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Effect of High-Speed Railways on City Industrial Sewage Discharge

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Abstract: Industrial wastewaters threatening the sustainability of society have increasingly become a key social issue across the globe. Consequently, countermeasures have been suggested across a broad range of research fields and policy cycles in both industrialized and industrializing countries. Thus, identifying factors that drive reductions in industrial wastewater discharge is a key task in the water research and policymaking fields. In contrast to previous studies that have focused on reducing industrial wastewater discharge through techniques, policy, management, and other tools, the aim of this study was to investigate the effect of transport infrastructure development, particularly high-speed railways (HSR), on industrial sewage discharge. Given the rapid development of high-speed railways in China and the country's severe water pollution, China was our research context, and our sample was 298 prefecture-level Chinese cities during the period 1999–2018. The empirical results show that cities with high-speed railways have greater reductions in industrial wastewaters, and that these effects are weakened in cities with a more developed economy and information environment. The results are consistent when using different methods to test their robustness, such as time-varying difference-in-difference (DID), instrumental variables, and placebo tests. These findings offer useful guidance for practitioners and policymakers in the management of water resources and the development of transport infrastructure in cities. These results contribute to the literature in the field of water management and to the assessment of the broader effect of high-speed railways.

Keywords: industrial wastewater; high-speed railway; time-varying DID; China

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1. Introduction

The discharge of industrial wastewaters, i.e., effluents from various types of industries such as metal smelting and refining, papermaking, chemistry, brewery, winery, textile dyeing, and cement, has been a major issue for many industrialized and industrializing countries [1–3]. For instance, since the 1980s, rapid industrialization in China has greatly strengthened its economy but at the expense of dramatic environmental degradation, including water pollution. Sewage discharge has resulted in widespread organic pollution, toxic pollution, and eutrophication, as well as severe ecological destruction [4–9]. According to Tao and Xiao's research [10], every year, approximately 190 million Chinese people fall ill and 60,000 people die from a wide range of diseases and injuries linked to water pollution.

Many industrial wastewaters, even after intensive treatment, still contain a notably high load of organic matter with undesirable inorganic and organic pollutants remaining in effluents [11,12]. The discharge of such industrial wastewaters can exert substantially harmful effects on natural water bodies, such as odor, eutrophication, toxicity, and hypoxia [11,13]. Great efforts have thus been invested into effectively reducing, detecting, monitoring, and controlling pollution to ensure downstream water quality and safety [4,14].

To reduce industrial wastewater discharge, various tools and their effects have been widely discussed in the literature and policy cycles from the perspective of techniques, policy, water infrastructure, water management, and other administrative means [2,4,7,14–20].

However, to date, little effort has been put into understanding how transport infrastructure influences the discharge of industrial wastewaters. This question has become increasingly salient as the construction of high-speed railways, a new and impressive development in transport infrastructure, has become a key priority for many countries in the last three decades. In contrast to traditional trains, the high-speed railway is defined by its speed: HSR trains have an average speed above 300 km/h. Since the birth of HSR, some of the extant literature has addressed the economic, environmental, and social effects of the construction and operation of these bullet trains [21–24]. Among these studies, a few have illustrated that the high-speed railway can influence the surrounding water environment and the landscape and ecological system [25–30]. Scholars have attempted to link the high-speed railway to water issues. Most of these studies have highlighted the negative effect of high-speed railways on the surrounding water system, and they have primarily applied qualitative research methods with anecdotal evidence. For example, Guo et al. [31] pointed out that overall, respondents in Beijing and Tianjin are most concerned with ecosystem deterioration and biodiversity loss, pollution, and the human health impacts of HSR, but the concern regarding water pollution is among their worst sources of anxiety. Therefore, a combination of theoretical and empirical study on the relationship between high-speed railways and wastewater discharge is particularly important.

In the present study, using the opening of the high-speed railway in cities as a natural experiment, we quantified the effect of transport infrastructure development on industrial wastewater discharge. The operation of a high-speed railway in a city can largely improve the city's accessibility to other cities and accelerate the mobility of people, information, capital, and other resources [24,32–34]. Thus, on the one hand, high-speed railways might increase industrial wastewaters due to increased production materials flowing into cities at a rapid speed and reduced cost. On the other hand, the operation of a high-speed railway in a city might reduce sewage discharge owing to the enhanced social pressure on firms to address environmental issues. This kind of social pressure may come from investors, governments, social media, and the public. Investors may no longer invest in one city due to its negative image in terms of environmental friendliness, and the general public may choose other cities to travel to [35]. These activities will apply pressure on local cities and consequently lead to their improved environmental performance, including a reduction in industrial wastewater emission.

At present, it is unclear whether the development of high-speed railways impacts industrial wastewater discharge and which perspective is more relevant. To address this issue, we extend recent studies that focused on tools and mechanisms for reducing industrial wastewater discharge and the burgeoning literature on the effects of high-speed railways on broader social aspects. Unlike previous studies, we adopted a quantitative method to study the effect of high-speed railways on industrial wastewater discharge in 298 prefecture-level cities in China by comparing cities with and without operating HSRs from 1999 to 2018. The empirical results show that the operation of an HSR in cities is able to reduce the discharge of industrial wastewaters, and this effect is weakened in cities with more developed economies and information environments. Different methods were used to test the robustness of these findings, including time-varying DID, instrumental variable method, and placebo tests, and our results remained consistent. We argue that the mechanism supporting our finding is the social pressure theory, which was tested using the moderating method. High-speed railways strengthen social pressure and thus increase the environmental protection awareness of industrial practitioners and the monitoring capability of the government, the press, and other third-party powers.

