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The effectiveness of a water resource tax policy in improving water-use efficiency: a quasi-natural experiment-based approach

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ABSTRACT

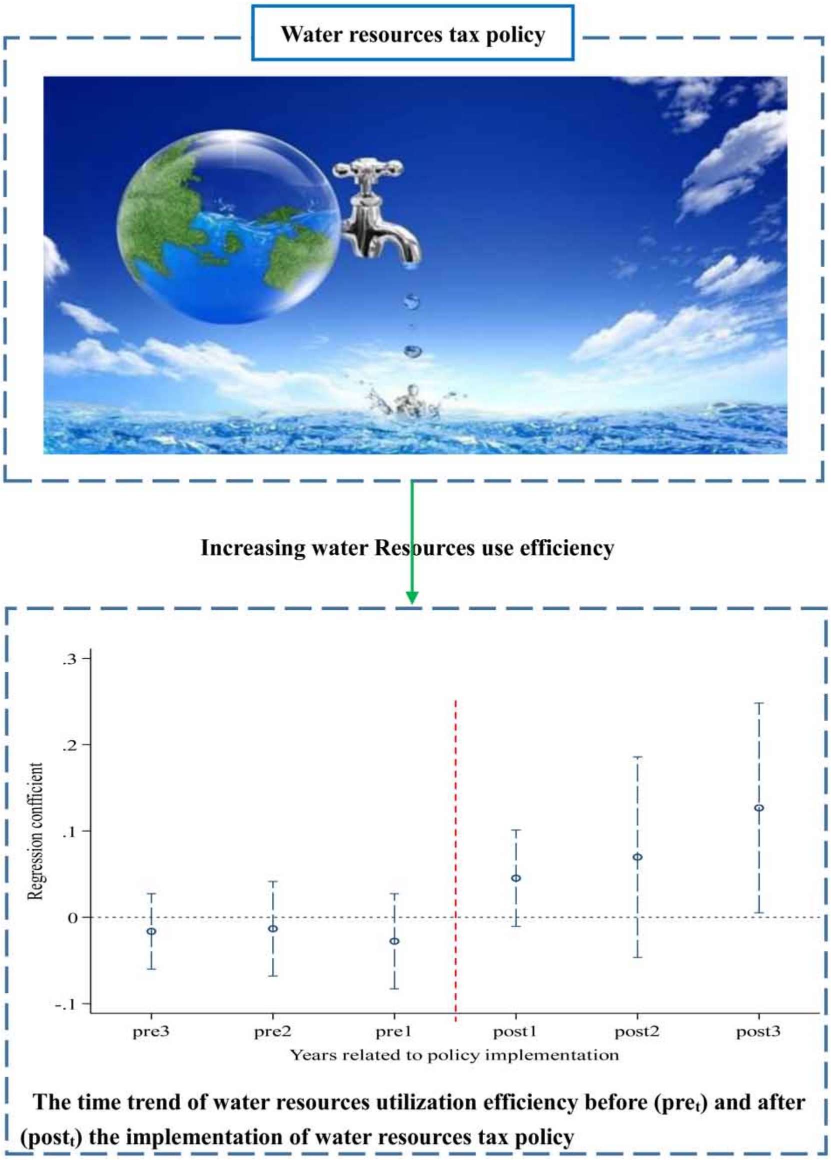
Comprehensively improving the efficiency of water resource utilization is not only an urgent need to resolve the prominent contradiction between water supply and water demand but also an inevitable requirement to promote the harmonious coexistence between humans and nature. The compulsory water resource tax is considered to be a powerful tool for resolving the worldwide water crisis and improving water resource utilization efficiency (WRUE). Based on a quasi-natural experiment of water resource tax policy in China, this study used panel data for 30 provinces (municipalities) from 2011 to 2019 to evaluate the impact of water resource tax policies on WRUE through a multistage difference-in-difference model. The results showed that the water resource policy can effectively improve the utilization efficiency of water resources by optimizing the allocation of resources. In addition, the analysis of the spatial heterogeneity showed that the policy of the water resource tax has a stronger lifting effect on improving water resource-use efficiency in eastern China than that in the central and western regions. This research provided insights into China's water policies that can be used to better manage natural resources.

Key words: Difference-in-difference approach, Policy implications, Theoretical mechanism, Water resource tax, Water-use efficiency

HIGHLIGHTS

- A multistage dynamic difference-in-difference (DID) model is applied to test the impact of water resource tax policy.
- There is temporal variation and spatial heterogeneity of water resource-use efficiency across China.
- The water resource tax policy has significantly improved water use efficiency.
- The mechanisms of the policy effect have been explored.

GRAPHICAL ABSTRACT



1. INTRODUCTION

Freshwater resources throughout the world are increasingly threatened by a rapidly increasing human population (Mnaya *et al.*, 2021). In addition, there are a number of human pressures (e.g., inefficient distribution, urbanization, over abstraction, intensive agriculture and exceptional demand) underpinning pollution, climate change and biodiversity loss that accelerate the water crisis (Gittins *et al.*, 2021). As the largest developing country and one of the fastest-growing economies in the world, China's situation in many respects exemplifies the global picture, particularly water scarcity in arid regions (Mu *et al.*, 2019). China, whose water resources per capita (PWR) are less than a quarter of the world's average, is one of the countries experiencing acute water scarcity, and water shortages in western and northern parts of China are more serious than those in other regions (Song *et al.*, 2018). In addition, the uneven distribution of total water resources among different provinces, low water-use efficiency, serious water pollution and other problems lead to serious imbalance between the supply and demand of water resources in China.

As a vital comprehensive index reflecting the effective development, utilization and management of water resources, the improvement in the water resource utilization efficiency (WRUE) is important to alleviate the issues of the water crisis in China (Chang & Zhu, 2021). WRUE is the ratio of input to output of water resources and other factors, measuring the effect of human allocation of water resources and economic activities in the process of social production, which is the result of economic development, technological progress, water resource consumption and other factors, with the characteristics of multi-input, multi-output and multi-decision (Luo *et al.*, 2018; Yang *et al.*, 2022). There is clear theoretical and empirical evidence for several scholars that water-economic leveraging is considered the most effective way to improve the WRUE (Tortajada *et al.*, 2019). The construction of a water resource tax policy is of great significance to further improve the WRUE and promote the management process of water resources in Germany, the UK and other European countries (Thomas & Zaporozhets, 2017). This framework has not previously been applied in China within the realm of water resource management and may prove a useful tool in planning for better management and, ultimately, future resilience (Tian *et al.*, 2021).

A water resource tax policy refers to a resource tax levied on units and individuals who exploit, process, consume and pollute water resources with respect to their exploitation, consumption, exploitation income and pollution amount to protect water resources (Chen *et al.*, 2021). Bringing the surface water and groundwater into the scope of tax policy, the water resource tax policy appropriately raises tax standards for industries with high water consumption and groundwater overexploitation areas, and maintains the original burden level of normal production and domestic water. Implementing quantitative taxation and differential tax rates, this water resource tax policy aims to regulate water demands through tax leverage, promote water conservation, protection and rational use (Gao & Yin, 2016). The work of the water resource tax policy ('fee to tax') was launched in July 2016 in Hebei Province in China. In November 2017, tax reform was based on success in Hebei Province, and to expand the scope of the water resource tax reform, the '1 + 9' pattern was formed in China. The feasibility of the nationwide promotion of water resource tax reform was further explored through pilot projects in different regions. Although Li (2017) analysed the actual situation of Hebei's (the first policy implementation province) water resource tax policy reform and put forward some theoretical suggestions, systematic evaluation studies about the effectiveness of improving WRUE before and after water resource tax policy implementation in implementation and non-implementation regions are largely unexplored in China.

