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Evaluating the impact of water resource fee-to-tax reform pilot on total factor water utilization efficiency: empirical evidence from Hebei Province, China

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ABSTRACT

Scientific evaluation of the impact of water resource fee-to-tax reform pilot on total factor water utilization efficiency in Hebei Province provides empirical evidence to inform further refinements of water resources tax system. Using 2010–2020 provincial panel data and the synthetic control method, our study reveals that the reform pilot in Hebei has indeed yielded a promotion effect on total factor water utilization efficiency, and notably, this policy shows a "policy-precedence" characteristic. Nevertheless, as the policy progressed, a diminishing effect became apparent in the later stages of its execution. Based on the above conclusions, policy recommendations are put forward such as promote pilot experiences in Hebei, differential water resource fee-to-tax reforms, and keep assessing and consolidate the trend of increasing policy effects.

Keywords: Water resource fee-to-tax reform; Pilot policy effect; Total factor water utilization efficiency; Synthetic control method

1. Introduction

A crucial and strategic concern for the long-term sustainable growth of the global economy and society is the sustainable use of water resources. Approximately 10% of the world's population, according to the United Nations World Water Development Report 2023, released by UNESCO on World Water Day (March 22, 2023), lives in nations with a severe or extreme water scarcity. China is among the nations that are experiencing a serious water deficit, especially at this time of year. China has 2.7 trillion m^3 of total water resource as of 2022, which makes up about 6% of all water resources worldwide. However, the water resource per capita amount to only 2,300 m^3, which is one-third of the global average water resource per capita. According to the China Water Resources Bulletin 2022, there are problems with the illogical growth of hydropower resources and the unequal distribution of water resources in China across time and space [1]. Due to these issues, the gap between the supply and demand of water has gotten worse, making water scarcity a barrier to China's sustainable growth.

The key to the sustainable use of water resources is to strengthen water resource management and improve water efficiency. China's water management system is constantly being reformed and improved. In 1979, attempts to collect water resource fees began in Shanghai, Shanxi, and other places. In 1988, the Law of the People's Republic of China on Water for the first time established the legal status of water resource fees; immediately after that, in 1993, the State Council issued the Water Permit and Water Resource Fee Collection Management Regulations, which gave specific legal basis for water resource fee collection [2]. In 2013, the National Development and Reform Commission, together with several ministries, issued the Notice on the Standards of Water Resources Fee Collection, which clarified the standard management approach to water resources cost collection. However, there are problems such as low pricing, high subjectivity and arbitrariness of the subject of the collection, a low actual levy rate, and a lack of regulation,

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leading to prices that do not effectively reflect the scarce water resources, restricting the protection of water resources, and making it difficult to adapt to the concept of green development [3,4]. Therefore, the progressive implementation of the tax on water resources at the national level has increasingly become the theoretical and policy consensus in order to offset this disadvantage and further promote the conservation, preservation, and rational use of water resources.

The announcement on the Comprehensive Advancement of Resource Tax Reform was jointly released by the Ministry of Finance and the State Taxation Administration on May 9, 2016. The pilot program on water resource fee-to-tax reform was started in July of the same year in Hebei province, which has seriously utilized groundwater. The pilot's scope steadily increased after observations and summaries of over a year of pilot experience were provided. The State Administration of Taxation, the Ministry of Finance, and the Ministry of Water jointly released the "Water Resource Fee-to-Tax Reform Pilot Implementation Region-expansion" in November 2017, which announced a new round of pilot reform province lists, containing nine provinces with different geographical location, level of economic development, and level of water resource abundance began to undertake water resource fee-to-tax reform (WRFTR) pilot, respectively for Beijing, Tianjin, Shanxi, Inner Mongolia, Shandong, Henan, Sichuan, Shaanxi and Ningxia, thus forming the "1+9" water resource fee-to-tax reform pilot pattern. The national level exemplifies the relevance of water resource fee-to-tax reform in the building of a sustainable economic system for the development of a green cycle, given the pressing need for reform and the steady growth of the pilot program. Seven years have passed since the implementation of the water resource fee-to-tax reform pilot in Hebei, and the impact of this pilot can be investigated to offer direction and a point of reference for future iterations aimed at improving the pilot's efficacy and expanding the water resource tax throughout the remaining provinces in China.

