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The impact of water resource taxes on total factor water efficiency

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ABSTRACT

Widespread promotion of resource tax reform is of critical importance in China's efforts to promote resource conservation and speed up the development of a more ecological planet. Using the Differences-in-Differences (DID) approach, this article empirically assesses the impact of water resource tax reform on total factor water efficiency and its mechanism of action in order to examine the effect of China's water resource tax reform policy from 2010 to 2019. According to the study, water resource tax reform enhances total factor water efficiency substantially. Following a battery of robustness tests, this conclusion remains valid. Further examination of the policy's mechanism finds that it encourages increases in total factor water efficiency through increasing marketization, enhancing innovation capabilities, supporting industrial structure upgrades, and strengthening the intensity of environmental regulations. The research in this article provides a basis for decision-making and so further promotes the pilot policy of water resource tax reform across the country.

Key words: DID, Total factor water efficiency, Water resource tax reform

HIGHLIGHTS

- We analyze the effect of resource tax reform on total factor water efficiency.
- We use the meta-frontier technique to measure total factor water efficiency.
- Water resource tax reform significantly improves total factor water efficiency.
- We analyze the effect mechanism of water resource tax reform.

1. INTRODUCTION

China is a water-stressed country, with per capita water sources accounting for less than a quarter of the global total. According to the United Nations, it is one of the world's 13 water-scarce countries. At the same time, China's water resources are distributed in an extraordinarily unequal temporal and geographical pattern. The Huaihe River Basin and its environs account for 63.5% of the total land mass but only 19% of its water supplies; the Yangtze River Basin and its environs account for 81% of the country's water resources and yet only 36.5% of its arable land[1]. Furthermore, not only is China's water resource utilization power low, but there is also a pervasive waste problem. The most recent data from the Ministry of Water Resources show the repetition rate of industrial water use in China is 30–40%, compared to 75–85% in developed countries; the average utilization

[1] https://water.chd.edu.cn/wgszygk/list.htm

coefficient of agricultural irrigation water in China is about 0.45, compared to 0.7–0.8 in advanced countries; the water loss rate of the urban water supply network is more than 30%, resulting in a large loss of water resources[2].

China has implemented a matching price scheme to reduce water resource waste and wasteful water consumption. In collaboration with multiple ministries and commissions, the China Development and Reform Commission in 2013 launched the *Notice on Issues Concerning Standards for the Collection of Water Resource Fees*, a directive that deals with the methods for managing standards for the collection of water resource fees. In May 2016, The Ministry of Finance and the State Administration of Taxation jointly released the *Notice on Comprehensively Promoting Resource Tax Reform* (hereafter referred to as the 'Notice'), declaring that, in July 2016, China would begin promoting a complete reform of the resource tax. According to the requirements of the notice, China would carry out a water resource tax reform pilot project, leading off with a pilot project in Hebei. Later, the pilot water tax reform would be expanded to nine other provinces (autonomous regions and municipalities), including Beijing.

The current water resource tax is a tax designed to safeguard water resources and is paid by units and people that exploit, process, use and pollute water resources in China. Water resource fees were previously one of the main economic levers reflecting the scarcity of water resources. However, there were issues with the process of developing and implementing water resource fee policies. Due to both the limitation of collection and the limitation of management institutions and personnel, the collection of water resources fees lacked the necessary rigidity, as well as the effective means, to prevent either delays or refusals to pay. Furthermore, the water intake was separate from the payment obligation. Water resource tax reform, on the other hand, is a reform measure that converts water resource fees into taxes. The purpose of the 'fee to tax' is to incorporate it into the fiscal and taxation system and make effective use of the role of leverage. The water resources tax, according to the Notice, is levied on a volume basis. Differential tax rates guide the preferential use of surface water and the strict limitation of groundwater. The Notice established the model of tax collection and management as that of 'tax collection and management, water conservation verification, independent declaration, and information sharing.'

Since the promulgation of the water resource tax, we cannot help asking whether it has improved water use efficiency. If it improves water use efficiency, what is its mechanism of action? This article attempts to investigate these issues both theoretically and empirically. The minimal contribution of this article, when compared to earlier studies, is in large part explained by the following three statements: First, this article investigates how changes in water resource taxes affect total factor water efficiency. Second, to calculate total factor water efficiency, this research applies the super-efficient Slack-Based Model (SBM) and the meta-frontier technique. Third, the DID approach is used to experimentally investigate the influence of a change in water resource tax on total factor water efficiency and its process.

2. LITERATURE REVIEW

The tax placed on entities and individuals who mine minerals and salt in China is known as the resource tax. Resource tax reform has the potential to reshape the economic growth model, increase fiscal income, and promote local economic development. When it comes to research on the influence of resource capital structure on profitability, the main points of view are divided into two categories: 'following costs' and 'generating productivity.' According to the 'follow the cost principle,' environmental restrictions increase company production costs but do not enhance production performance or economic growth and may even have a

[2] http://news.10jqka.com.cn/20130717/c522797853.shtml

restraining effect (Christainsen & Haveman, 1981). Yu *et al*. (2019) investigated Chinese coal resource tax reform and discovered that, as resource tax burdens rise, output falls, resulting in a negative relationship between Gross Domestic Product (GDP) and higher tax rates. Jiang *et al*. (2020) investigated the iron ore resource tax reform and discovered that a rate of 3–6% has a negative impact on economic growth and consumer welfare. Hu *et al*. (2021) used Computable General Equilibrium (CGE) simulations to determine that increasing the resource tax rate by 50% would reduce China's GDP by 0.1%. On the other hand, the 'productivity increase theory' believes that environmental regulations can stimulate innovation and productivity levels to a certain extent, offset the constraints of increased costs, and promote economic growth (Brunnermeier & Cohen, 2003). For example, Mazzanti & Zoboli (2009) looked at the efficiency of environmental regulation and labor productivity in Italy and discovered that environmental regulation laws can boost enterprise productivity and influence economic gains.