Theoretically, the water resource tax policy is meant to contribute to WRUE in the following ways. First, since the levy of water resource tax will lead to an increase in the tax burden on the water consumption of each entity, this can stimulate them to adopt new water-saving technology, which has long been seen as an effective method to increase efficiency and change water-use patterns in high-consumption sectors (Benyezza *et al.*, 2021). Second, water conservancy departments will conduct a large amount of water-saving consciousness publicity work based on the policy, thus affecting the cognition of water consumption departments and improving water efficiency, which has been proven by many scholars (Jin *et al.*, 2013). Finally, the water resource tax can optimize the combination of resources in resource allocation to a certain extent. With the expansion of the production scale, scale efficiency becomes more obvious, thus improving the efficiency level (Naghdi *et al.*, 2021). In contrast, some researchers argued that the water resource tax policy not only fails to achieve the water-saving effect required by the policy but also increases the burden of taxpayers. Therefore, it will not increase the WRUE (Anonymous, 2009; Kilimani *et al*., 2015). However, there are few studies on the influence of water resource taxes on WRUE, and the existing research results are still controversial.

As a normative economic model introduced by Ashenfelter (1978), the difference-in-difference (DID) approach based on the quasi-natural experiment is commonly used to estimate the effects of specific public policies. Different from ordinary scientific research, the implementation of public policy makes it difficult to ensure complete randomness in sample allocation between the experimental and control groups because of the certain differences in the samples of different groups before the policy implementation. Such an experiment based on an exogenous intervention with a non-random allocation of sample selection and grouping is called a quasi-natural experiment, and the estimation bias of which may be caused by a single before and after comparison or a horizontal comparison (Dinardo, 2010). Since the implementation of a public policy is usually not affected by the subject, the implementation of the policy can be recognized as an exogenous 'intervention' for the subject; therefore, the implementation of the water resource tax policy can also be considered a quasi-natural experiment. By subtracting the changes before and after the policy intervention in the experimental group and the changes in the control group, the DID model makes up for the defect of 'quasi-natural experiment' in sample allocation that cannot be random, so as to obtain a real evaluation of the policy effect (Cao & Zhang, 2020). In recent years, an increasing number of researchers have applied the DID model to conduct causal analysis or public policy effects (Dendir *et al*., 2019; Yeon *et al*., 2020). China's practice of water resource tax policy provides a good case for the scientific evaluation of the economic issues of WRUE.

Therefore, on the basis of the multistage DID model, this research intended to explore the influences and mechanisms of water resource policies on WRUE. Panel data of 30 provinces from 2011 to 2019 in China were estimated. To achieve the research objectives, this study explored three key questions: (1) To what degree does the water resource tax policy affect WRUE? Does this impact exhibit any spatial and temporal characteristics? (2) What are the mechanisms' effect on WRUE? (3) How can the relationship between water resource tax policy and sustainable water utilization be coordinated?

2. POLICY BACKGROUND

Water is not only the significant element of production, but also one of the core contents of the construction of ecological civilization. There are three major problems in China's water resources: lack of water resources, uneven distribution of water resources and serious water pollution, which have become important factors restricting China's sustainable economic development. In recent years, the government has continuously issued relevant policies to implement the system of paid utilization of water resources, using economic means to promote water conservation, especially the exploitation of urban groundwater, so as to promote the sustainable development of water resources. Under the circumstances, the collection of a water resource fee in China started in 1988, which was an important measure for the state to use price levers to realize the paid use of water resources. However, due to the lack of compulsion and standardization, there are a series of problems such as insufficient awareness of the payer, weak rigidity, and lack of effective means of management in the collection process of water resource fees, which make it difficult to achieve the purpose of saving water.

In July 2016, Hebei Province took the lead in carrying out the work of water resource tax reform and strengthened the government's ability to regulate the use of water resources by using tax as a mandatory and normative means. Since the implementation of water resource tax reform, the unreasonable water demand in Hebei Province has been effectively restrained, and the growth of finance and taxation in the province has been promoted (Xu, 2020). Due to the success of the reform in Hebei, the government proposed to expand the reform of water resource tax, which has been implemented in nine provinces (municipalities) including Beijing, Tianjin, Shanxi, Inner Mongolia, Shandong, Henan, Sichuan, Shaanxi and Ningxia since December 2017 (Figure 1). As an effective policy of water resource management, water resource tax policy has effectively promoted the water resource conservation and protection in China, effectively curbed the waste of water resources, and is of great significance to the sustainable development of society. However, there are few studies on the role of water resource tax policy in improving the WRUE. Therefore, through the econometric model, this paper quantitatively analyses the effect of water resource tax on the improvement of water resource utilization efficiency, in order to provide a reference for further promoting the reform of water resource tax.

3. THEORETICAL HYPOTHESIS

3.1. Water resource tax policy and WRUE

The water resource tax policy determines the tax standard by industry according to surface water and groundwater. First, the tax policy can internalize the negative externalities of water resources into producers' production costs, regulate production and consumer behaviour, and reduce excessive water demand (Li *et al.*, 2019). Second, through differential tax, the water resource tax policy inhibits groundwater exploitation, reduces water use in special industries, and controls water-intensive industries to save water (Zhang, 2017). In addition, the strict reform of the water resource tax makes water users actively accept water management and strengthens

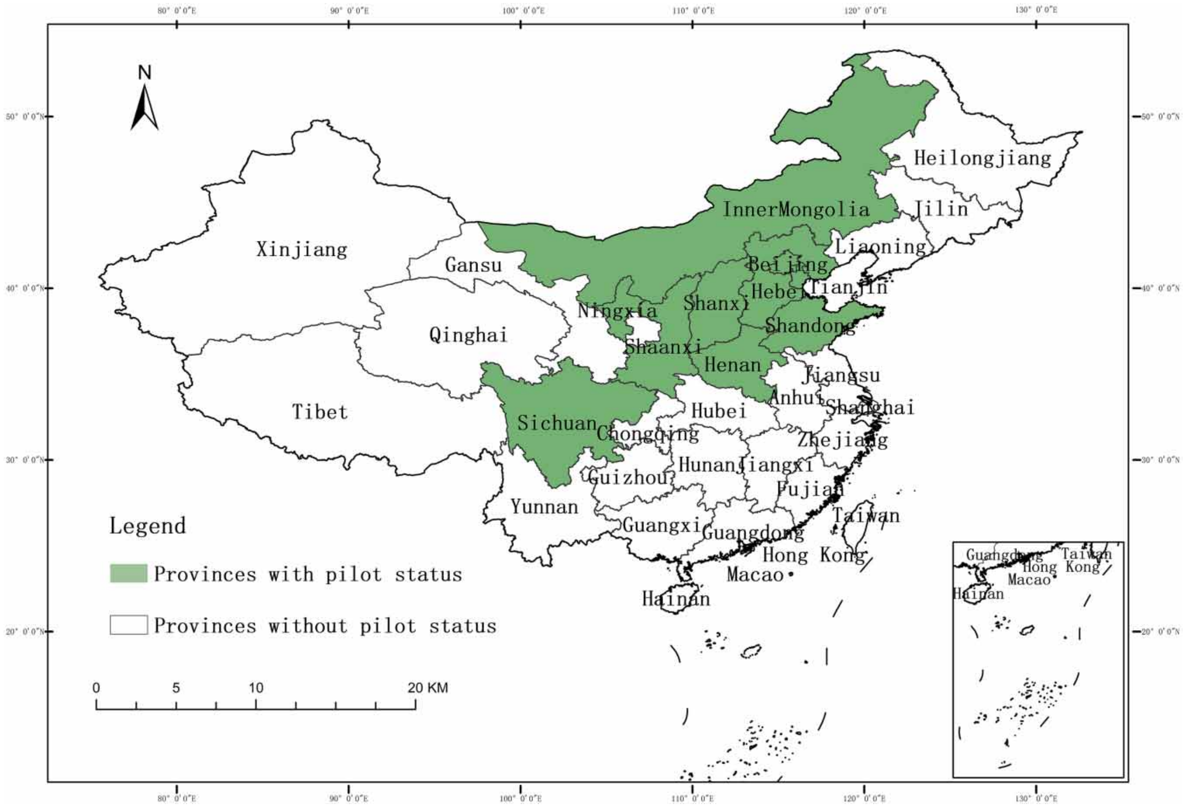


Fig. 1 | Province distribution of China's water resource tax policy in 2016–2017.

taxpayers' green development and life concepts (Xu, 2020). Based on the above analysis, the first theoretical hypothesis of this study was proposed:

Hypothesis 1: The water resource tax policy can significantly improve the WRUE.

