the benchmark regression results, we have confirmation that the BC strategy positively impacts river pollution.

Robustness Test of Replacement Samples

This paper replaced the explanatory variables with four alternative water quality indicators, shown in Table 7. The explanatory variables in columns (1)-(4) are *lnnph*, *lndo*, *lnnh3n*, and *WQ*. The regression results show that *did* has no significant impact on *lnnph* but has a significantly negative effect on the positive indicator *lndo*. This result means that the BC strategy has aggravated river pollution; *did* has a significant positive impact on the negative indicators *lnnh3n* and *WQ*, once again verifying the BC strategy's aggravating effect on river pollution.

Endogenous Treatment

There is a possibility of non-randomness in the pilot cities selected by the BC strategy. To deal with the endogenous problem, we employ urban terrain relief (UTR) as a tool variable and the two-stage least squares method (2SLS) to re-examine the impact of the BC strategy on river pollution. The regression results are shown in Table 8. The first-stage regression results show that UTR significantly affects the BC strategy. In the first stage, the F-test value was 62.4, considerably more significant than the empirical value of 10. Moreover, the Cragg-Donald Wald F statistic was 2881.85, higher than the threshold of 16.38 under the 10% error level of the Stock-Yogo weak instrumental variable. Therefore, selecting UTR as a tool variable is appropriate, and there is no weak tool variable problem. The second-stage regression results show that the BC strategy significantly promotes river pollution. In the instrumental variable model, the absolute value of the estimated coefficient of river pollution is more significant than that in the benchmark model, indicating that the potential endogenous problem makes it easy to underestimate the negative impact of the strategy on river pollution.

Table 7. Robustness test.

	(1)	(2)	(3)	(4)
	lnnph	*lndo*	*lnnh3n*	*WQ*
did	-0.0559	-0.0559*	0.1330*	0.1420*
	(0.0652)	(0.0321)	(0.0800)	(0.0795)
Constant	-0.5140***	2.1410***	-1.2470	4.0080***
	(0.1900)	(0.2980)	(1.8440)	(0.6880)
Control variables	Yes	Yes	Yes	Yes
Individual effects	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes
Observations	69722	68128	73000	68679
R^2	0.3780	0.5060	0.6420	0.6040

Mechanism Analysis

This paper further uses the intermediary effect model to investigate the impact mechanism of the BC strategy on river pollution, in which industrial agglomeration (*agglo*), innovation capacity (*innovation*), and environmental regulation (*enre*) are the mediating variables. In the impact of the BC Strategy on river pollution, the secondary industry plays a leading role. Therefore, industrial agglomeration adopts the secondary industry agglomeration level index. Referring to Shen and Peng [46], we use the location entropy method to calculate the secondary industry agglomeration level and take the industrial output value data as the output index. The calculation formula applied is: $agglo = \frac{P_{c,r}/\sum_c P_{c,r}}{\sum_r P_{c,r}/\sum_c \sum_r P_{c,r}}$, where $P_{c,r}$ represents the output value of industry c in region r. The numerator represents the output value of industry c in the region r, accounting for the output value of all industries. The denominator represents the output value of industry c in all regions accounting for the output value of all industries. For innovation capability, this paper uses the number of green invention patent applications to represent it. For environmental regulation, this paper refers to Ren et al. [47] and uses three indicators, industrial wastewater emissions, industrial SO_2 emissions, and industrial smoke emissions, to calculate a comprehensive index of environmental regulation intensity using the entropy weight method.The calculation formula is: $\mathrm{enre} = \sum_{j=1}^{m} w_j X_{ij}^*$. Among them, X_{ij}^* is the proportion of standardized index j in the city i in the comprehensive evaluation index system of environmental regulation, W_j is the weight corresponding to the index j. enre is the comprehensive level of environmental regulation.

Table 9 presents the regression results of industrial agglomeration, innovation capability and environmental regulation as mediating variables. Column 1 is the impact of the BC strategy on industrial agglomeration. Its regression coefficient is 0.00598, which is significantly positive at the 5% level, affirming that the strategy has dramatically improved industrial agglomeration. Column (2) shows the regression results of industrial agglomeration as an intermediary variable. The regression coefficient of industrial agglomeration is 1.404, which is significantly positive at the 10%. It indicates that the improvement of industrial agglomeration levels intensifies river pollution. Column (3) shows the effect of the BC strategy on innovation capability and column (4) exhibits the regression result of innovation capability as an intermediary variable, which are not significant. It indicates that the BC strategy cannot significantly affect river pollution through innovation capability. An explanation for this may be that the innovation capability of enterprises

Table 9. Mechanism test.