The relationship between resource tax policy and energy utilization efficiency has been the focus of various papers in the literature, but there are certain controversies surrounding the evaluation results. The main conclusions can be divided into three categories: The first believes that resource tax policy improves resource utilization efficiency. This is primarily because a resource tax can effectively serve as a tax regulator, suppressing unreasonable resource demand and waste and promoting resource efficiency. Jin *et al*. (2019) analyzed industry panel data from 2003 to 2011 to find that resource tax reform is beneficial to optimizing industrial structure (IS), reducing resource demand, and driving energy efficiency improvements. Ji *et al*. (2021) assessed the efficiency of resource tax policies using the slack-based measure, integrating data envelopment analysis method (SBM-DEA) criteria. They discovered that pollution control costs and energy demand have a beneficial impact on efficiency, demonstrating that overall, resource tax policy efficiency, although fluctuating, has increased in most provinces. Tan & Lin (2020) reached the same conclusion, namely that resource taxes can significantly improve energy efficiency, which is relevant to studies of environmental taxes in non-OECD (Organization for Economic Co-operation and Development) countries.

The second group of findings in the literature reaches a different conclusion, claiming that resource tax policy is ineffective. This could be because a resource tax rate that is too high or too low will distort the market price of resources, making it difficult to enhance resource extraction and difficult to use efficiently. Research by Li & Shi (2014) found that, due to the transfer of revenues from resource-based enterprises and the central government to local governments, low tax rates, narrow taxation scopes, and unreasonable price mechanisms will be combined, hindering the realization of the environmental goals of reform. The main significance of the resource tax reform is to support local finances, not to save energy and reduce emissions.

A few papers in the literature that fall into the third category believe that, although the current resource tax policy has achieved certain results, the effect of the system is short-lived or limited. Due to both the various complex influencing factors in the real world and the possible imperfections of the policy itself, the policy's utility may be limited to the near term and have no long-term consequences. Ge & Lei (2018) conducted research on rare earth resource tax reform by establishing a CGE model. The findings indicate that resource tax policies would raise rare earth prices while reducing demand, but the market reaction to these theories is short-lived in reality. For long-term effects, other factors must also be considered.

In the evaluation of the effect of resource tax implementation, the methods used can be divided into three categories: The first method, the current mainstream research method, is to consider the policy as if it were a natural experiment, use the DID method to evaluate and then guarantee the robustness of the results by the propensity score matching method (Fan, 2021). The second method primarily employs numerical simulation methods, such as CGE, to investigate the impact of regional resource tax policies (Lin & Jia, 2019; Zhao & Guan, 2019). Some researchers have used the CGE model to investigate the effects of various resource tax rates on the economy. The third method is to construct a more reasonable control group through the use of composite control methods and weights (Wang *et al.*, 2019a, 2019b). The DID method is a macroeconomic method that calculates findings using an empirical or quasi-experimental design (Ashenfelter, 1978). As it can effectively differentiate the genuine results of policy influence while controlling ex-ante disparities between study objects, this article adopts the DID method to conduct water resource tax research.

To date, research on water resource tax reform has primarily focused on two aspects. The first is the effect water resource tax reform has on both water consumption and water efficiency in pilot areas. The current literature mostly analyzes water efficiency from the demand side, measuring it by dividing GDP by water consumption. Yang *et al.* (2020) examined the impact of water resource tax reform using two measures: water usage per 10,000 yuan of GDP and water efficiency. Zhao & Zhang (2021) found through further research that, although the current water resource tax reform has improved water use efficiency, it has had no effect on the total amount of water used. The second concerns the issues that have arisen as a result of the pilot water resource tax reform. At present, the Chinese water pricing mechanism is in the exploratory stage and there are many difficulties in the reform of water resources ad valorem calculation. Water resources tax ad valorem calculation can only be introduced if the pricing system for water resources has been perfected. The research of Berbel *et al.* (2019) on water resource taxes formulated by European Union (EU) countries found that, despite a certain degree of effort, taxes are still very low due to the lack of relevant regulatory mechanisms.

The majority of research papers focus on water use efficiency; just a few studies look at the effect of water tax reform on total factor water use efficiency. Total factor water resource utilization efficiency is a statistic that assesses the economic and environmental efficiency of water resource exploitation. It has a broader and more complex meaning than water efficiency. In accordance with the principles of sustainable development, undesirable outputs are considered in addition to desirable outputs to make the research results more realistic and instructive. The findings indicate that water tax reform may still considerably enhance total factor water efficiency, demonstrating that the DID model's regression result is not due to sample selection bias and that the conclusion is rigorous and credible.

3. MECHANISM ANALYSIS

Based on environmental regulation theory and the way China's water tax reform has been implemented, we believe that reform of the water resources tax could be conducive to enhancing both the water-saving awareness and motivation of enterprises and other social entities (Figure 1). This would stimulate the vitality of market-oriented water rights trading, speeding up technological innovation, optimizing water use structure, reducing unreasonable water demand and thus effectively improving total factor water efficiency. Specifically, water tax reform can have an impact on total factor water efficiency through market-based, innovative, structural and regulatory effects.