3.2. Mechanism of water resource tax policy improving the WRUE

In theory, a water resource tax policy may improve the WRUE by enhancing water-saving technology and awareness and optimizing resource allocation. However, the development of water-saving technologies requires strong financial support and long-term exploration. On the other hand, non-scaled users usually have no access to advanced water-saving transformation technologies (Ma *et al.*, 2021). Water-saving consciousness indirectly affects water-saving behaviour mainly by influencing water-saving expectations; the economic benefit expectation of behaviour is the key link between water-saving consciousness and behaviour, which weakens the final impact of water-saving consciousness on water-saving behaviour (Quesnel & Ajami, 2017; Li *et al.*, 2019). With the expansion of production inputs, economies of scale have become more obvious, thereby improving the utilization rate of water resources (Tian *et al.*, 2020). Based on the above analysis, the second theoretical hypothesis of this study was proposed:

Hypothesis 2: The policy of a water resource tax can increase WRUE by optimizing resource allocation.

3.3. Regional effect of water resource tax policy on the WRUE

Obvious regional differences occur in the level of water-use efficiency among China's provinces (municipalities). Compared with the eastern regions, there is less precipitation and uneven distribution of precipitation time in the central and western regions, which easily causes a flood disaster of single precipitation events in the arid area (Hu *et al.*, 2019). Second, overexploitations such as excessive logging and grazing reduce ecosystem productivity (Irisarri *et al.*, 2016). Third, since the reform and opening up, although the economy of the central and western regions has developed rapidly, its economic level is generally lower than that of the eastern region, and the wastewater discharge per 100 million yuan of GDP is higher than the national average. The increase in sewage discharge will inevitably lead to the accelerated deterioration of the water resource environment (Wei *et al.*, 2021). Therefore, compared with the central and western regions, the implementation of water resource tax policies may have a better effect on improving water resource-use efficiency in the eastern region and provide spatially heterogeneous results. Based on the above analysis, the third theoretical hypothesis of this study was proposed:

Hypothesis 3: The water resource tax policy will have a stronger impact on the WRUE in the eastern region than that in the western and central regions.

4. METHODOLOGY

Based on the research framework, a flowchart of the method used in this study shown in Figure 2 was designed to highlight the steps followed in the research process.

4.1. WRUE measurement

4.1.1. Three-stage data envelopment analysis model

Data envelopment analysis (DEA), which was created by operations researcher Charnes *et al.* (1978), is an effective method to evaluate the input–output efficiency of decision-making units (DMUs). However, the traditional DEA method cannot eliminate the impact of random errors or external environmental factors on environmental

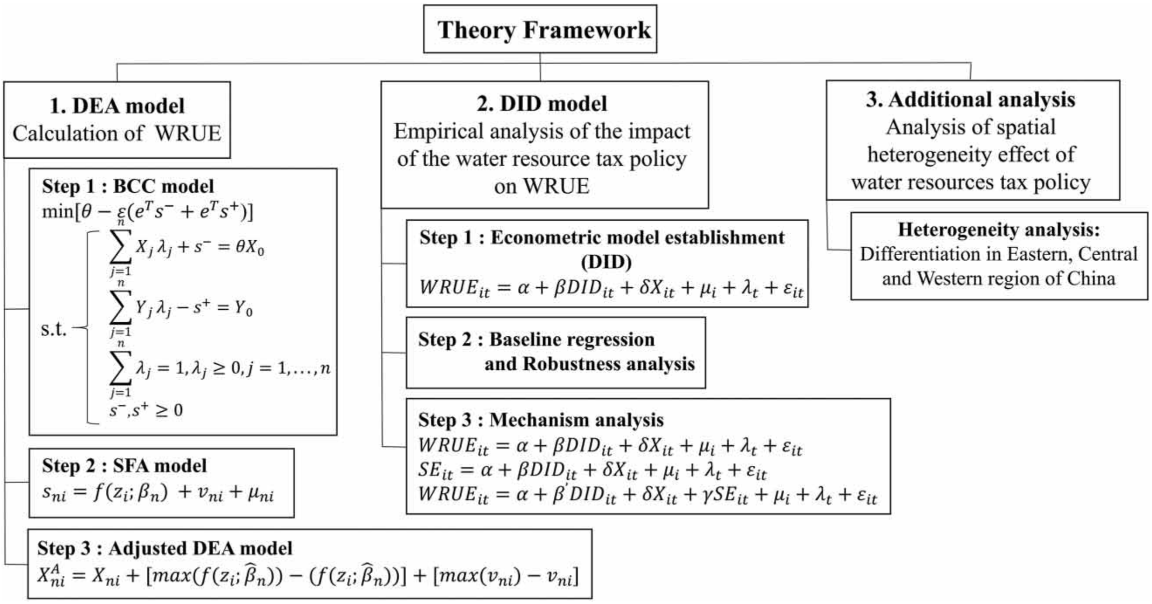


Fig. 2 | Research flowchart of the method for water resource tax policy raising the WRUE.

efficiency, leading to the inauthentic reflection of environmental efficiency, which may play a misleading role in the formulation of environmental policies (Ren & Li, 2016; Li & Pan, 2017). To avoid this issue, the three-stage DEA model was introduced by Banker *et al.* (1984) and Fried *et al.* (2002), which can eliminate the influence of the external operating environment and random factors to identify the impact of the water-use efficiency.

The first stage is the R. D. Banker & A. Charnes & W. W. Cooper (BCC) model, which assumes variable returns to scale and adds the convexity hypothesis based on the A. Charnes & W.W. Cooper & E. Rhodes (CCR) model, decomposing the comprehensive efficiency into pure technical efficiency and scale efficiency. For any DMU, the dual programming formula of the input-oriented BCC model is:

$$\min[\theta - \varepsilon(\mathrm{e}^{\mathrm{T}} s^- + \mathrm{e}^{\mathrm{T}} s^+)]$$

$$\text{s.t.} \begin{cases} \sum_{j=1}^{n} X_j \lambda_j + s^- = \theta X_0 \\ \sum_{j=1}^{n} Y_j \lambda_j - s^+ = Y_0 \\ \sum_{j=1}^{n} \lambda_j = 1,\ \lambda_j \geq 0,\ j = 1,\ \ldots,\ n \\ s^-,\ s^+ \geq 0. \end{cases} \tag{1}$$

In Equation (1), n represents the number of DMUs; X and Y, respectively, represent the input and output variables; θ represents the valid value; ε is a constant that represents Archimedes infinitesimal; s^- and s^+, respectively, represent the input and output slack variables.

The second stage is the stochastic frontier approach (SFA) model, which is based on the slack variables obtained from the first stage. The following regression function model is constructed:

$$s_{ni} = f(z_i;\, \beta_n) + v_{ni} + \mu_{ni}, \quad i = 1,\, \ldots,\, I; \qquad (2)$$

$$n = 1,\, \ldots,\, N.$$

In Equation (2), s_{ni} represents the slack variables of the input n of DMU i; z_i represents the environmental variable; β_n represents the coefficient of z_i; and $v_{ni} + \mu_{ni}$ represents the mixed errors. According to the input variable of the most efficient DMUs, the input variable of other DMUs is adjusted. The formula is as follows:

$$\begin{aligned} &X^A_{ni} = X_{ni} + [\max(f(z_i;\, \hat{\beta}_n)) - (f(z_i;\, \hat{\beta}_n))] + [\max(v_{ni}) - v_{ni}], \\ &i = 1, \ldots, I \\ &N = 1, \ldots, N. \end{aligned} \qquad (3)$$

In Equation (3), X^A_{ni} and X_{ni}, respectively, represent the input variable before and after the DMU adjustment;-$[\max(f(z_i;\, \hat{\beta}_n)) - (f(z_i;\, \hat{\beta}_n))]$ indicates the adjustment of the external environment; and $[\max(v_{ni}) - v_{ni}]$ makes the random factors of each DMU consistent.

The third stage is the adjusted DEA model. Replacing X_{ni} with X^A_{ni}, the first-stage model was run again to calculate the WRUE with the remaining output variable.