2. Background and Method

2.1. China's HSR System

High-speed railways were first developed more than 50 years ago, first in Japan in the 1960s, followed by France in the 1980s, and later in Spain, Germany, the UK, the US, China, and other countries. The construction of high-speed railways has become an important priority for many countries. A decade ago, China entered an era of high investment in and rapid expansion of HSR transport infrastructure.

According to the definition of the Regulations on Railway Safety Management promulgated in 2013, a high-speed railway is defined as a dedicated passenger train line with a design speed of more than 250 km per hour, including reserved stations and an initial operating speed of more than 200 km per hour. It is important to note that the reserved station is a reserved high-speed rail station. If requested by the local government, the reserved station will be activated in due course. However, the use of reserved stations does not mean that the high-speed rail will slow down. During operation, some trains will depart from the starting point and directly arrive at the end without stopping along the route, while some trains will stop at stations along the route. Taking into account that the high-speed rail basically maintains a speed of 350 km per hour, the reserved station and the departure station will not be very close; otherwise, it will affect the speed of vehicles. According to this definition of the Regulations on Railway Safety Management, railway trains operating in China with a speed of more than 200 km per hour mainly include passenger trains in classes D, G and C (G-head trains are also known as high-speed electric multiple -unit (EMU) trains, the maximum speed of which must reach 300 km/hour or more during the entire operation; D-head trains are also called EMU trains, the maximum speed of which does not exceed 250 km/h; C-head trains are an intercity trains). In order to facilitate research, this article does not distinguish between these classes and refers to them collectively as high-speed railways.

The development of China’s high-speed railway started with the Qinhuangdao-Shenyang Passenger Dedicated Line, for which construction started in 1999 and began to operate in October 2003. Since the operating speed was only 160 km per hour, it did not meet the threshold of 200 km per hour or more at the initial stage of the opening of the high-speed railway. Therefore, many people regard the Beijing–Tianjin intercity railway, which opened in 2008, as China’s first real high-speed railway. Since 2008, China has successively built a number of high-speed railway passenger-dedicated lines, including high-speed railway lines with design speeds of 350 and 250 km per hour. According to the plan, the government will build a grid of HSRs with four east–west lines and four north–south lines, named the Four Vertical and Four Horizontal Corridor.

Since the birth of the high-speed railway, public concerns and protests have emerged along their tracks in almost all countries. HSR has four main technical characteristics. First, according to its technical definition, the operating speed of a high-speed railway is usually more than three times that of ordinary trains, which can effectively shorten the intercity travel time. Second, a high-speed railway adopts more advanced communication signal systems and train control systems, and the operating density is much higher than that of ordinary trains, which can effectively improve the efficiency of passenger transportation. Third, China’s high-speed railway trains generally operate on the newly built passenger-dedicated lines, and the separation of passengers and cargo has improved the level of professional operation and effectively increased the capacity of the line. Fourth, as the growth of China’s high-speed railway has accelerated and become a network, the network’s positive externalities appear to be gradually increasing the market demand for high-speed railways, which results in a positive feedback mechanism between supply and demand.

These technical and economic characteristics clearly indicate that a high-speed rail can effectively improve regional accessibility. Due to accessibility, people can disseminate information and communication more quickly in response to events that have negative impacts, which can attract more attention. For example, corporate financial fraud is easier to detect because the HSR helps stakeholders conduct on-site investigations [36]. Therefore, the operation of the HSR can raise social pressure on firms from shareholders, governments, and society.

2.2. Industrial Wastewater Introduction

Industrial wastewater refers to wastewater, sewage, and waste liquid produced in the industrial production process, which contains industrial production materials, intermediate products and products that are lost to water, and pollutants generated in the production process. Industrial wastewater is characterized by a complex composition, difficult treatment, and great harm. In industrializing countries, such wastewater mainly comes from the petrochemical, textile, paper, iron and steel, and electroplating industries.

According to data from the Statistical Yearbook of Urban Construction, in 2014, China's total industrial wastewater discharge was 445.34 million cubic meters. In 2020, the Ministry of Ecology and Environment released the monitoring results of 448 direct sea pollution sources with more than 100 cubic meters of daily wastewater discharge. The data revealed that the discharge of industrial wastewater was 588.65 million cubic meters, a year-on-year increase of 32.18%. Figure 1 shows the trend chart of China's industrial wastewater discharge from 2014 to 2020.