Water tax reform → Formation and improvements to the market mechanism → Market effect → Improvements in total factor water efficiency. The market-based mechanism, brought about by the modification of the water resource tax, is a key step toward increasing total factor water efficiency. By fully implementing the reforms of clearing fees and establishing taxes and ad valorem, water resource tax reform can straighten out the relationship between resource taxes and fees, thereby establishing a standardized, reasonable, and efficient resource tax system. This will allow the organization's money to be used more efficiently, manage the economy, encourage resource conservation, and play a part in ecological environmental preservation. In their study of carbon emissions trading markets, Wang *et al.* (2021) discovered that as long as the government concurrently pursues the dual goals of lowering carbon emissions and boosting renewable energy, the market may help policymakers achieve higher efficiency. Comprehensive water resource tax reform helps to improve the price formation mechanism of water resource goods and allows water pricing to more accurately reflect changes in the market. This

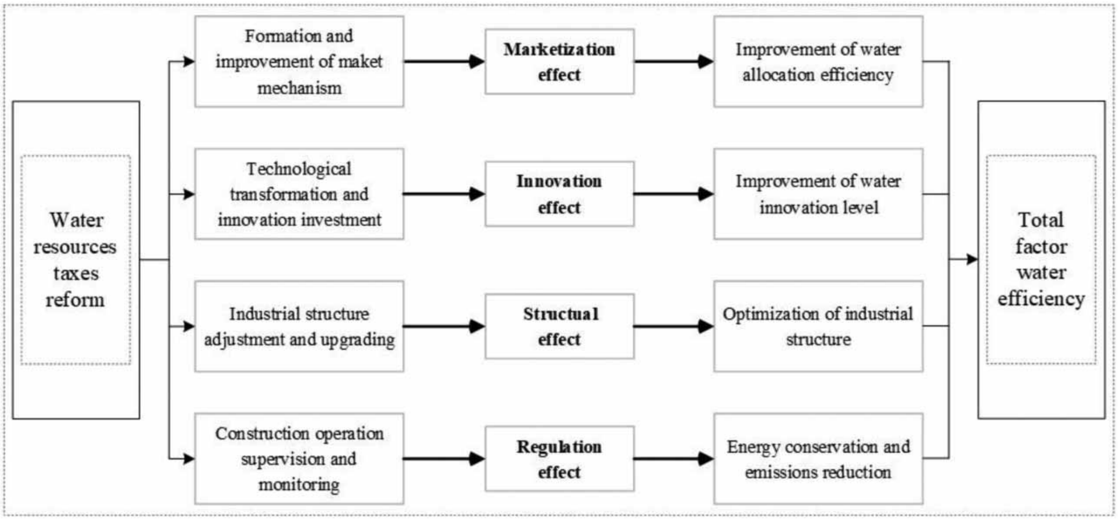

Fig. 1 | Action mechanism diagram (generated by Visio).

can assist in properly marketing water resources and more completely play a tax leverage function in controlling water resource consumption, which supports water use efficiency improvement.

Hypothesis 1: Water resource tax reform can help increase total factor water efficiency through a marketization effect.

Water tax reform → Technological transformation and innovation investment → Innovation effect→ Improvements in total factor water efficiency. First, although it exempts or reduces a water resource tax, water resource tax reform generally raises the standard tax for both high water-consuming industries and special industries, thereby encouraging enterprises to increase investment in technological transformation and encouraging them to upgrade their technology. Zhao *et al.* (2022a, 2022b) found that environmental policy plays an important role in improving technological innovation. Water reuse should be improved, and water conservation should be promoted. Second, pilot areas continue to organize the implementation of key energy-saving projects and, by doing so, promote the large-scale production and application of major energy-saving technology products. Finally, by increasing investment in innovation through special fiscal transfer payments, tax cuts and interest discounts, pilot areas not only carry out joint research on key technologies, but also promote both technology transfers and achievement transformation. This way, they gradually realize sustainable development centered on scientific and technological progress and innovation.

Hypothesis 2: Water resource tax reform can promote improvements in total factor water efficiency through an innovation effect.

Water tax reform → IS adjustment and upgrading → Structure effect → Improvements in total factor water efficiency. Water resources tax reform results in the transformation and upgrading of economic structure, which helps to increase overall factor water efficiency. Water resource tax reform increases the burden on high water-consuming companies, especially the less competitive companies and zombie companies that face greater pressure; this speeds up their elimination and is supportive of both broader IS change and the upgrade to a service-oriented model. On the other hand, water resource reform grants reduced tax rates or water resource tax exemptions for projects and technological processes that can save resources and improve resource utilization efficiency. Zhao *et al.* (2022a, 2022b) empirically explored the relationship between energy efficiency and China's IS adjustment and found that IS upgrading can effectively improve efficiency. This prompts industrial enterprises to increase water-saving investments to improve water use efficiency, adjust water use structures, and change their ways of taking in water, thereby effectively curbing unreasonable water demand and helping transform and upgrade the IS to a more high-tech one.

Hypothesis 3: Water resource tax reform can promote improvements in total factor water efficiency through a structural effect.

Water tax reform → Supervision and monitoring of construction and operations → Regulatory effect → Improvements in total factor water efficiency. The reform of the water resources tax requires provincial governments to strengthen their leadership in the reform process. The financial department takes the lead in formulating reform plans and provides the policy basis; the tax department strengthens tax collection and management and optimizes the tax environment; the water conservancy department scientifically approves the amount of water and provides information support; the development and reform, housing construction, and other departments at all levels actively cooperate and advance in an orderly manner to design a 'water conservancy approval, tax declaration, land tax collection, joint supervision, and information sharing' water resource tax reform model. By examining the influence of environmental regulation on China's industrial green total factor productivity, Cheng & Kong (2022) found that a number of policy combinations are more favorable to the growth of total factor productivity. The fiscal and taxation departments in the pilot areas should, in a timely manner, form a joint force with relevant departments, go to the grassroots to strengthen investigation and research, track and analyze the pilot's operation and then report the progress of the pilot work and major policy issues to the Ministry of Finance, the State Administration of Taxation, and other departments.