4.1.2. Selection of indicators

Since the data for Tibet, Hong Kong, Macau and Taiwan are not available, this research selects the remaining 30 provinces (municipalities) in China as the DEA model DMUs. Based on the existing research, the selected indicators of this study are as follows.

The first indicator type was the input and output variables. By referring to the previous literature and available data, this study takes fixed asset investment, labour force and total water consumption as input indicators and regional GDP as an output indicator.

The second indicator type was the environmental variables. Combined with this research theme, three environmental factors were the focus: industrial structure, water resource endowment and economic level. The utilization rate of water resources was closely related to the industrial structure. Currently, the proportion of agricultural water consumption in most provinces in China exceeds 60% (Ji *et al.*, 2018). Therefore, this study uses the proportion of the added value of the primary industry in GDP to measure the industrial structure. Additionally, regional water resource endowment is affected by objective conditions such as terrain, climate and population. To better analyse the water resource richness of each region, this study used per capita water resources to measure the regional water resource endowment. For the economic level of various regions, this research used per capita GDP to measure it. The descriptive statistical analysis results of the variables are shown in Table 1.

4.2. Econometric model

4.2.1. DID method

This research used the DID specification to assess the impact of the water resource tax policy on water-use efficiency and its mechanism, which was a quasi-natural experiment based on the implementation of the policy. To effectively analyse the net impact of water resource tax policies on water-use efficiency in different provinces (municipalities) in different periods, the area where the policy is implemented was set as the experimental group and the remaining provinces (municipalities) as the control group. Specifically, Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Shandong, Henan, Sichuan, Shaanxi and Ningxia represented the intervention group,

Table 1 | Statistical description of indicators selected in the measurement of the water resource-use efficiency (WRUE).

Variables	Definitions	Mean	SD	Minimum	Maximum
Input variables					
Investment in fixed assets	Investment in fixed assets of the whole society (hundred million yuan)	17,670.42	12,655.81	1,435.58	58,766.88
Labour force	Number of people employed (10,000 people)	1,515.25	1,191.72	125.10	7,133.10
Water consumption	Total water consumption (hundred million cubic metres)	203.39	143.42	23.10	619.10
Output variables					
Regional GDP	Regional gross domestic product (hundred million yuan)	24,641.96	19,582.63	1,670.44	107,986.90
Environmental variables					
Industrial structure	The proportion of the added value of the primary industry in GDP (%)	9.90	5.32	0.29	25.84
Water resource endowment	Per capita water resources (cubic metre)	6,697.16	24,478.95	51.90	145,779.80
Economic level	Real per capita GDP (yuan)	37,729.49	20,340.33	9,806.47	125,032.00

and the remaining provinces (municipalities) represented the control group to analyse the impact and mechanism of water resource tax policies on water-use efficiency. The following econometric regression model was established:

$$\text{WRUE}_{it} = \alpha + \beta \text{DID}_{it} + \delta X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \tag{4}$$

$i = 1, \ \ldots, \ 30; \ t = 2009, \ \ldots, 2019.$

In Equation (4), i represents the province (municipality), t represents the year, and WRUE_{it} is a measurement of the water-use efficiency that has been calculated in the three-stage DEA model of province (municipality) i in year t. DID_{it} is a dummy variable that indicates whether the water resource tax policy was conducted in province (municipality) i in year t, and it has a value of 1 if province (municipality) i is a policy implementation area in year t and 0 otherwise. Specifically, the water resource tax policy was implemented in Hebei in 2016 and implemented in Beijing, Tianjin, Shanxi, Inner Mongolia, Shandong, Henan, Sichuan, Shaanxi and Ningxia at the end of 2017. Considering the lag of policy implementation and ignoring the 1-month time of policy publicity and deployment, this study regards 2018 as the second batch of water resource tax policy processing years. X_{it} represented the control variables at the provincial level, including economic development level, R&D expenditure of industrial enterprises above designated size (RD), per capita water resources, foreign direct investment, year-end resident population (YERP), urbanization rate (UR), effective irrigation area (EIA) and the proportion of the added value of the tertiary industry in GDP (PAVTIG). In addition, μ_i and λ_t are vectors of province and year dummy variables that account for province and year fixed effects. In addition, ε_{it} is a random perturbation term. In Equation (4), the coefficient of interest in this study was β, and if its estimated value was more than 0, then the policy improves water-use efficiency in the implementation areas compared with the other areas.

4.2.2. Selection of related variables

This research selected the WRUE calculated by the three-stage DEA model as the dependent variable, comprehensively measuring the water-use level of provinces (municipalities) in China. The core independent variable was the water resource tax policy, which was represented by a dummy variable. For example, if province (municipality) *i* was a policy implementation area in year *t*, the value was 1; otherwise, the value was 0. According to relevant research on regression analyses, other variables that affect WRUE need to be controlled, including PWR, YERP, UR, EIA, the PAVTIG, the consumer price index (CPI), RD, and fixed effects of time and the provinces (municipalities). Among them, the logarithm for variables with standard deviations greater than 10^4 was considered, including PWR and RD.

4.3. Data sources and analysis

The research objects used in this study were 30 provinces (municipalities) in China from 2011 to 2019. Since data for Tibet, Hong Kong, Macau and Taiwan were not available, these provinces (municipalities) were not within the scope of this study. The final sample of this article includes 270 observations based on data from the 'China Statistical Yearbook', 'China Environmental Statistics Yearbook', 'China Water Resources Bulletin' and National Bureau of Statistics of China. Table 2 displays the definitions and descriptive statistics for all variables. All the data were analysed using Stata 15 software.

5. RESULTS

5.1. Calculation results of WRUE

5.1.1. Temporal and spatial variations of WRUE

In this study, the WRUE in 2011, 2015 and 2019 was selected and divided into five types using ArcGIS software and the geometric interval method to describe the spatiotemporal variation trend of the water-use level in each province (municipalities). The results are shown in Figure 3.

Table 2 | Variable definitions and descriptive statistics.

Variables	Definitions	Mean	SD	Minimum	Maximum
Dependent variable					
WRUE	Water resource utilization efficiency	0.91	0.08	0.00	1.00
Independent variable					
DID	Takes the value of 1 if province *i* is a water policy pilot area in year *t*; otherwise, takes 0				
Control variables					
PWR	The natural logarithm of water resource per capita	7.19	1.54	3.95	11.89
YERP	Year-end resident population	4,589.96	2,824.46	568.00	12,489.00
UR	Urbanization rate	57.67	12.36	34.36	94.15
EIA	Effective irrigation area	2,178.63	1,648.72	109.24	6,177.59
PAVTIG	The proportion of the added value of the tertiary industry in GDP	48.62	8.96	32.66	83.69
CPI	Consumer price index	102.51	1.23	100.60	106.30
RD	The natural logarithm of R&D expenditure of industrial enterprises above designated size	14.28	1.34	10.96	16.96