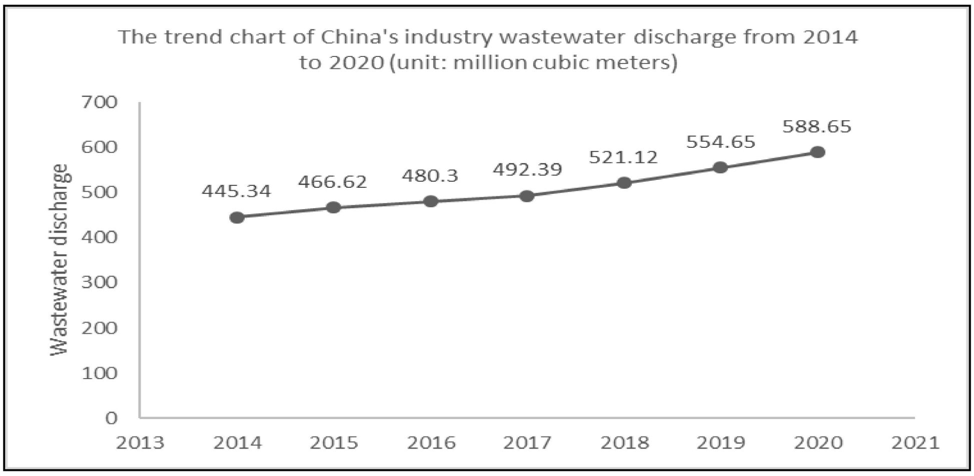

Figure 1. The trend chart of China's industry wastewater discharge from 2014 to 2020 (unit: million cubic meters). Data sources: Statistical Yearbook of Urban Construction.

As illustrated in Figure 1, the amount of wastewater discharge is gradually increasing. In order to reduce wastewater discharge, the government has taken a series of measures. First, in terms of financial investment, according to the analysis and prediction of the Environmental Planning Institute of the State Environmental Protection Administration and the National Information Center, the total investment in wastewater treatment (including treatment investment and operating costs) during the 12th Five-Year Plan and 13th Five-Year Plan periods will reach CNY 1058.3 billion and CNY 1392.2 billion, respectively. Second, the government has issued a series of related policies, including different policy approaches: laws and regulations, standardized management, supervision and management, governance planning, financing mechanism, charging mechanism, planning management, etc. Third, the government commends companies that effectively treat industrial wastewater. For example, in 2019, 14 companies were shortlisted for leading companies. Most of these are distributed in Beijing, Guangdong Province, and Jiangsu Province, which demonstrates that these regions have better water handling technology to some degree.

Above all, we can see that wastewater discharge in China is an important issue related to population health and economic development. Analyzing the factors that influence wastewater discharge is of pivotal importance. With the development of infrastructure, determining whether HSR operation has an influence on wastewater discharge is worth exploring.

2.3. Data Sources and Variables

2.3.1. Data

Our primary data source for the high-speed railway is the Train Schedule Book (2008–2018), which can be obtained from the Railway Official Website (China Railway 12306 official Website: https://www.12306.cn, accessed on 25 March 2019). The Train Schedule Book provides detailed information about the high-speed railway line, including the departure station, terminal station, departure time, arrival time, stay time, etc. In addition, data on prefecture-level cities were mainly obtained from the China City Statistical Book (1999–2018). Several types of data reflect the development of prefecture-level cities, such as economic, environmental, and social variables. We selected several variables appropriate to the research objectives of this article. After processing missing and abnormal values, we finally obtained 298 prefecture-level cities and 4222 city–year observations.

2.3.2. Variables

The operation of HSR (HSR): In this study, the operation of the high-speed railway is regarded as a quasi-natural experiment. Therefore, the difference-in-difference method is an appropriate choice. To apply this method, it is essential to establish a grouping variable (treat) and time variable (time). The sample observations range from 1999 to 2018. Since 2008, prefecture-level cities have gradually implemented high-speed railways. In this study, cities with operating HSRs from 2008 to 2018 were defined as the treatment group, and cities without operating HSRs from 2008 to 2018 were defined as the control group. If cities belong to the treatment group, treat = 1; otherwise, treat = 0. If a city did not open an HSR in the observation year, then time = 0; otherwise, time = 1. Therefore, the interaction term treat*time is the core focus of the analysis, which reflects the effect of the HSR, and HSR = treat*time.

Polluted water emissions (Wastewater): The wastewater that causes environmental pollution is mainly industrial wastewater; to reduce heteroscedasticity, the logarithm of industrial wastewater discharge was used to measure the water pollution in the region.

Population size (Population): A large number of studies have shown that the population size in an area has an influence on environmental pollution [21,37]. To adjust for skewness, the logarithm of the population size of the prefecture-level city was used to represent the local population.

Industrial characteristics (Manufacturing): The manufacturing industry is the main source of environmental pollution. If the number of manufacturing employees is larger, then the development of the manufacturing industry is more advanced. The logarithm of manufacturing employees was used to represent the impact of the manufacturing industry on environmental pollution to reduce heteroscedasticity.

Firm size (Large_firm): Large firms engage in more economic activities in the course of business and are likely to produce more pollution than small firms. Therefore, this study also determined the number of state-owned firms and non-state-owned firms whose sales revenue exceeds CNY 5 million in a region, and we took the logarithm value of the variable to adjust for skewness.

Openness level (FDI): Foreign direct investment (FDI) is an important influencing factor in environmental pollution [38,39]. Previous studies have provided two prominent views. The negative view holds that FDI will accelerate environmental pollution in order to promote economic development, while the positive one asserts that FDI can push local firms to adopt new technology that improves the environmental quality. In this study, to adjust for skewness, the logarithm of FDI in a city was used to represent the openness level.

Education conditions (Students): The number of students in colleges and universities in a region represents the education level of a city. Education is a fundamental factor of economic and social development which also influences environmental protection. To reduce heteroscedasticity, the logarithm of students in colleges and universities was used to represent education conditions.