Hypothesis 4: Water resource tax reform can help improve total factor water efficiency through a regulatory effect.

4. METHODOLOGY

Using the pilot provinces for water resource tax expansion as a research sample, we undertake an in-depth analysis, followed by a set of robustness tests, on the way water resource tax reform effects all the components and the path it takes. Furthermore, given the scarcity of current research on heterogeneity, this work investigates the impact of regional and resource endowment heterogeneity, providing a solid empirical framework and particular policy reference for future water tax reform pilot research. The instrumental variable technique is employed in this work to eliminate the endogenous issue in the experimental group's city selection.

4.1. Calculation model

Data envelopment analysis, a modeling method based on linear programming and distance functions, includes several models such as CCR, BCC, and SBM. The first two are radial distance functions but SBM is non-radial; it is generally believed that SBM solutions will be a little better.

We employ a meta-frontier approach and a super-efficiency non-radial directional distance function to measure total factor water efficiency, based on the assessment of total factor energy efficiency (TFEE) in Cheng *et al.* (2020). TFWE is calculated using indications such as input, desirable output, and undesirable output. Input indicators include: (1) Resource input is one of the input indicators. To illustrate the resource input, each province's total water usage is used. (2) Capital investment is chosen to express capital investment as a fixed asset investment amount. (3) Labor input is calculated using the number of employees in each province. Output indicators include: (1) Desirable output. This paper uses real GDP calculated at constant prices in 2010 as the desirable output of each province. (2) Undesirable output. In this paper, domestic wastewater discharge and industrial wastewater discharge are used to represent undesirable output.

4.2. Econometric model

Since the reform of the water resources tax, its impact on water efficiency in various regions may be derived from policy effects on the one hand and time effects, due to changes in time trends, on the other. Correct analysis of policy effects is particularly important. The DID technique is frequently utilized in policy and effect evaluations because it can successfully detect policy effects while avoiding the inherent difficulties that have plagued prior methods. This research employs the DID approach to control variances in different locations by using various control variables to see if the pilot areas have fulfilled their goal of boosting total factor water efficiency after water resource tax reform (Wang *et al.*, 2019a, 2019b). The model is set out as follows:

$$TFWE_{i,t} = \alpha + \beta time_t \times treated_i + \gamma time_t + \delta treated_i + \varphi X_{i,t} + \mu_{i,t} + \pi_{i,t} + \varepsilon_{it} \tag{1}$$

where $TFWE_{it}$ is the explanatory variable, denoting total factor water efficiency; i indicates the city, and t represents the year; α is a constant term, β is the interaction term's coefficient; Υ and δ are the coefficients of their corresponding items; $treated_i$ is a dummy variable of the control group and the treatment group that indicates whether city i has implemented water tax reform. When it is the control group, the value is 0, and when it is the treatment group the value is 1; $X_{i,t}$ are macroeconomic control variables; time is a dummy variable of the pilot expansion policy. The value is 0 before the pilot expansion in 2017, and is 1 in 2017. The interaction term represents the implementation effect of the water resource tax, which is an explanatory variable of the model. $\varepsilon_{i,t}$ is a random disturbance term, $\pi_{i,t}$ is time fixed effect, and $\mu_{i,t}$ is regional fixed effect.

4.3. Variable description

4.3.1. Core explanatory variables

The year of implementation of the water tax reform is utilized as a time dummy variable (Time) in this study to examine the changes in total factor water efficiency between the experimental and control groups before and after the reform. Assign 1 if a local-level city announces a water resource tax reform at time t; otherwise, assign 0 if all else fails. Then add the geographical dummy variable (Treat) to check if the policy affects various groups differently. Finally, as a key explanatory variable, this paper introduces the interaction term (Time × Treat), made up of time dummy variables and regional dummy variables, to assess the true changes in total factor water efficiency of the experimental and control groups under implementation of the policy.

4.3.2. Control variables

In addition to water resource taxes, there are other macroeconomic variables that affect the total factor of water efficiency. This paper also considers the impact of water resources endowment, population size (PS), technology level, fiscal expenditure (FE), urbanization rate (UR), and economic development level, among which are:

Water resources endowment (WR): The availability of water resources is an important component in determining a region's water efficiency, yet the availability of water resources and water efficiency may have a negative relationship. The curse effect of resources is not only reflected in economic development but also in resource utilization efficiency (Wang & Shen, 2016). To describe the endowment of water resources, this paper selects the amount of water resources per capita in each province.

PS: The impact of population growth on the environment has obvious dis-economies of scale. Population expansion both brings direct environmental pressure and increases consumption of exhaustible resources;

population growth strengthens the demand for industrial products and brings higher levels of pollution (Dietz & Rosa, 1997). This article uses the year-end population density of each province as a measure of this variable.

Technical level (TL): Technological investment is a firm basis for technology growth; improvements in total factor water efficiency are inextricably linked to technological advancement. Technological advancement may minimize water usage and resource input, as well as undesirable outputs such as wastewater discharge (He *et al.*, 2020). The research and development budgets of each province at the end of the year are used as the benchmark to measure the technological level in this study.

FE: FE reflects a country's policy inclination and is usually dominated by either expenditure on people's livelihood or expenditure on technological innovation and development. The larger the government's support for scientific and technological innovation, as well as investment in the basic livelihoods of people, the better the sewage treatment rate or the promotion of water resource recycling and the greater the positive influence on total factor water efficiency (Chen *et al.*, 2018). The annual public budget spending of each province is used to describe FE in this article.

UR: The UR significantly increases water consumption in the region. The urbanization of the population is not only a change in household registration, but also a change in lifestyle. Compared with rural residents, urban residents use more water-intensive equipment. As a result, the per capita water consumption of urban residents tends to be higher (Li *et al.*, 2020). The UR is described in this article by employing the fraction of the people living in cities in each province.