	(1)	(2)	(3)	(4)	(5)	(6)
	agglo	lncod	lnInnovation	lncod	enre	lncod
did	0.0060**	0.0646*	0.0088	0.0790**	-0.0077	0.0808**
	(0.0027)	(0.0382)	(0.0917)	(0.0370)	(0.0069)	(0.0378)
agglo		1.4040*				
		(0.7230)				
innovation				0.02190		
				(0.0186)		
enre						-0.2340
						(0.1830)
Constant	0.9900***	-0.2350	-10.4000	-2.0840	0.8600*	-2.1820
	(0.1400)	(1.5460)	(6.4320)	(3.1450)	(0.4570)	(3.0970)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Individual effects	Yes	Yes	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	70994	69269	65357	63693	69,622	67,907
R^2	0.9940	0.7200	0.9410	0.7320	0.9090	0.7230

has not been fully transformed into green innovation achievements, and the role of river pollution reduction has not been fully played in the short term. Column (5) shows the effect of the BC strategy on environmental regulation, and column (6) exhibits the regression result of environmental regulation as an intermediary variable. It indicates that the BC strategy also fails to suppress river pollution through environmental regulation. The reason may be twofold: first, environmental regulation is a top-down approach to governance, and the change of local officials' decision-making philosophy plays a more critical role than the convenience brought by information technology. The effect of pollution control may depend more on the decisions of local officials. Second, environmental governance intelligence requires the simultaneous development of big data and other modern information technology. China's supporting technology and facility development is not perfect, and the development of the internet alone cannot drive environmental governance intelligence, so network infrastructure construction cannot yet play a role in pollution reduction through environmental regulation.

Heterogeneity Analysis

Distinguish Regional Characteristics

Different regions have different resource allocation and industrial structure, which may result in policy effects that differ across regions. In this paper, the sample is divided into the Eastern, Central, Western, and Northeastern regions, and the regression results are shown in Table 10.

The BC strategy in the Eastern region increases river pollution, with a regression coefficient of 0.121, which is significant at the 5% level. The BC strategy in the Central region also aggravates river pollution, the regression coefficient is 0.133, and it is significant at the 10% level. In terms of the influence magnitude, there is little difference between the two regression coefficients; in terms of significance, the significance level in the Eastern region is higher than that in the Central region. In the Western and Northeastern regions, the BC strategy has a positive but not significant impact on river pollution. One possible explanation is that the Eastern and Central regions have more developed economies and advantages in factor endowment and infrastructure compared to the Western and Northeastern regions. Therefore, in the East and Central regions, the BC strategy has had a more noticeable effect on the accumulation of secondary industries. These industries have attracted many enterprises and a significant population. Compared with other areas, the production activities of enterprises are more intensive, thus causing more severe harm to river pollution.

Distinguish Urban Characteristics

Cities with different levels of digital economy development may have different internet application scenarios, resulting in different effects of network infrastructure construction on river pollution. Referring to Zhao et al. [48], we construct a comprehensive index system and use principal component analysis to obtain the digital economy development level. The indicator system consists of five items: the number of internet broadband access users per 100 people, the total amount of telecommunications services per capita, the proportion of computer software and software industry employees in urban units, and the number of mobile phone users per 100 people. Then, we divide the cities according to the average of the digital economy development level. Cities with values greater than the mean have higher levels of digital economy development, whereas cities with values lower than the mean have lower levels of digital economy development.

Table 11 shows that in cities with high levels of digital economy development, the BC strategy has a significant positive impact on river pollution, whereas it has no significant effect in cities with a less developed

Table 10. Heterogeneity analysis by region.