Civilization level (Library_book): The number of books in a regional library represents the degree of civilization of a region. The higher the degree of regional civilization, the more attention is paid to issues such as environmental protection [40]. The logarithm of library collections per capita in the region was used to represent the local civilization level to adjust for skewness.

Regional visibility (Passenger): The greater the number of regional passengers transported, the higher the reputation of the region and the more people are coming and going. The movement of people contributes to information dissemination and communication, which can increase concern about pollution and lead the local government to focus on environmental pollution [33]. The logarithm of regional transport passengers was adopted to represent regional visibility to adjust for skewness.

Economic development (GDP): Previous studies have identified several relationships between economic development conditions and environmental pollution [41]. In this study, to reduce heteroscedasticity, the logarithm of gross domestic product (GDP) per capita was used to represent the economic development level.

Information environment (Internet): The supervision and control of environmental pollution are inseparable from the network information environment [42]. The number of international Internet users as a percentage of the total population in the region was adopted to represent the local information environment.

2.4. Regression Method

The operation of a high-speed railway is an exogenous factor, which can be seen as a quasi-natural experiment. The top-down rapid expansion of the HSR network potentially creates exogenous variation in the travel costs of passengers that does not depend on trade conditions across regions. Therefore, this study adopted the time-varying DID method to establish the research design. As a common research method for evaluating policy effects, the DID method has been widely used all over the world [43]. The principle of the DID method is to construct a treatment group with policy treatment and a control group without policy treatment. By controlling other factors, the difference between the treatment group and the control group before and after the implementation of the policy is evaluated to determine the effect of the policy. Moreover, in some cases, the timing of the research object is processed differently. The policy starts from a pilot stage and is gradually promoted, which constitutes a time-varying DID model.

As previously mentioned, we constructed the variable HSR which represents the high-speed railway effect. Then, the baseline regression model is as follows:

$$\begin{aligned} Wastewater_{\mathrm{ct}} = \partial_0 + \partial_1 HSR_{\mathrm{ct}} + \partial_2 Population_{\mathrm{ct}} + \partial_3 Manufacturing_{\mathrm{ct}} + \partial_4 \mathrm{Large}\_firm_{\mathrm{ct}} + \partial_5 FDI_{\mathrm{ct}} \\ + \partial_6 Students_{\mathrm{ct}} + \partial_7 Library\_book_{\mathrm{ct}} + \partial_8 Passenger_{\mathrm{ct}} + \partial_9 GDP_{\mathrm{ct}} + \partial_{10} Internet_{\mathrm{ct}} + R_c + Year_t + \varepsilon_{ict} \end{aligned} \tag{1}$$

In Equation (1), $Wastewater_{\mathrm{ct}}$ represents the wastewater discharge of a region in the observation year. HSR_{ct} represents the treat * time. $Population_{\mathrm{ct}}$, $Manufacturing_{\mathrm{ct}}$, $\mathrm{Large}\_firm_{\mathrm{ct}}$, FDI_{ct}, $Students_{\mathrm{ct}}$, $Library\_book_{\mathrm{ct}}$, and $Passenger_{\mathrm{ct}}$ represent the control variables of this study. GDP_{ct} and $Internet_{\mathrm{ct}}$ are moderator variables, R_c represents the regional fixed effect, $Year_t$ represents the time-fixed effect, ε_{ict} is the error term, and ∂_1 is the core coefficient that we need to observe.

In order to verify that the mechanism of the study is rational, two moderator variables—GDP and Internet—were adopted. The regression models are as follows:

$$\begin{aligned} Wastewater_{\mathrm{ct}} = \partial_0 + \beta_1 HSR_{\mathrm{ct}} + \beta_2 HSR_{\mathrm{ct}} * GDP_{\mathrm{ct}} + \partial_2 Population_{\mathrm{ct}} + \partial_3 Manufacturing_{\mathrm{ct}} + \partial_4 \mathrm{Large}\_firm_{\mathrm{ct}} \\ + \partial_5 FDI_{\mathrm{ct}} + \partial_6 Students_{\mathrm{ct}} + \partial_7 Library\_book_{\mathrm{ct}} + \partial_8 Passenger_{\mathrm{ct}} + \partial_9 GDP_{\mathrm{ct}} + \partial_{10} Internet_{\mathrm{ct}} + R_c + Year_t + \varepsilon_{ict} \end{aligned} \tag{2}$$

$$\begin{aligned} Wastewater_{\mathrm{ct}} = \partial_0 + \delta_1 HSR_{\mathrm{ct}} + \delta_2 HSR_{\mathrm{ct}} * Internet_{\mathrm{ct}} + \partial_2 Population_{\mathrm{ct}} + \partial_3 Manufacturing_{\mathrm{ct}} + \partial_4 \mathrm{Large}\_firm_{\mathrm{ct}} \\ + \partial_5 FDI_{\mathrm{ct}} + \partial_6 Students_{\mathrm{ct}} + \partial_7 Library\_book_{\mathrm{ct}} + \partial_8 Passenger_{\mathrm{ct}} + \partial_9 GDP_{\mathrm{ct}} + \partial_{10} Internet_{\mathrm{ct}} + R_c + Year_t + \varepsilon_{ict} \end{aligned} \tag{3}$$

In Equations (2) and (3), $HSR_{ct} * GDP_{ct}$ and $HSR_{ct} * Internet_{ct}$, respectively, represent the interaction terms of the operation of HSR and the moderator variables. β_2 and δ_2 are the main coefficients that we need to observe. Other variable definitions are the same as Equation (1).