The study of water resource taxation abroad is relatively early and has grown to maturity. It is widely recognized that a water resource tax is a "green" and "win-win" type of tax, which not only effectively reduces resource exploitation but also improves resource efficiency [5–9]. But there are scholars who argue that developing countries such as Uganda lack experience in managing the collection of water resource taxes, and the pilot policy effect needs further consideration [10].

There are two stages to the current research on China's water resource tax. The first phase is before the water resource fee-to-tax reform. On the basis of summarizing the experience of foreign countries in levying water resources tax, many academics of this period investigated issues such as the need for water resource fee-to-tax reform in China [11] and its theoretical underpinnings [12], as well as the proposal for water resource tax collection guidelines and recommendations [13–15].

The second stage refers to the period from the initiation of the water resource fee-to-tax reform pilot project in Hebei Province to the present. During this period, scholars have explored the achievements of the WRFR from various perspectives, including water-saving awareness among businesses, water withdrawal volumes, and the demonstrative effects of the reform. The main focus has been on two aspects. On the one hand, relevant studies involved analysis of the current status of the taxation system, existing issues, and recommendations regarding the water resource tax. For instance, Ren [16] discussed the optimal approach to WRFR from a fairness perspective. Yue and Qian [17] argued that the current tax reform might lead to the occurrence of a "resource curse" and provided policy recommendations for harmonizing resource taxes, fees, and rents. Furthermore, some scholars have explored the possibilities of water resource fee-to-tax reform in regions such as western China [18]. Additionally, scholars approached the topic from an industry perspective, summarizing issues in the theoretical and practical aspects of taxing agricultural water utilization [19]. On the other hand, there is an assessment of the efficacy and accumulated experience pertaining to water resource fee-to-tax reform in pilot areas. By analyzing the characteristics and reform outcomes in water resource tax pilot regions and summarizing the practical experience in these pilot areas, scholars have proposed policy recommendations for improving the water resource tax system and its comprehensive nationwide implementation [20]. Scholars have conducted quantitative comparisons based on relevant indicators and found that after the implementation of water resource fee-to-tax reform, Initial water-saving effects that can be demonstrated include the reduction of groundwater extraction, the raising of enterprise awareness of water conservation, the alteration of water consumption structures in particular industries, and the adoption of water-saving measures by water-intensive enterprises in the pilot provinces [21–23]. In summary, it can be observed that most studies have predominantly consisted of qualitative descriptions or brief statistics. Only in recent years have a small fraction of scholars started to employ quantitative methods such as the Difference in Differences (DID) method to assess the impact of water resource fee-to-tax reform on water consumption and water resource utilization efficiency. These studies have been conducted in specific regions, including Hebei [24], or in all pilot areas [25–27].

The aforementioned studies have significantly deepened our understanding of the effects of water resource fee-to-tax reform pilot projects on water resource utilization efficiency. However, there are some limitations. Firstly, the majority of the literature analyzing the effects of water resource fee-to-tax reform pilot projects tends to employ a comparative analysis method, directly contrasting relevant data before and after the pilot projects in the pilot provinces. This approach is used to measure the impact of water resource fee-to-tax reform pilot projects. However, given that water resource utilization efficiency in non-pilot provinces has generally improved during the same period, it becomes challenging to isolate the influence of water resource fee-to-tax reform pilot areas on water resource utilization efficiency. Secondly, existing literature primarily uses two indicators, namely, water consumption per 10,000 yuan of GDP and water resource utilization efficiency, to gauge water resource utilization efficiency. Measuring water utilization efficiency with water consumption per 10,000 yuan of GDP offers the advantages of simplicity and objectivity, making it easy to compare. Conversely, water resource utilization efficiency reflects the comprehensive productivity of multiple factors and is often calculated using methods such as Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA). However, different calculation methods can yield significantly different results, and they often fail to consider the comparison of non-expected outputs and the already efficient part of DEA. Thirdly, the commonly used Difference-in-Differences (DID) method may exhibit subjectivity and arbitrariness when selecting control groups. Furthermore, since policies are generally endogenous and there are systematic differences between pilot provinces and other provinces, these factors may lead to biased estimation results in the research.