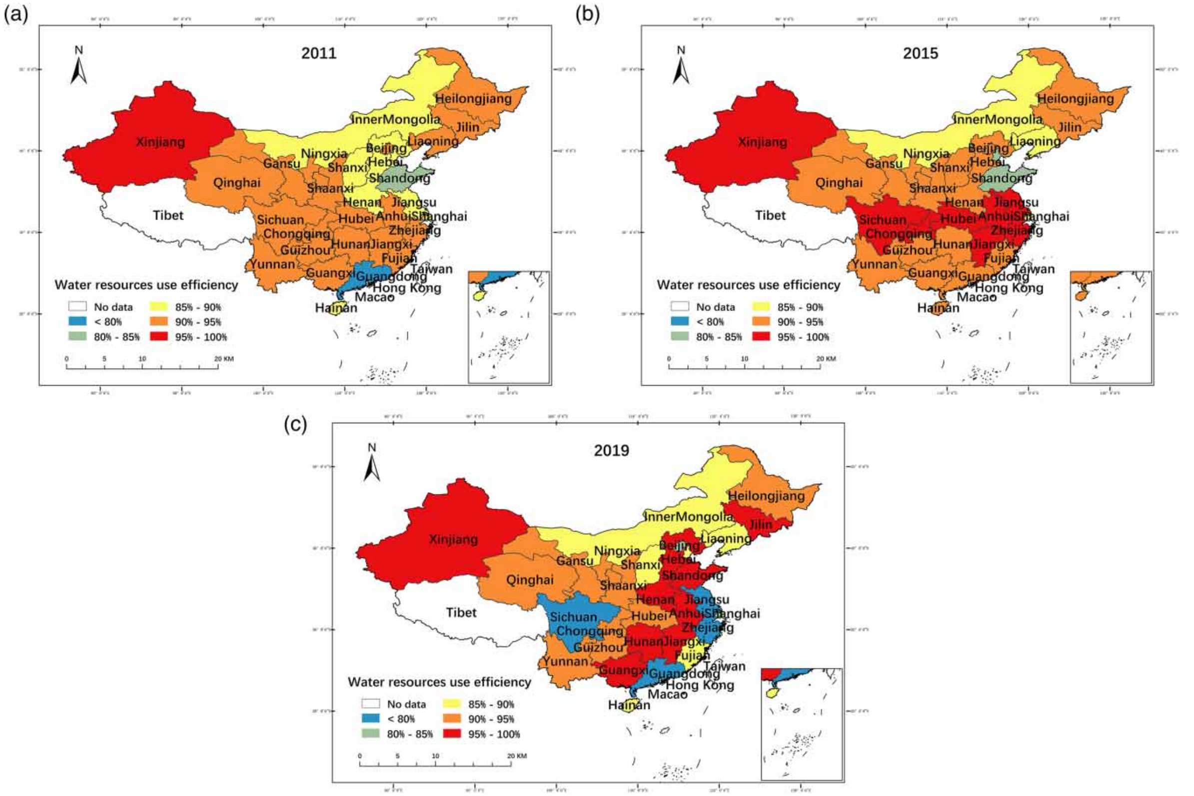


Fig. 3 | Spatial and temporal distributions of WRUE in China from 2011 to 2019.

In general, the level of WRUE in China's provinces (municipalities) showed an upward trend from 2011 to 2019. In 2011, the WRUE of China's provinces (municipalities) was roughly between 0.80 and 0.95. After 2015, the WRUE was improved. From 2015 to 2019, there were more than eight provinces with water resource utilization efficiencies between 0.95 and 1.00.

Specifically, the WRUE in China's provinces (municipalities) from 2011 to 2019 presented regional heterogeneity. The result indicates that the WRUE of the southeastern region has shown a downward trend. In addition, the central region shows the greatest changes in the WRUE. Since 2011, the WRUE in Hunan, Jilin, Jiangxi, Henan and Shanxi had significantly increased. Moreover, the WRUE in the western region varied among provinces (municipalities). Xinjiang Province always has higher WRUE than most parts of the country, while Inner Mongolia is near the lowest in China.

5.1.2. Changes in the WRUE before and after water resource tax policy implementation

Tables 3 and 4 show the average value of WRUE in the implementation and non-implementation areas from 2011 to 2019 and attempt to reveal the changing trend of WRUE through a comparison of the conditions before and after policy implementation. Specifically, before the implementation of the water resource tax policy, the average water-use efficiency value in the non-implementation areas was higher than the average in the implementation areas. After implementing the policy, the water resource-use efficiency in the implementation areas increased significantly, and the rising range was much greater than that in the non-implementation areas. This finding demonstrates that compared with non-implementation areas, the implementation of the water resource tax

Table 3 | The differences in the WRUE between Hebei Province and non-implementation regions from 2011 to 2019.

	Before policy implementation						After policy implementation				
	2011	2012	2013	2014	2015	Mean	2016	2017	2018	2019	Mean
Hebei Province	0.86	0.87	0.86	0.88	0.91	0.88	0.91	0.91	0.96	0.96	0.93
Non-implementation areas	0.91	0.91	0.93	0.93	0.94	0.92	0.94	0.94	0.91	0.86	0.91
All	0.90	0.90	0.91	0.92	0.93	0.91	0.93	0.92	0.91	0.88	0.91

Table 4 | The differences in the WRUE between the second batch of implementation areas and non-implementation regions from 2011 to 2019.

	Before policy implementation								After policy implementation		
	2011	2012	2013	2014	2015	2016	2017	Mean	2018	2019	Mean
The second batch of implementation areas	0.89	0.88	0.89	0.89	0.90	0.91	0.89	0.89	0.90	0.90	0.90
Non-implementation areas	0.91	0.91	0.93	0.93	0.94	0.94	0.94	0.93	0.91	0.86	0.88
All	0.90	0.90	0.91	0.92	0.93	0.93	0.92	0.92	0.91	0.88	0.90

policy has significantly increased water resource utilization efficiencies in the implementation areas. However, further research conclusions must be obtained using an econometric model.

5.2. Empirical analysis of the influence of water resource tax policies on WRUE

5.2.1. Baseline regression results of the water resource tax policies on WRUE

Columns (1) and (2) of Table 5 examine the results before and after adding the control variables, and Columns (1) and (2) control for the time and regional effects. The regression results show that the coefficient sign of the variable Treat (estimated quantity of the water resource tax policy) was positive and significant at the 5% level. The results for the coefficient of DID show that after the implementation of the policies, the water-use efficiency of the implementation provinces (municipalities) increased by an average of 4.4 percentage points compared with the non-implementation provinces (municipalities). Therefore, research showed that the water resource tax policy can indeed improve water-use efficiency, which validates Hypothesis 1.

The results of the control variables show that the resident population at the end of the year had a negative impact on water resource-use efficiency, and the differences were significant at the 1% level. Specifically, the increase in the population in an area will inevitably lead to the weakening of the resource base, therefore reducing water efficiency to a certain extent. The improvement in the UR promotes the improvement of water resource-use efficiency, and the differences were significant at the 10% level. Compared with high water consumption methods such as extensive irrigation in rural areas, urban water facilities were more perfect, and water consumption per unit of GDP was lower. In addition, although the influence coefficient of PWR, CPI and scientific research expenditure of industrial enterprises above a designated size on water-use efficiency was positive, the value was not significant, indicating that it cannot effectively improve the WRUE.

5.2.2. Robustness analysis: parallel trend test

The effective premise of the DID model was that if the water tax policy does not have external influences, then the development trend between the experimental group and its control group should be parallel. Specifically before

Table 5 | Baseline regression results of water resource tax policy.

	Dependent variable: WRUE	
Independent variable	**(1)**	**(2)**
DID	0.051***[a]	0.044**
	(0.019)	(0.019)
PWR		0.018
		(0.018)
YERP		−0.000***
		(0.000)
UR		0.006*
		(0.003)
EIA		−0.000
		(0.000)
PAVTIG		−0.001
		(0.003)
CPI		0.000
		(0.011)
RD		0.001
		(0.026)
_cons	0.906***	0.963
	(0.004)	(1.188)
Province_FE	Yes	Yes
Year_FE	Yes	Yes
N	270	270
R^2	0.365	0.422

PWR, the natural logarithm of water resources per capita; YERP, year-end resident population; UR, urbanization rate; EIA, effective irrigation area; PAVTIG, the proportion of the added value of the tertiary industry in GDP; CPI, consumer price index; RD, the natural logarithm of R&D expenditure of industrial enterprises above designated size.