3. Empirical Results

3.1. Descriptive Results

Table 1 shows the descriptive results of the variables. The results show that the logarithm of average wastewater is 8.34, and the average HSR is 0.23. The values of other control variables have no outliers. The variance inflation factors (VIFs) of these variables are no more than 10, which indicates that there is no multi-collinearity among them [21].

Table 1. Descriptive statistics.

Variable	Observation	Mean	Std. Dev.	Min	Max	VIF
Wastewater	4222	8.34	1.11	3.09	11.35	
HSR	4222	0.23	0.42	0.00	1.00	1.44
Population	4222	5.84	0.71	2.78	8.13	2.19
Manufacturing	4222	4.29	4.25	−2.12	14.60	2.92
Large_firm	4222	3.05	3.21	0.00	9.58	2.64
FDI	4222	7.83	3.91	0.00	14.55	1.85
Students	4222	4.21	1.23	−0.23	7.15	1.94
Library_book	4222	0.40	2.29	−3.91	6.10	2.20
Passenger	4222	8.54	0.95	5.02	12.03	2.34
GDP	4222	15.70	1.15	12.60	19.36	5.51
Internet	4222	2.75	3.92	−3.54	9.55	2.65

Table 2 reports the pairwise correlation test results of all samples and variables. All variables are correlated with wastewater and the coefficients are no greater than 0.5, which proves that these variables are appropriate.

Table 2. Correlation test results.

	Wastewater	HSR	Population	Manufacturing	Large_Firm
Wastewater	1				
HSR	0.125 ***	1			
Population	0.491 ***	0.163 ***	1		
Manufacturing	0.093 ***	0.397 ***	0.170 ***	1	
Large_firm	0.187 ***	−0.391 ***	0.077 ***	−0.530 ***	1
FDI	0.361 ***	0.155 ***	0.287 ***	0.038 ***	0.057 ***
Students	0.313 ***	0.355 ***	0.048 ***	0.327 ***	−0.024 *
Library_book	0.111 ***	−0.026 *	−0.079 ***	0.232 ***	−0.131 ***
Passenger	0.310 ***	0.311 ***	0.322 ***	0.240 ***	0.064 ***
GDP	0.393 ***	0.472 ***	0.331 ***	0.482 ***	−0.147 ***
Internet	0.135 ***	−0.459 ***	−0.054 ***	−0.683 ***	0.831 ***
	FDI	**Students**	**Library_Book**	**Passenger**	**GDP**
FDI	1				
Students	0.402 ***	1			
Library_book	−0.049 ***	−0.002	1		
Passenger	0.336 ***	0.378 ***	−0.099 ***	1	
GDP	0.487 ***	0.611 ***	−0.133 ***	0.699 ***	1
Internet	0.129 ***	−0.050 ***	−0.052 ***	−0.037 **	−0.249 ***

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

3.2. Parallel Trend Test

A particularly important assumption for the use of DID is that the parallel trend is satisfied. That is, the treatment group and control group must be comparable before shocks or policies occur, because the performance of the control group is assumed to be counterfactual to the treatment group. In this study, the control group was composed of cities without the operation of high-speed railways, and the treatment group was cities with the operation of high-speed railways. Due to the operation year of high-speed railways being different among cities, in the regression, we added the interaction term of year dummy variable and the operation of high-speed railways at each time point. If the interaction term is not significant before the operation of high-speed railways, then the parallel trend exists. Figure 2 illustrates two key observations: wastewater discharge did not precede HSR operation, and the impact of HSR operation on wastewater discharge quickly materialized. As is shown, the coefficients on the HSR dummy variables are not significantly different from zero for all years before the operation of HSR, with no trends in wastewater discharge prior to HSR operation. Next, the wastewater discharge fell immediately after HSR operation. Therefore, the adoption of the DID method in this study is reasonable.

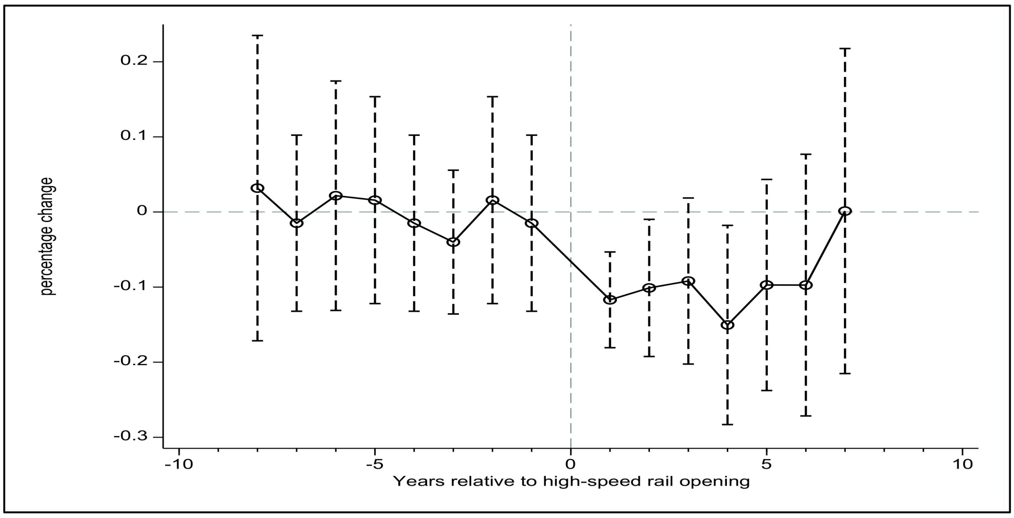

Figure 2. Parallel trend test.