	(1)	(2)	(3)	(4)
	Eastern region	Central region	Western region	Northeastern region
did	0.1210**	0.1330*	0.0923	0.2040
	(0.0577)	(0.0666)	(0.0651)	(0.1310)
Constant	6.7820	-1.2460	0.1650	2.1580
	(4.4700)	(2.6730)	(1.3040)	(8.4910)
Control variables	Yes	Yes	Yes	Yes
Individual effects	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes
Observations	24046	21759	13564	10916
R^2	0.7260	0.7700	0.6830	0.6170

Table 11. Heterogeneity of digital economy development level.

	(1)	(2)
	high	low
did	0.1170**	0.0337
	(0.0508)	(0.0621)
Constant	-2.1310	5.0770
	(3.8010)	(4.8680)
Control variables	Yes	Yes
Individual effects	Yes	Yes
Year effects	Yes	Yes
Observations	36880	35517
R^2	0.6850	0.7400

digital economy. Cities with a high degree of digital economy development are often more attractive to network infrastructure construction, which requires a lot of energy and emits pollutants [49]. When internet development is less developed, its emission reduction capacity is not enough to offset the pollution emissions caused by network infrastructure construction and internet applications. With internet development reaching a certain level, its ability to reduce pollution and emissions may gradually become apparent, playing a positive role in the environment.

Conclusions

In comparison to other studies on the environmental externalities of network infrastructure, we use a multi-period DID method to evaluate the influence and internal mechanisms of network infrastructure construction on environmental pollution from the perspective of river. The following conclusions are drawn.

First, network infrastructure construction aggravates river pollution. After adding individual effects, year effects, and all control variables, the influence is significantly positive at the 5% level. After a series of robustness tests, the conclusion is still valid. This research conclusion helps us fully understand the environmental externalities of network infrastructure construction, and when internet development has not reached a certain level, it cannot give full play to the advantages of energy conservation and emission reduction.

Furthermore, we employ the intermediary effect model to investigate the influence mechanism via the three paths, namely industrial agglomeration, innovation capability and environmental regulation. The study found that network infrastructure construction mainly promotes secondary industry accumulation, expands enterprise-scale, specialized aggregation, and increases total population, aggravating river pollution. Network infrastructure construction cannot significantly affect river pollution through innovation capability and environmental regulation.

Finally, the influence effect has heterogeneity. From a sub-regional perspective, network infrastructure construction significantly aggravates river pollution in the Eastern and Central regions and has no significant influence on other regions. From a sub-urban perspective, network infrastructure construction significantly promotes river pollution in cities with higher levels of digital economy development but has no significant impact on cities with lower levels of digital economy development.

Based on the above research, we propose the policy recommendations for reducing river pollution:

(1) Reasonable layout of network infrastructure to form the driving force of river pollution reduction. The unreasonable layout of network infrastructure construction will promote river pollution. We need to reasonably arrange network infrastructure and form a virtuous circle of industrial agglomeration, innovation ability, and river pollution reduction. In addition, it is necessary to promote the deep integration of digital technology and real industry, accelerate the digital transformation of traditional industries and make the network infrastructure construction a continuous driving force for river pollution reduction.

(2) Promote diversified agglomeration and give full play to the advantages of industrial agglomeration. From the current point of view, the agglomeration type of secondary industry in China tends to be specialized, and the agglomeration type is relatively single, which harms river pollution. For cities with a single type of agglomeration, local governments should encourage and introduce new enterprises to form more diversified industrial agglomerations and stimulate the positive externalities of diversified industrial agglomeration to the environment. For cities with a high level of diversified agglomeration, it is necessary to exert their radiation effects and industrial advantages to drive surrounding cities to form their own diversified industrial agglomeration advantages.

(3) Improve the innovation ability of enterprises and accelerate the transformation of green innovation achievements. As the key path for network infrastructure construction to affect river pollution, innovation has not had a positive effect. This has a lot to do with the fact that the innovation capability of enterprises is not strong enough, and the transformation of green innovation achievements is not timely enough. Therefore, the government and relevant departments need to establish an effective mechanism of production, teaching, and research. On the one hand, it is necessary to promote the exchange and cooperation among local universities, scientific research institutions, and enterprises to improve the green innovation ability of enterprises. On the other hand, we should strengthen the enterprises' leadership in innovation, fully exploit the market's decisive role in the allocation of innovation

resources, and stimulate the endogenous power of innovation achievement transformation to accelerate the transformation of green innovation achievements.

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Conflict of Interest

The authors declare no conflict of interest.

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