[a] The standard errors adjusted by province-year clustering are in brackets; ***, ** and * indicate significance at the levels of 1, 5 and 10%, respectively.

the implementation of this policy, there should be no significant differences in the intensity of water-use efficiency between the experimental group and the control group. Therefore, to verify the correctness of the double difference method, this research constructs the following model to test the parallel trend:

$$\begin{aligned}\mathrm{WRUE}_{it} = {} & \alpha_0 + \beta_1 pre_1 + \beta_2 pre_2 + \beta_3 pre_3 + \beta_4 current + \beta_5 post_1 \\ & + \beta_6 post_2 + \beta_7 post_3 + \delta X_{it} + \mu_i + \lambda_t + \varepsilon_{it}\end{aligned} \tag{5}$$

In Equation (5), pre_1, pre_2, pre_3, $current$, $post_1$, $post_2$, and $post_3$ are dummy variables. The water resource tax policy was implemented in 2016, which was set as the base year. Pre_t takes 1 ($t = 1, 2, 3$) if province i is t year(s) before the implementation of the water resource tax policy, and when t was greater than 3, pre_t was also equal to 1; otherwise, pre t takes 0 ($t = 1, 2, 3$); current takes 1 if province i was in the current year of water resource tax reform; otherwise, it takes 0; and $post_t$ takes 1 ($t = 1, 2, 3$) if province i was t year(s) after the implementation of the water resource tax policy; otherwise, $post_t$ takes 0. The regression coefficient β_n ($n = 1\ldots,7$) indicated whether there is a significant difference in the water-use efficiency between the experimental group and the control group. Table 6 and Figure 4 both intuitively reveal the test results. Columns (1) and (2) of Table 6, which control for the time and regional effects, examine the results before and after adding the control variables. The coefficients of pre_1, pre_2 and pre_3 were not significant, indicating that before the water resource tax reform, there was no significant difference in the development of water-use efficiency between the experimental group and the control group, which satisfies the parallel trend hypothesis. The estimated values of $post_3$ were significantly different from 0, indicating that the water resource tax reform is indeed the main factor leading to the change of water-use efficiency in the experimental group.

5.2.3. Robustness analysis: placebo test

To verify the robustness of the above baseline regression results, this paper randomly selects individuals as the experimental group to generate ‘pseudo policy dummy variables’ for the placebo regression test. Since different individuals have different policy time points, individuals were randomly selected as the experimental group but also randomly select time as the policy time point.

The idea of this study was to randomly select individuals as treatment groups, then randomly select a time for each treatment group as its policy time point, finally generating ‘pseudo policy dummy variables’ for regression. The process was repeated 1,000 times, and the distribution of estimated coefficients and corresponding t-value distribution of 1,000 ‘pseudo policy dummy variables’ were drawn to intuitively display the results of the placebo test.

Specifically, the time span of the data was from 2011 to 2019, with 10 provinces (municipalities) in the experimental group and 20 provinces in the control group. Therefore, 10 provinces (municipalities) were randomly selected from 30 provinces (municipalities) as the ‘pseudo processing group’. Assuming that these 10 provinces (municipalities) implemented water resource tax policies, other provinces (municipalities) were taken as the control group, and then 1 year was randomly selected as the policy time point (‘pseudo policy time’). DID regression was performed for each of these 10 ‘pseudo treatment groups’ and repeated 1,000 times. In Figure 5, the solid line indicates the real coefficient estimated by the baseline regression of 0.044, and the dotted line marks the mean value of 1,000 ‘virtual’ coefficients of 0.000. In Figure 6, the solid line marks the true t-value of 2.31 in the baseline regression, the long dotted line indicates the mean t-value of -0.021 after randomization, and the two short dotted lines represent $t = -1.65$ and $t = 1.65$ (i.e., the t-value corresponding to the significance level of 10% in a large sample). Table 7 intuitively shows that most of the estimated coefficients and t values were concentrated approximately 0, the distance between the mean value and the real value was great, and most of the estimated coefficients were not significant, which revealed that the improvement effect of the water resource tax policy on water resource utilization efficiency was not affected by other unobserved factors, and the results of this study were stable.

5.2.4. Mechanism analysis of the water resource tax policy for improving WRUE

This study will discuss the mechanism of the water resource tax policy on WRUE from the perspectives of resource allocation, which was measured by the scale efficiency of water resource utilization. Referring to the research of Wen *et al.* (2004), the following three recursive test models are established:

$$\mathrm{WRUE}_{it} = \alpha + \beta \mathrm{DID}_{it} + \delta \mathrm{X}_{it} + \mu_i + \lambda_t + \varepsilon_{it} \tag{6}$$

$$\mathrm{SE}_{it} = \alpha + \beta \mathrm{DID}_{it} + \delta \mathrm{X}_{it} + \mu_i + \lambda_t + \varepsilon_{it} \tag{7}$$

$$\mathrm{WRUE}_{it} = \alpha + \beta' \mathrm{DID}_{it} + \delta \mathrm{X}_{it} + \gamma \mathrm{SE}_{it} + \mu_i + \lambda_t + \varepsilon_{it} \tag{8}$$

Table 6 | Common trend test: analysis of the time trend of WRUE before and after policy implementation.

	Dependent variable: WRUE	
Independent variable	**(1)**	**(2)**
pre3	−0.027	−0.016
	(0.027)	(0.026)
pre2	−0.026	−0.013
	(0.034)	(0.033)
pre1	−0.034	−0.028
	(0.034)	(0.033)
post1	0.038	0.045
	(0.034)	(0.034)
post2	0.077	0.070
	(0.072)	(0.070)
post3	0.125*[a]	0.127*
	(0.075)	(0.073)
PWR		0.024
		(0.018)
YERP		−0.000***
		(0.000)
UR		0.006*
		(0.003)
EIA		−0.000
		(0.000)
PAVTIG		−0.001
		(0.003)
CPI		−0.001
		(0.011)
RD		−0.000
		(0.027)
_cons	0.915***	1.089
	(0.009)	(1.199)
Province_FE	Yes	Yes
Year_FE	Yes	Yes
N	270	270
R^2	0.375	0.434

PWR, the natural logarithm of water resources per capita; YERP, year-end resident population; UR, urbanization rate; EIA, effective irrigation area; PAVTIG, the proportion of the added value of the tertiary industry in GDP; CPI, consumer price index; RD, the natural logarithm of R&D expenditure of industrial enterprises above designated size.

The standard errors adjusted by province-year clustering are in brackets; *** and * indicate significance at the levels of 1% and 10%, respectively.

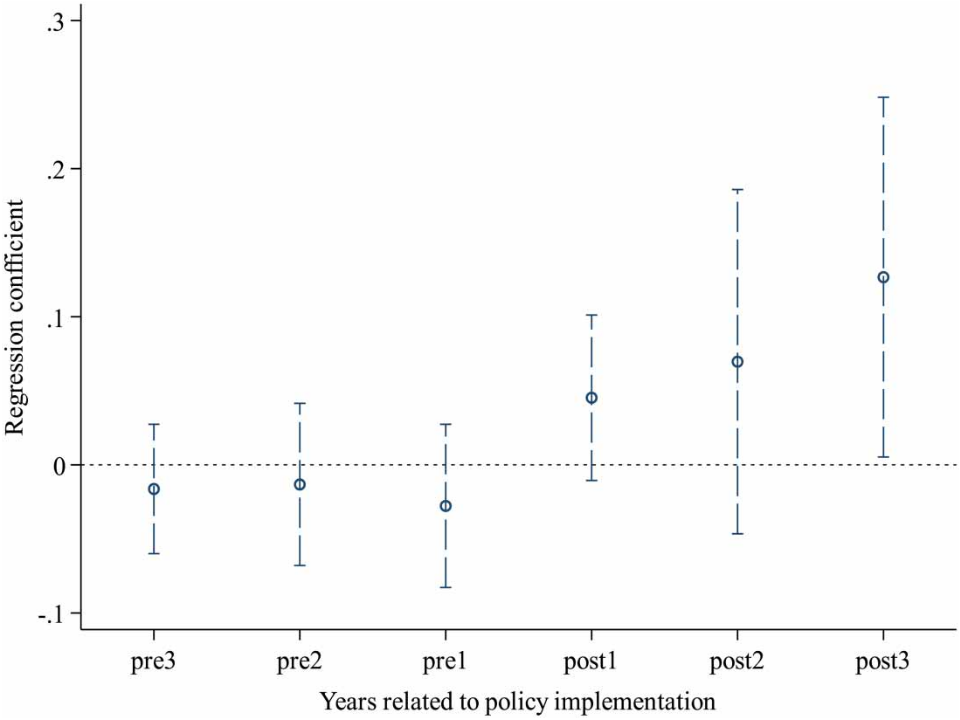


Fig. 4 | Parallel trend test chart (pre_t ($t = 1, 2, 3$) means *t* year(s) before the implementation of water resource tax policy, and $post_t$ ($t = 1, 2, 3$) means *t* year (s) after the implantation of water resource tax policy): analysis of the time trend of WRUE before and after the implementation of water resource tax policy.