3.3. Regression Results

Table 3 examines the relationship between HSR operation and wastewater discharge. Model 1 only verifies the relationship without control variables, and Model 2 includes all variables. In Models 1 and 2, there is a significant negative relationship between HSR operation and wastewater discharge (C = -0.066, $p < 0.01$), which means that the operation of an HSR can decrease wastewater discharge. In addition, from the results of control variables, we can see that, in a city with more manufacturing employees, there is more wastewater discharge (C = 0.245, $p < 0.01$). The relationship between large firms and wastewater discharge is also positive (C = 0.073, $p < 0.01$), which represents that large firms discharge more wastewater due to their production and operation needs. In order to clarify the results, we did not account for control variables one by one.

Table 3. The baseline regression methods of the time-varying DID method.

	Model 1	Model 2
Variables	**Wastewater**	**Wastewater**
HSR	−0.063 ***	−0.066 **
	(−2.63)	(−2.20)
Population		0.049
		(1.05)
Manufacturing		0.245 ***
		(9.28)
Large_firm		0.073 ***
		(5.58)
FDI		0.006
		(1.14)
Students		−0.023
		(−1.00)
Library_book		−0.011
		(−0.48)
Passenger		0.060 ***
		(3.06)
GDP		0.337 ***
		(6.72)
Internet		0.026
		(1.34)
Constant	8.240 ***	1.459 **
	(127.83)	(2.35)
Year	Yes	Yes
City	Yes	Yes
N	4221	3003
Wald Chi2	746.56 ***	575.81 ***

Note: *z*-statistics in parentheses. *** $p < 0.01$, ** $p < 0.05$.

3.4. Endogenous Treatment

Although the operation of a high-speed railway is a top–down activity, some scholars have also raised the concern that the operation may also be influenced by economic development and other factors and have tried to use instrumental variables to solve this problem [21,37]. In order to reduce the interference of external factors, the approach taken by Yang et al. [37] was followed in this study, and geographic information—the slope of the city—was taken as the instrumental variable. Table 4 represents the endogenous treatment results. Model 1 includes only the control variables. Model 2 uses the ordinary least squares (OLS) regression to analyze the relationship between HSR operation and wastewater discharge, and the result is consistent with the main effect result. Models 3, 4, 5, and 6 use the two-stage least square (TSLS), limited information maximum likelihood (LIML), generalized moment method (GMM), and iterative generalized moment method (IGMM), respectively, to test the relationship between the mean slope of the city and wastewater discharge. The results show that there is a pronounced negative relationship between the mean slope and wastewater discharge (coefficient = −3.327, $p < 0.01$), which is also consistent with the main effect result.

3.5. Placebo Test

A placebo test involves determining whether the policy effect is obtained with the implementation of a fake policy in the time or treatment group. If the policy effect is still obtained in the placebo test, then the policy effect in the benchmark is not reliable. Furthermore, the results may be caused by other unobservable factors, rather than the policy of interest. In this study, in order to determine whether the decrease in wastewater discharge is caused by HSR operation, we randomly constructed 1000 observations, ran 200 times, and randomly selected 50, 100, 200, and 400 observations each time, the results of which are shown in Figure 3a–d, respectively. The results show that most coefficients are larger than 0, which differs from the baseline regression results and proves that the negative relationship between HSR operation and wastewater is stable.

Table 4. Endogenous test results.

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	Ols_no_Train Wastewater	**Ols_with_Train Wastewater**	**TSLS Wastewater**	**LIML Wastewater**	**GMM Wastewater**	**IGMM Wastewater**
HSR		−0.146 ***	−3.327 *	−3.327 *	−3.327 *	−3.327 *
		(−3.52)	(−1.83)	(−1.83)	(−1.83)	(−1.83)
Constant	−2.967 ***	−3.127 ***	−6.593 ***	−6.593 ***	−6.593 ***	−6.593 ***
	(−7.49)	(−7.77)	(−3.17)	(−3.17)	(−3.17)	(−3.17)
Control	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
City	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.491	0.493	/	/	/	/
Wald chi2	/	/	1076.6 ***	1076.6 ***	1076.6 ***	1076.6 ***

Note: z-statistics in parentheses. *** $p < 0.01$, * $p < 0.1$.