GDP: The impact of economic expansion on environmental quality is complicated and, to some extent, unknown. Regional economic expansion may be accompanied by an overuse of natural resources, accelerating environmental degradation but, when economic growth reaches a certain level, the willingness to use environmental resources in exchange for economic growth will gradually decline (Grossman & Krueger, 1995). This article uses GDP per capita as a measure of this variable.

4.3.3. Mechanism variables

Marketization level (ML): The overall level of marketization reflects the degree of facilitation of the flow of factors from low-efficiency sectors to high-efficiency sectors. A high level of marketization gives enterprises sufficient autonomy to enhance their enthusiasm and is more conducive to the effective implementation of policies (Albrizio *et al.*, 2017). This article adopts the general marketization index as the proxy variable to quantify the extent of marketization.

Technological Innovation Level (TIL): Resource taxes, as a market-based environmental regulation mechanism, will have an impact on business investment and R&D improvements in technological innovation, spurring pollution emission reductions, with green innovation as the starting point. The number of valid invention patents in each province each year is used as a proxy for technical innovation in this study.

IS: Not only is water efficiency in different regions influenced by IS, but there are also significant variations in water efficiency between industries. Calel & Dechezleprêtre (2016) found that an IS that focuses on industry is more likely to pollute the region's water and produce more unwanted output. As a measure of this variable, the proportion of secondary industry to tertiary industry is used in this article.

Intensity of regulation (RI): Environmental standards must be followed in order for resource taxes to be implemented effectively. Policy design must be reasonable in order for environmental regulations to be implemented effectively; this requires a solid legal system as a support to strictly implement the various policies. In regions with higher regulatory intensity, the environmental effects of resource taxes may be more significant (Cai *et al.*, 2016). This article uses the water resources reuse rate of each province as a proxy variable.

4.4. Data sources

The *China Statistical Yearbook*, the *China City Statistical Yearbook*, and the various provincial statistical yearbooks available were used to compile the sample data for this article, all of which contain annual panel data for cities above prefecture level from 2010 to 2019. The experimental groups mentioned in this article that will execute water tax reforms include Beijing, Tianjin, Shanxi, Inner Mongolia, Henan, Shandong, Sichuan, Shaanxi, and Ningxia. Anhui, Guizhou, Jiangsu, Liaoning, Fujian, Jilin, Jiangxi, and Shanghai, with the 20 provinces that have not implemented water tax reforms, including Chongqing, classified as a control group. The descriptive statistics results are shown in Table 1.

5. EMPIRICAL RESULTS AND ANALYSIS

5.1. Parallel trend test

This article employs the event analysis method to conduct a parallel trend test to determine whether changes in the trend of total factor water efficiency in the treatment and control group provinces were identical before the water resource tax reform policy was implemented, i.e., whether the important premise of using the DID method is met. The horizontal axis in Figure 2 indicates the years before and after the policy was adopted (the empirical findings of this research were obtained by stata16). For example, 0 means the base year, generally the year before the policy is implemented, that is, 2016; 1 means 1 year after the base year (2017), which is the year the policy was implemented; −2 means the first 2 years of 2016 (2014), that is, the year that the policy has not been implemented; and so on; the vertical axis represents the difference between the treatment group and the control group on the outcome variable. The figure shows that prior to the pilot expansion of the water tax reform in 2017, the difference between the two groups oscillated around 0, indicating that there was no significant difference between the treatment group and the control group that could be compared, which is consistent with the hypothesis.

5.2. Benchmark regression results and analysis

The benchmark regression results are shown in Table 2. Column (1) shows the regression results before the addition of control variables, while Column (2) shows the regression results after the addition of the

Table 1 | Descriptive statistics of main variables.

	Before the pilot expansion			After the pilot expansion	
Variables	**Unit**	**Treatment group mean**	**Control group mean**	**Treatment group mean**	**Control group mean**
WR	m^3	845.41	2,845.46	812.78	2,831.17
PS	person/km^2	2,757.29	2,872.86	2,998.49	2,918.50
TL	hundred million	367.68	309.26	517.76	495.93
UR	%	58.27	54.48	63.66	59.88
FE	hundred million	3,998.28	3,878.34	6,125.55	6,087.33
GDP (per capita, ¥)	ten thousand	4.86	4.26	6.96	6.23
ML	–	6.41	6.29	–	–
TIL	piece	8,834.25	15,180.36	24,292.56	42,259.53
IS	%	1.07	1.00	0.77	0.75
RI	%	74.65	60.00	72.61	62.75
TFWE	–	1.00	1.11	1.12	1.11

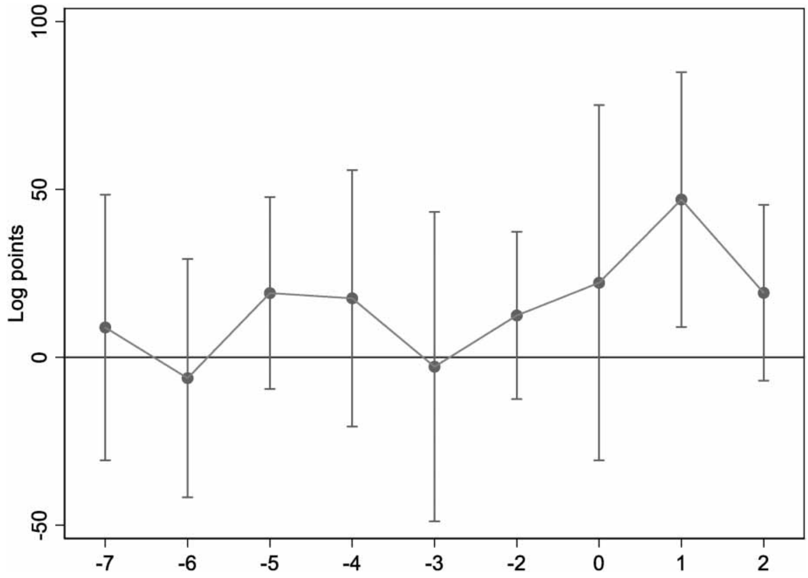

Fig. 2 | Parallel trend dynamic effect diagram.