Among them, SE reflects the intermediary variable scale efficiency, and other variables are consistent with Model (4). The three columns in Table 8 represent the estimation results of the three equations of Models (6)–(8). The results show that the total causal effect of the water resource tax policy on WRUE was 0.044, which was significant at the 5% level, indicating that the water resource tax policy does improve the WRUE. The impact of the water resource tax policy on the scale efficiency of water resource utilization was 0.032, which was significant at the 10% level, indicating that the water resource tax policy significantly improves the scale efficiency of water resource utilization and promotes the rational allocation of resources. After controlling the scale efficiency of water resource utilization in the model, the direct effect of the water resource tax policy on WRUE was reduced to 0.013, which was not significant. This shows that there was a complete intermediary effect at this time; namely, the policy of the water resource tax first improves the scale efficiency of water resource utilization to improve the efficiency of water resource utilization. Based on the above regression results, Hypothesis 2 of this study was verified.

5.2.5. Heterogeneity analysis: differences in the eastern, central and western regions

The WRUE level in China's provinces (municipalities) varies by the region. Therefore, the policy effects may be spatially heterogeneous. This study analysed the differences in the impact of the tax policy on the eastern, central and western regions, which were divided according to the three regions of the National Bureau of Statistics. The regression results in Table 9 show that the influence of water resource tax policy on WRUE in the eastern region was positive and significant at the 5% level. For the central region, the water resource tax policy had a positive

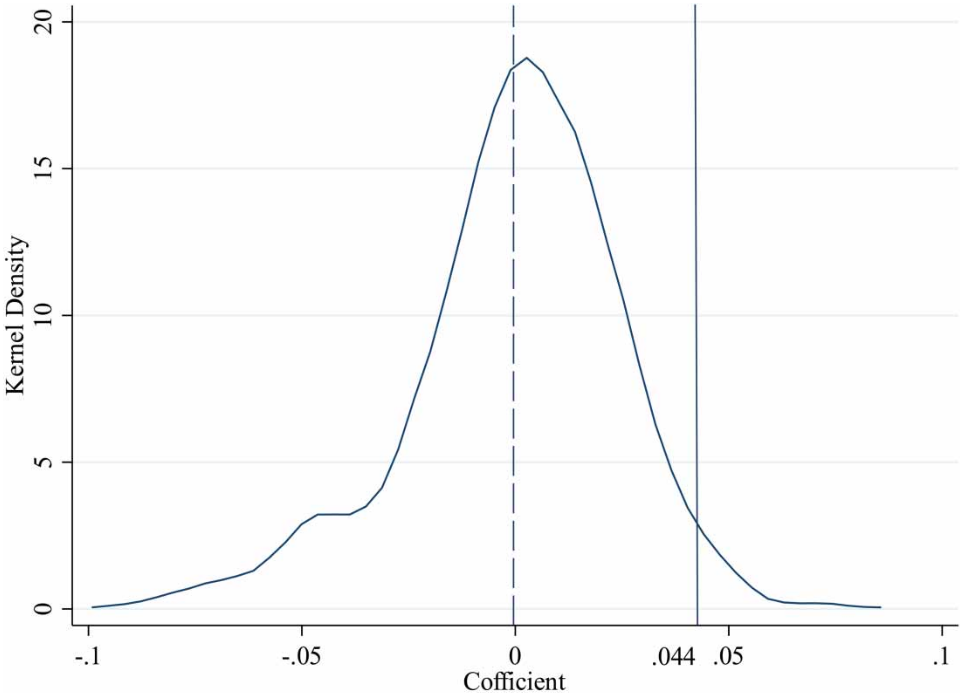


Fig. 5 | Kernel density estimation diagram of coefficient.

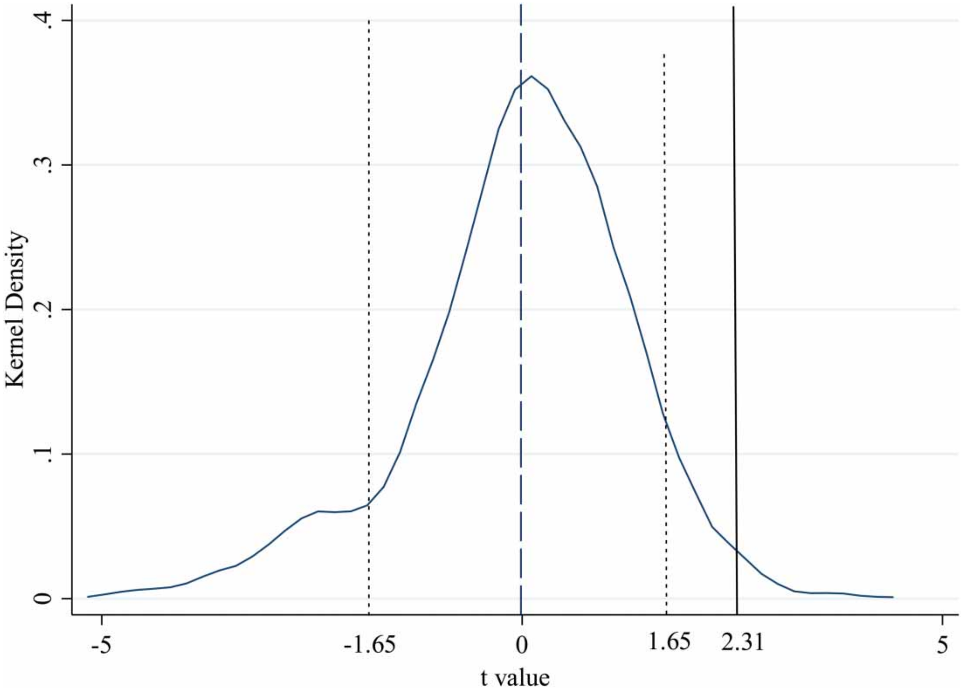


Fig. 6 | Kernel density estimation diagram of *t*-value.

Table 7 | Statistical distribution of 1,000 placebo tests.

Variables	*N*	Mean	SD	5% quintile	25% quintile	50% quintile	75% quintile	95% quintile
Coefficient	1,000	0.000	0.025	−0.046	−0.014	0.003	0.0148	0.037
t-value	1,000	−0.021	1.314	−2.362	−0.730	0.160	0.771	1.986
p-value	1,000	0.455	0.306	0.008	0.172	0.447	0.713	0.950

Table 8 | Mechanism analysis of water resource tax policy on improving the WRUE from the perspective of resource allocation.

Independent variable	WRUE (1)	SE (2)	WRUE (3)
DID	0.044**[a]	0.032*	0.013
	(0.019)	(0.017)	(0.010)
SE			0.971***
			(0.037)
PWR	0.018	0.011	0.008
	(0.018)	(0.016)	(0.009)
YERP	−0.000***	−0.000***	0.000***
	(0.000)	(0.000)	(0.000)
UR	0.006*	−0.003	0.009***
	(0.003)	(0.003)	(0.002)
EIA	−0.000	−0.000	0.000
	(0.000)	(0.000)	(0.000)
PAVTIG	−0.001	0.000	−0.001
	(0.003)	(0.002)	(0.001)
CPI	0.000	−0.009	0.009*
	(0.011)	(0.010)	(0.006)
RD	0.001	0.057**	−0.054***
	(0.026)	(0.024)	(0.013)
_cons	0.963	2.478**	−1.443**
	(1.188)	(1.062)	(0.598)
Province_FE	Yes	Yes	Yes
Year_FE	Yes	Yes	Yes
N	270	270	270
R^2	0.422	0.457	0.858

SE, scale efficiency of water resource utilization; PWR, the natural logarithm of water resources per capita; YERP, year-end resident population; UR, urbanization rate; EIA, effective irrigation area; PAVTIG, the proportion of the added value of the tertiary industry in GDP; CPI, consumer price index; RD, the natural logarithm of R&D expenditure of industrial enterprises above designated size.