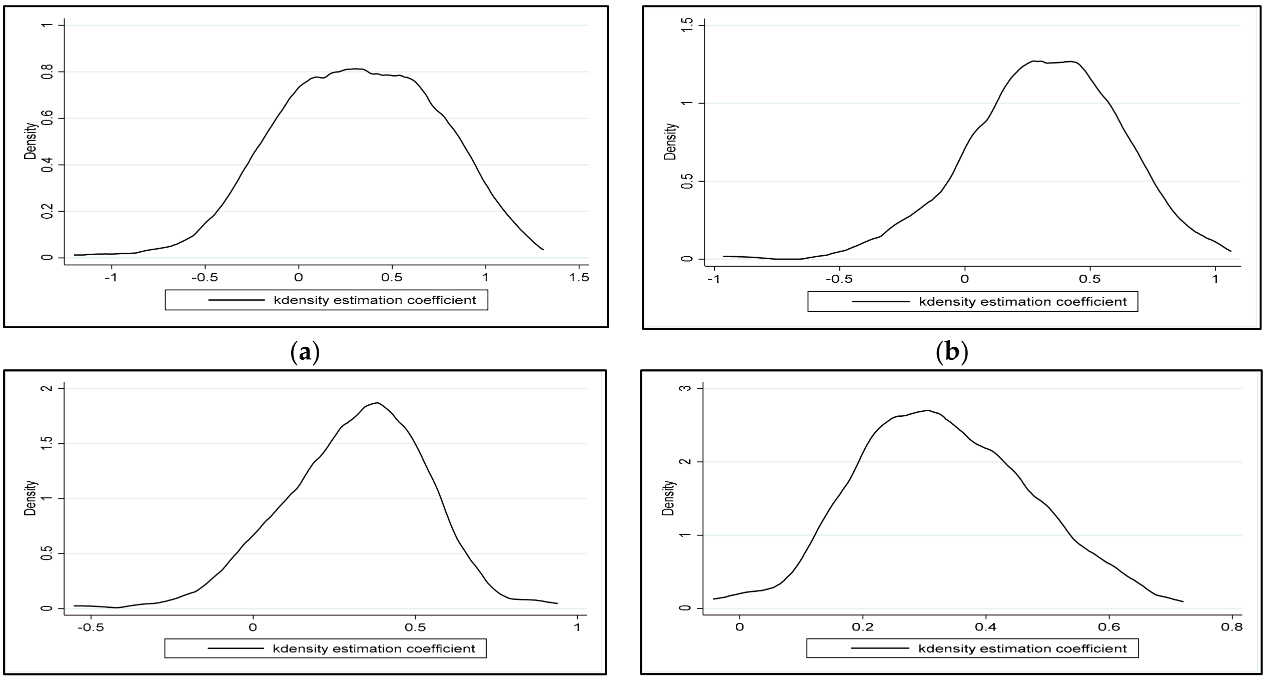

Figure 3. Placebo tests. (**a**) Placebo results of 50 observations. (**b**) Placebo results of 100 observations results. (**c**) Placebo results of 200 observations results. (**d**) Placebo results of 400 observations results.

4. Mechanism Tests

This study proposes that the effect of the high-speed railway is driven by social pressure. To test this mechanism, we adopted the moderating method, which assumes that if the core logic is correct, then the effect may be strengthened or weakened in particular contexts that are aligned with the primary logic. Then, we provide two conditions that were used to verify our explanation.

First, if HSR operation reduces wastewater discharge by increasing social pressure, then the impact of HSR operation should be weakened in cities where the economic development level is high. Traditional views posit that economic growth results in harmful environmental effects [44]. Countries or cities attempt to promote economic development through loose environmental regulations, thus remaining competitive. With the development of the economy and society, economic development drives technological progress to reduce pollution. On the other hand, as economies grow, consumers are more likely to have a high demand for environmental protection and cleaner products and will oppose polluting and irresponsible firms [45]. Therefore, if the economic development level in a city is high, then the shock of the operation of high-speed railways on wastewater discharge will be weakened.

Model 1 in Table 5 shows the results of the interaction term between HSR operation and economic development (GDP). The results show that the economic development level has a pronounced influence on HSR operation and wastewater discharge. In order to directly observe the direction of the influence, Figure 4 indicates the effect of economic development. These results reveal that, in the case of low economic development, HSR operation has more substantial influence on wastewater discharge than in the case of high economic development.

Table 5. The moderating effect.

	Model 1	Model 2
Variables	**Wastewater**	**Wastewater**
HSR	−1.156 **	−0.075 **
	(−2.42)	(−2.49)
HSR × GDP	0.318 ***	
	(6.27)	
GDP	0.066 **	0.338 ***
	(2.29)	(6.75)
HSR × Internet		0.010 **
		(2.00)
Internet	0.032 *	0.028
	(1.67)	(1.44)
Constant	1.592 **	1.419 **
	(2.55)	(2.29)
Control	Yes	Yes
Year	Yes	Yes
City	Yes	Yes
N	3003	3003
Wald chi2	580.91 ***	582.66 ***

Note: *z*-statistics in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

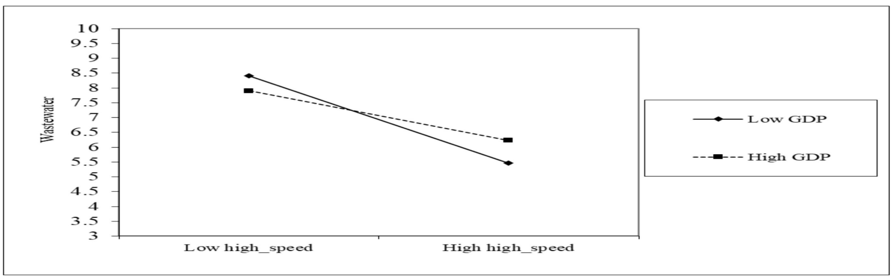

Figure 4. The moderating effect of GDP.