Table 2 | Benchmark regression results.

	(1)	(2)
Key	0.1708***	0.0925*
	(0.0494)	(0.0490)
PS		−0.0003*
		(0.0002)
WR		0.0002***
		(0.0001)
TL		0.0001***
		(0.0001)
FE		−0.0001*
		(0.00002)
UR		0.0140
		(0.0085)
GDP		0.0162
		(0.0268)
Constant	0.8748***	1.2447
	(0.0046)	(0.8002)
Year fixed effects	YES	YES
Regional fixed effects	YES	YES
N	290	290
R^2	0.0282	0.0969

Note: Standard errors in parentheses.*$p < 0.10$, ***$p < 0.01$.

above-mentioned control variables (this expression is also used later). Both demonstrate that the water tax reform pilot area's total factor water efficiency is much higher than the other locations, demonstrating that the difference between the experimental and control groups is persuasive. This is mostly due to the government's adoption of resource tax policies and regulations to form a concept of water conservation at the source to reduce water waste; this supports the improvement of total factor water efficiency.

5.3. Endogenous problem: instrumental variable method

The DID approach, which can successfully address the endogenous problem, is based on the random selection of water tax reform pilot provinces from all provinces. This is obviously not the situation in reality. As a result, the instrumental variable (IV) technique is employed to mitigate the effects of endogeneity to the greatest extent feasible. Precipitation has been chosen as the IV in this article for the following reasons: (1) When the total amount of water consumption is constant, cities with less annual precipitation have fewer water resources and tend to adopt stricter environmental regulations, so they have a better chance of being chosen as a pilot city for water resource tax reform. This is in line with the IV correlation assumption. (2) Precipitation is influenced by meteorological and geographic factors and can thus satisfy the assumptions about exogenous instrumental variables.

Table 3 displays the estimated outcomes of instrumental variables. The natural logarithm of yearly precipitation in the sample city is represented by IV. The first stage of regression occurs when the IV coefficient of the IV is significant, suggesting that it meets the correlation condition. In the second stage of regression, policy is still important, and the direction of action on the total factor water efficiency of the explained variable is in line with the regression baseline, indicating that after eliminating the endogenous problem in the experimental group city selection, water resources are available.

5.4. Robustness test

5.4.1. Placebo test

The placebo test is based on the idea of using a dummy policy occurrence period or experimental group to see if the policy impact may be attained. The goal is to make sure that other unobserved factors are not causing the policy effect in the benchmark regression. In this study, several virtual treatment groups were randomly selected from all samples to perform a regression consistent with the benchmark regression, providing a strong assurance

Table 3 | Estimation of instrumental variables.

Variables	First Policy	2SLS TWFE
Key		0.1037* (0.4258)
IV	− 0.0760** (0.0318)	
Controls	YES	YES
Constant	0.2561 (0.2075)	0.8177*** (0.1379)
Cragg–Donald Wald F-statistic	10.27	
N	290	290

Note: Standard errors in parentheses.
*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

of the original research findings. The kernel density distribution map of the coefficients and the descriptive statistics of the virtual coefficients are produced after 1,000 samplings. The mean and *t* value of 1,000 dummy coefficients are provided in Supplementary material, Table A1. Supplementary material, Figure A1 shows a graph of the kernel density estimate of regression coefficients after randomization. The majority of the sampling estimation coefficients and t values are concentrated around 0, and the majority of the estimated parameters are not significant, indicating that the policy effect of the water resources tax reform on total factor water efficiency is unaffected by other unobserved factors. (The charts in this section are presented in the Supplementary material, Appendix.)

5.4.2. PSM test

The sample in this article includes 29 provinces from around the country; however, under normal conditions, the DID technique is prone to 'selectivity bias'. The geographical and economic disparities between the samples are enormous, as are the individual differences. As a result, the Propensity Scores Matching Technique (PSM) is used. It employs a control variable as the sample point's identification feature to match the treatment and control group provinces. After that, the DID approach is used to regress the matching results. Supplementary material, Table A2 displays the regression findings of the PSM–DID model. It can be demonstrated that the water resource tax reform continues to boost the pilot provinces' total factor water efficiency, indicating that the study's findings are still relevant.

This paper also compares the deviations between standardized co-variates before and after matching, as shown in Supplementary material, Figure A2. Observation shows that the propensity scores of the pre-matched water tax reform pilot expansion provinces and the non-pilot provinces are quite different, while the deviation of the two after matching is significantly reduced, once again proving robustness.

5.4.3. Replacement of total factor water efficiency measurement method

In order to prevent the test results from being different due to measurement method problems and thus affecting the robustness of the results, this article discusses the theory by substituting the explained variables. Based on Guo & Yuan (2020) TFEE measurement, we use the super-efficiency SBM model that incorporates undesired output to recalculate total factor water efficiency and do regression analysis. Supplementary material, Table A3 summarizes the findings. The regression results are largely consistent with the foregoing, indicating that the article's conclusions are sufficiently sound, as shown in the table.