[a] The standard errors adjusted by province-year clustering are in brackets; ***, ** and * indicate significance at the levels of 1, 5 and 10%, respectively.

impact on WRUE, but it was not statistically significant. However, for the western region, the results show that the water resource tax policy had neither a positive impact on WRUE nor a statistically significant impact. Based on the abovementioned empirical test, Hypothesis 3 in this article has been verified.

Table 9 | Heterogeneity analysis results: differentiation in eastern, central and western regions.

	Dependent variable: WRUE		
Independent variable	**(1) Eastern**	**(2) Central**	**(3) Western**
DID	0.132**[a]	0.006	−0.021
	(0.051)	(0.023)	(0.019)
PWR	0.035	0.006	0.000
	(0.045)	(0.009)	(0.002)
YERP	−0.000	−0.000	−0.000
	(0.000)	(0.000)	(0.000)
UR	0.002	0.001	−0.001
	(0.007)	(0.001)	(0.000)
EIA	0.000	−0.000	0.000***
	(0.000)	(0.000)	(0.000)
PAVTIG	0.006	−0.001	−0.002*
	(0.009)	(0.001)	(0.001)
CPI	−0.031	−0.003	−0.006**
	(0.033)	(0.002)	(0.002)
RD	0.004	0.022*	0.010**
	(0.088)	(0.012)	(0.004)
_cons	3.709	0.845**	1.553***
	(3.517)	(0.335)	(0.288)
Province_FE	Yes	Yes	Yes
Year_FE	Yes	Yes	Yes
N	99	72	99
R^2	0.411	0.321	0.492

PWR, the natural logarithm of water resources per capita; YERP, year-end resident population; UR, urbanization rate; EIA, effective irrigation area; PAVTIG, the proportion of the added value of the tertiary industry in GDP; CPI, consumer price index; RD, the natural logarithm of R&D expenditure of industrial enterprises above designated size.

[a] The standard errors adjusted by province-year clustering are in brackets; ***, ** and * indicate significance at the levels of 1, 5 and 10%, respectively.

6. FURTHER DISCUSSION

Water resources are the lifeblood for regional development and human survival (Tian *et al.*, 2020). The rational utilization and development of water resources support and guarantee the sustainable growth of the regional economy, which has become a national concern and focus (Roozbahani *et al.*, 2015). With the rapid development of economic and trade globalization, the water resource system has undergone profound changes due to excessive water consumption and pollution, posing a huge threat to sustainable development (An *et al.*, 2021; Malakar & Lu, 2021). From the perspective of foreign experience, water resource tax policy, as an economic tool to control the demand for water resources and protect the water environment, has been adopted by many countries worldwide (He & Chen, 2021). Based on foreign water resource management policies, the Chinese government has explored the Chinese characteristics of the water resource tax policy model. Additionally, evaluating water resource-use efficiency to guide water management decision-making was one of the most important issues to ensure the effective and sustainable utilization of water resources (Song *et al.*, 2018). Currently, no one has studied the impact of the water resource tax policy implemented in different time periods on WRUE. Therefore, using the panel data of 30 provinces (municipalities) in China from 2011 to 2019, this study uses the double difference method to evaluate the 'net impact' and attempts to analyse its impact mechanism.

This study used a DID benchmark regression model to test Hypothesis 1. The findings show that the water resource tax policy can effectively improve the WRUE of the implementation provinces (municipalities) and that the water efficiency value of the implementation province (municipalities) was increased by an average of 4.4 percentage points compared with other non-implementation provinces (municipalities). This may be because that taxation was more compulsory and normative compared with water resource fees, thereby strengthening the ability of the government to regulate and control the use of water resources (Liu & Liu, 2021). Additionally, the water resource tax policy adds the social cost of water users to the production cost through taxation, which internalizes the external cost, solving the issue of water resource allocation efficiency to a certain extent (Huang & Li, 2016). Furthermore, the implementation of differential tax rates, such as higher tax standards for groundwater use in groundwater overexploitation areas and lower tax rates for mining drainage recycled by enterprises, limits groundwater exploitation and water consumption industries and encourages enterprises to recycle water, which contributes to the conservation and efficient utilization of water resources (Wang *et al.*, 2017). Last but not least, with the orderly and steady progress of reform, several enterprises actively change their way of water use, strengthen investment in technological innovation, and implement water conservation measures, which ultimately improve the utilization level of water resources (Liu *et al.*, 2019). Hypothesis 2 of this study proposed that a water resource tax policy can improve WRUE by improving and optimizing resource allocation. The results showed that the impact of the water resource tax policy on the scale efficiency of water resource utilization was 0.032, which was significant at the 10% level, thus verifying Hypothesis 2. Optimal resource allocation refers to the reasonable allocation of limited resources to achieve high production efficiency and a substantial increase in economic benefits. Specifically, the sustainable use of water resources was affected by economic, social and environmental aspects, and multi-objective resource optimization and balance can effectively solve water resource problems (Davijani *et al.*, 2016; Ghazali *et al.*, 2018). Increased investment in other resources will drive regional economic growth (He *et al.*, 2020), play a certain role in improving the utilization efficiency of water resources, and increase scale efficiency. With the expansion of the production scale, such scale benefits become increasingly obvious, improving the utilization rate of water resources (Tian *et al.*, 2020).

Furthermore, this study validated Hypothesis 3 through spatial heterogeneity analysis. The results show that compared with the central and western regions, the policy had a more pronounced effect on the eastern region and increased the water-use efficiency of the implementation provinces (municipalities) by an average of 13.2%. The reason may be that the water resource situation in the central and western regions was more complex and serious. First, the central and western regions are the most important water shortage areas in China. Although there has been a 'warm and wet' trend in recent years (Chen *et al.*, 2015; Wang *et al.*, 2020), the pressure on water resources was still high (Bajracharya *et al.*, 2018). Second, the water shortage in the central and western regions, especially the northwest region, coupled with overdevelopment, such as logging, has resulted in an extremely fragile ecological environment, leading to the degradation of water ecology and restricting the construction of a water ecological civilization (Zou & Cong, 2021). Third, due to the relatively developed industrial economy in the central region, there were many industrial and mining enterprises with high pollution probability, leading to more water pollution and environmental incidents, which implied the emergence of a water resource crisis (Wei *et al.*, 2021). Therefore, compared with the central and western regions, the policy will be more effective in the eastern region (Zhang *et al.*, 2020).

7. CONCLUSIONS AND IMPLICATIONS

Based on panel data from 30 provinces (municipalities) in China from 2011 to 2019, this study performed a quasi-natural experiment on the water resource tax implementation areas and used the DID method to explore the 'net effect' of water resource tax policies on raising water resource utilization efficiency. Additionally, this study conducted a robustness analysis through parallel trend testing and common trend testing. It also discussed the impact mechanism of the water resource tax policy on WRUE from the aspect of optimizing resource allocation. Finally, through spatial heterogeneity analyses, the study tested whether the policy has spatially heterogeneous effects. The results showed that China's water resources tax policy can effectively improve WRUE. They also showed that water resource tax policies can improve WRUE by optimizing resource allocation. In addition, there were obvious regional differences in WRUE among provinces (municipalities) in China, and the WRUE in the central and western regions was relatively low. Therefore, the empirical study also found that compared with the central and western regions, the policy had a more significant effect on improving water-use efficiency in the eastern region.

In view of the above conclusions, the following policy recommendations were proposed. First, the implementation scope of water resource tax policies should be expanded. The research shows that the water resource tax policy can effectively improve the efficiency of water resource utilization, which fully showed the importance of the water resource tax policy for breaking through the bottleneck of water resources and improving the efficiency of water resource utilization. Therefore, the Chinese government should further expand the implementation scope of the water resource tax policy and promote it throughout the country. Second, water resource tax policies should be implemented accurately and effectively. The policy had a stronger effect on improving water resource-use efficiency in eastern China. Therefore, the government should continue to strictly implement the policy of the water resource tax in the eastern region. Additionally, due to differences in water resource endowments and economic development in China's provinces (municipalities), the water resource issues faced by various regions will also differ. Therefore, the implementation of the policy should be adjusted to local conditions, and each region should choose a local water resource tax incentive model to give full play to the role of the policy of water resource tax in improving the efficiency of water resource utilization.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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