Second, social pressure is mainly exerted by shareholders, governments, and consumers [46,47]. In the information era, the main channel to obtain information is the Internet. Therefore, in a city, the greater the number of people using the Internet, the more rapid the communication of information, resulting in more social attention on firms. Therefore, in cities with high level information transparency, stakeholders can quickly master the information about wastewater discharge of firms. Then, the shock of high-speed railways on the wastewater discharge will be weakened in these highly transparent information cities. Model 2 in Table 5 shows the influence of the ratio of Internet users on HSR operation and wastewater discharge. Figure 5 shows the direction of the moderating effect of the Internet. In the case of a low ratio of Internet users, the HSR operation has a more pronounced influence on wastewater discharge than in the case of a high ratio of Internet users.

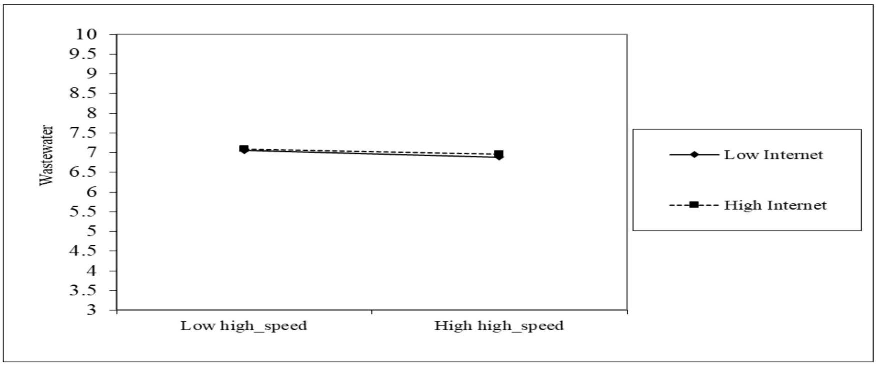

Figure 5. The moderating effect of Internet users.

Overall, the results of moderator variables verify that the proposed mechanism of this study is reasonable, which supports the relationship between high-speed railways and wastewater discharge.

5. Discussion

In this study, a quantitative method was used to evaluate the effects of high-speed railways on industrial wastewater discharge in China. The top–down rapid expansion of high-speed railway construction potentially causes exogenous variation in cities' external pressure that does not rely on industrial development or the resulting wastewater discharge across regions. The empirical results show that the development of high-speed railways can reduce industrial wastewaters, and this reduction effect is weakened in cities with a well-developed economy or information environment.

The contribution of this study to the literature is two-fold. First, a growing number of studies have emphasized the threats and risks of industrial wastewaters for the sustainable development of human beings and accordingly suggested various countermeasures to reduce them [16,48,49]. These works have not addressed the role of transport infrastructure [50]. With the rapid development of high-speed railways in the past three decades, particularly in China, scholars have started to link the construction of these bullet trains to water resources and the environment and have largely emphasized the negative effects of high-speed railways on the water system [26,31]. Our study thus extended this line of inquiry by quantitatively examining the impact of high-speed railways on the discharge of industrial wastewaters in the daily operation stage instead of qualitatively studying the construction stage. Importantly, our findings demonstrate that the high-speed railway has a positive effect on sewage discharge reduction. Second, this study also contributes to the understanding of the broader effect of high-speed railways on a global scale. Most papers, which are largely based on China, Japan, Europe, and the US, assess HSR projects from a wide range of social aspects, such as the economy, corporate location selection, environment, and innovations [21,32,37]. Our study adds to this body of literature by investigating the effect of the HSR on industrial wastewater discharge.

Some important implications may be drawn from our study. First, for water management, our study illustrates the ability of "soft power" to reduce water pollution. This differs from previous studies which have focused on important "hard power" aspects, such as techniques. With economic and social development, including the information environment, the tools to reduce water pollution and ensure its safety can be enhanced, with increasing emphasis placed on social roles, including ordinary people, the press, and other third-party entities, such as non-governmental organizations (NGOs). For the development of transport infrastructure, such as high-speed railways, policymakers should comprehensively evaluate the effect of developing bullet trains and carefully design the road in order to enhance its positive effects while limiting its social concerns. More attention should be paid to industry-heavy cities in terms of reducing wastewaters when HSRs are introduced to the cities.

Our study is not without limitations. First, this study was based on Chinese cities, and the results may not be generalizable to other countries. Second, different industries have different characteristics, including the propensity and intensity to produce wastewaters, and how this heterogeneity among industries influences our results is not clear. Third, similarly, although we controlled for several factors in cities, important city characteristics may have been missed, which could influence the interpretation of our results and should be explored in future studies.

6. Conclusions

This study assessed the effect of high-speed railways on industrial wastewater discharge in China. Various methods were used, including regular regressions, time-varying DID, and instrumental variable method. The main findings are as follows: First, the operation of a high-speed railway was negatively related to the reduction in industrial wastewater discharge in cities. Second, the negative correlation between high-speed railway and city industrial sewage discharge reduction becomes weaker in economically developed cities. Third, the negative correlation between a high-speed railway and city industrial sewage discharge reduction becomes weaker in cities with transparent information environments.

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