5.5. Analysis of heterogeneity

5.5.1. Regional heterogeneity

Due to China's vast territory, there are substantial differences in economic development and IS across the country. The northern and southern regions have vastly different economic development and energy characteristics, especially in recent years. As a result, the following essay will examine heterogeneity. China is divided into three areas according to the National Bureau of Statistics standards classification: eastern, central, and western. According to the classification, Beijing, Tianjin, and Shandong belong to the eastern region; Shanxi, Inner Mongolia, and Henan belong to the central region; and Shaanxi, Sichuan, and Ningxia belong to the western region. Based on the above divisions, DID is performed to examine the regional heterogeneity of water resource tax reform. Table 4 shows the results in Columns (1)–(3). The results show that the estimated coefficients of the core explanatory variables are positive in the central region and pass the 95% significance test. Similarly, the calculated coefficients of the core explanatory factors are significantly positive in the eastern region, with the estimated coefficients being larger than those in the central region. The western area also passes the significance

Table 4 | Analysis of heterogeneity.

Variables	(1) Central	(2) East	(3) Western	(4) High	(5) Middle	(6) Low
Key	0.3256**	0.4813***	0.2929***	0.0391***	0.0742***	0.2249***
	(0.1234)	(0.1155)	(0.0764)	(0.0001)	(0.0209)	(0.0648)
Controls	YES	YES	YES	YES	YES	YES
Year fixed effects	YES	YES	YES	YES	YES	YES
Regional fixed effects	YES	YES	YES	YES	YES	YES
N	110	90	90	100	90	100
R^2	0.1044	0.1859	0.1023	0.1081	0.0976	0.1221

Note: Standard errors in parentheses.
$^{**}p < 0.05$, $^{***}p < 0.01$.

test, but with a lower coefficient than the eastern region. This illustrates that the water resource tax reform policy has a stronger impact on boosting total factor water efficiency in the eastern area than it has in the western region. This could be due to the eastern region's more developed economy and technological innovation capabilities, as well as the fact that the water tax has a greater influence on total factor water efficiency. As a result, it demonstrates that water resource tax reform is unique to each location.

5.5.2. Resource endowment heterogeneity

Dynamic changes in resource endowments have an impact on water resource utilization efficiency. Indeed, water resources are an important strategic resource, this article uses the per capita water resources of each province reported in the *2020 China Statistical Yearbook* to test the relationship between water resource endowments and policy effects in different locations under the water resource tax reform policy. It designates areas with per capita water resources above 3,000 (cubic meters per person) as high endowment areas; 1,000–3,000 (cubic meters per person) as medium endowment areas; and those under 1,000 (cubic meters per person) as low endowment areas. Results of research on the heterogeneity of water resource endowment are shown in Columns (4)–(6) of Table 4. As indicated in the table, water resource tax reform has the greatest noticeable effect on boosting total factor water efficiency in low-resource endowment areas, followed by medium-resource endowment areas and high-resource endowment areas. One factor might be that locations with little resource endowment have low-resource consumption and environmental constraints. At the same time, labor and capital are experiencing net inflows, causing TFEE to trend upward. As a result, in low-resource endowment locations, the water resource tax has the greatest impact on boosting total factor water efficiency. Regions with rich resources and high usage of resources have generally steady resource utilization and low pollutant outputs. More factors, such as labor and capital, may be allocated to resource-based industries. The technological differences between enterprises are relatively small, resulting in water resource tax reform having a relatively small impact on improving total factor water efficiency.

5.6. Analysis of transmission mechanism

Both the foregoing DID model results and a series of robustness tests confirm that whole factor water efficiency can be greatly improved by water resource tax reform. So how is this effect achieved? This article classifies and investigates this question, specifically looking at it from the point of view of four mechanisms: the market mechanism, the innovation mechanism, the industrial mechanism, and the regulatory mechanism. This article selects

Table 5 | Analysis of transmission mechanism.

Variables	Valid invention patent	Total market index	Industrial organization	Regulatory strength
Key	1.2384***	0.2997**	−0.2923***	0.3542***
	(0.0679)	(0.1225)	(0.0486)	(0.0821)
Controls	YES	YES	YES	YES
Year fixed effects	YES	YES	YES	YES
Regional fixed effects	YES	YES	YES	YES
N	290	203	290	290
R^2	0.8979	0.0547	0.1556	0.1704

Note: Standard errors in parentheses.
$^{**}p < 0.05$, $^{***}p < 0.01$.

the complete marketization index, the number of effective invention patents, the percentage of secondary industry in tertiary industry, and the reuse rate of water resources as moderating variables. From the regression results in Table 5, Hypotheses 1, 2, 3, and 4 are verified.

Based on the above transmission mechanism test, it can be seen that water resource tax reform can affect the total factor water efficiency through a marketization effect, an innovation effect, a structural effect, and a regulatory effect; this verifies the core hypothesis that water resource tax reform can promote total factor water efficiency.

6. DISCUSSION

According to the transmission mechanism analysis presented above, water resource tax reform primarily affects total factor water use efficiency via a market mechanism, an innovation mechanism, a structural mechanism, and a regulatory mechanism. In-depth analysis shows that there are two main ways for water resource tax reform to produce effectiveness: first, directly reduce exploitation and utilization of water resources at the source; second, encourage enterprise technological innovation and control undesirable output. The innovation mechanism and the structural mechanism mainly address the first two points, primarily promoting energy conservation and emissions reduction by encouraging enterprises to increase investment in technological transformation, accelerating industrial upgrading, and improving the efficiency of all factors with respect to water use. The market and regulatory mechanisms have an impact on total factor water use efficiency primarily because increased marketization facilitates rationalizing the relationship between resource taxes and fees, allowing the water resource tax to effectively play its role in organizing income, regulating the economy, promoting resource conservation and intensive use, and protecting the ecological environment. This conclusion dispels some foreign scholars' concerns about China's market-oriented reform (Allen *et al.*, 2005). Second, the high levels of environmental regulation has put some strain on businesses. Strict supervision and monitoring have prompted businesses to raise their awareness of energy conservation, invest more in sewage treatment research, and thus improve the efficiency of all factors affecting water use.

The preceding is a theoretical analysis of the water resources tax action path. In order to achieve the desired results, the tax on groundwater is higher than that on surface water during the actual operation process. To combat the phenomenon of groundwater over-exploitation, the tax on groundwater in over-exploited and severely over-exploited areas is higher than in non-over-exploited areas. Furthermore, the tax standard for golf courses, car washes, public baths, and other special industries has been significantly raised, forcing special industries to change their water use practices. Furthermore, in order to encourage high-water consumption enterprises to conserve water, the reform will double the water resource tax on excess water consumption, forcing high-water consumption enterprises such as iron and steel to increase investment and strengthen internal water management. According to the pilot area's government work report, the pilot reform of water resources tax has indeed reduced groundwater pumping to some extent, and enterprise awareness of water conservation has generally increased, achieving the central government's reform goal.

In keeping with the spirit of comprehensively promoting resource tax reform, the water resource tax will gradually broaden the scope of the pilot depending on what happens and will be rolled out nationwide when conditions are favorable. This means that the water resource tax will gradually broaden the scope of the pilot project and, in the future, will replace the water resource fee as a national tax. Water resource tax, as a type of tax, is highly standardized when compared to fees. Furthermore, the central government's tax power is highly centralized and unified. If the water resource tax is implemented across the country, the enormous gap between regions with rich and poor water resources, as well as disparities in economic and social development levels between regions, must be taken into account in order for the water resource tax to be more inclusive. Based on the study findings on the heterogeneity of water resource tax acquired in this work, the following proposals and measures are proposed:

- Promotion: Intensify the promotion of water resource tax reform pilot plans across the country and further improve the efficiency of all-factor water use in various regions. Due to the heterogeneity of the impact of this policy, the government should adjust and optimize the energy use efficiency of regions with high-, medium-, and low-resource endowments. The government should study and formulate water resource tax reform plans in pilot areas, coordinate and solve major issues in the water resources reform pilot process and guide the implementation of water resources reform pilot policies across the country.
- In terms of the market mechanism: Water resource tax reform should closely follow trends in market reform; the market-oriented nature of water resource tax reform should be fully exploited. When implementing water resource tax reform, the government should regulate the synergy effect between the government and the market while also providing necessary monitoring. Encouraging the participation of social capital and giving play to the supporting role of industry associations to enterprises should be encouraged.
- Innovation-driven aspects include both encouraging businesses to experiment with new technologies and guiding enterprises to develop in a clean and environmentally friendly direction. The key to boosting resource utilization efficiency is to establish an enterprise-led R&D innovation system, either highlighting R&D investment or technology or launching innovation funds for water recycling and utilization technologies, and expediting energy sector supply-side reform. Further measures include providing relevant policy assistance to industry and making full use of R&D innovation channels to promote the fundamentally enhancing effect of water resource tax reform on the growth of resource utilization efficiency.

7. CONCLUSION AND INSPIRATION

Based on the quasi-natural experiment of the pilot expansion policy of water resource tax reform and, using the DID method, this paper empirically analyzes the impact of the pilot expansion policy of water resource tax reform on total factor water use efficiency and its transmission mechanism. The findings indicate that this strategy contributes to increased total component water usage efficiency depending on resource endowments and geographical variability. Further examination of its transmission mechanism reveals that the policy encourages the development of total factor water usage efficiency by increasing, inter alia, marketization, enhancing technical innovation capability and changing IS. This research differs from earlier literature in that it investigates the influence on total factor water consumption efficiency. Total factor water use efficiency, as different to general water usage efficiency, combines both desirable and undesirable outputs. Furthermore, given the lack of research on heterogeneity in the available literature, this work provides specific policy references for strengthening the pilot reform of water resources tax. For example, because the effect of this policy is best in low-resource endowment regions and worst in high-resource endowment regions, it is suggested that the government should adjust and optimize energy utilization efficiency in different resource endowment regions. It should also let it be known that the key link to improving resource utilization efficiency is the establishment of an enterprise-led R&D innovation system, with an emphasis on either R&D investment or the introduction of in-house R&D technology.

The description of the measurement index of the explained variable of total factor water usage efficiency in this research shows that only two portions of industrial wastewater and household wastewater are considered in the undesirable output, whereas agricultural wastewater is not. At the time, this was primarily due to the following two factors: first, due to the high demand for agricultural water, the policy made it clear that agricultural production water within the specified quota was exempt from the water resource tax; and second, the tax on agricultural production water exceeding the quota was to be determined at a low level. As a result, it is desirable that the water resource tax will have little influence on agricultural water consumption and agricultural wastewater discharge since it will be impossible to effectively assist agricultural water users to build a water-saving consciousness. Furthermore, the aforementioned hypothesis is supported by study findings from the earlier literature, namely that the water resource tax has no major influence on either agricultural water consumption or agricultural water use efficiency. As a result, agricultural wastewater was not considered when drafting this article. This policy may be expanded and enhanced nationally in the future, and the conclusion that 'water resources tax has no substantial influence on agricultural water use' may be found untrue with the growth of agricultural economics and technology. It is therefore only a suggestion for improvements to and, potential for, this work to incorporate indicators such as agricultural water usage within the measuring range of variables. This may result in different responses in the future.

AUTHOR CONTRIBUTIONS

Y.S. did formal analysis and software analysis; wrote, reviewed, and edited the article. Z.C. conceptualized the study; did formal analysis; studied the methodology; and wrote the original draft.

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DATA AVAILABILITY STATEMENT

All relevant data are available on request.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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