Given this context, we embark on our research, guided by the principle of "pilot first, gradual expansion", with a central focus on investigating how water resource fee-to-tax reform influences total factor water resources utilization efficiency (TWUE).

Compared to previous work, the contributions are listed below.

- To provide a more scientifically rigorous evaluation of the current state of water resources utilization, our study employs a super slack-based measure, which incorporates both non-radial and non-angular aspects in assessing total factor water utilization resources efficiency (TWUE). This represents a valuable attempt to obtain a more precise and realistic assessment of water resource utilization.
- Our study employs the synthetic control method, which leverages data-driven techniques to construct a control group specific to Hebei. This approach can effectively mitigate the challenge of matching experimental and control groups. Furthermore, we conduct robustness check such as placebo tests to validate the stability of our results. This enriches the existing body of research findings and aims to provide robust data support and policy insights for future WRFR.
- Our study findings implicate that WRFR pilot in Hebei has a certain promotion effect on TWUE, and it shows a "policy-precedence" characteristic. Nevertheless, we observed a "fatigue" phenomenon during the later stage of policy implementation.

2. Pilot policy background

Water resources are relatively unevenly distributed spatially in China. Based on the water resource per capita data from the 2022 China Statistical Yearbook, among the 31 provinces and regions excluding Hong Kong, Macao, and Taiwan, there are 4 provinces facing extreme water scarcity, 6 provinces experiencing severe water scarcity, 4 provinces with moderate water scarcity, 6 provinces with mild water scarcity, and only 9 provinces that are not facing water scarcity (Fig. 1 and Table 1).

Taking specific data into account, it can be observed that in 2010 and 2016, the total water resources in Hebei Province were 13.781 and 20.831 billion m^3, respectively. Water resource per capita in these years were 195.3 and 279.7 m^3, significantly below the internationally recognized extreme water scarcity threshold of 500 m^3. Due to the severe water resource shortage, Hebei Province has heavily relied on over-extracting groundwater to sustain economic and social development. This excessive groundwater extraction has triggered a series of geological and ecological disasters. Implementing effective measures to enhance water efficiency has become an urgent priority. Therefore, in February 2016, Hebei Province was selected as a pilot region for water resource fee-to-tax reform by the national government. In July of the same year, as the first pilot province, the People's Government of Hebei Province issued the "Implementation Measures for the Pilot Reform of Water Resource Tax in Hebei Province" (Table 2), taking the lead in implementing the reform of replacing water resource fees with taxes.

Based on the table analysis, it can be observed that water resources are relatively scarce in Hebei province. To promote the protection and rational use of water resources, tax enforcement measures can be implemented. Specifically, differential tax rates, control of groundwater extraction, and regulation of excessive water consumption are employed to establish a water resource tax management mechanism characterized by "water resource approval, tax declaration, tax collection, joint supervision, and information sharing". Since the pilot implementation on July 1, 2016, until the end of the same year, more than 2,600 water extraction permits have been reissued in the province.

A total of 9.98 billion m^3 of taxed water was approved, resulting in the collection of water resource taxes amounting to 8.85 billion yuan, which was more than double the revenue generated from water resource fees during the same period in the previous year.

As the pilot program progressed, water conservation awareness significantly increased across various industries. Groundwater extraction decreased from 125.03 billion m^3 in 2016 to 88.16 billion m^3 in 2020. Additionally, there was an

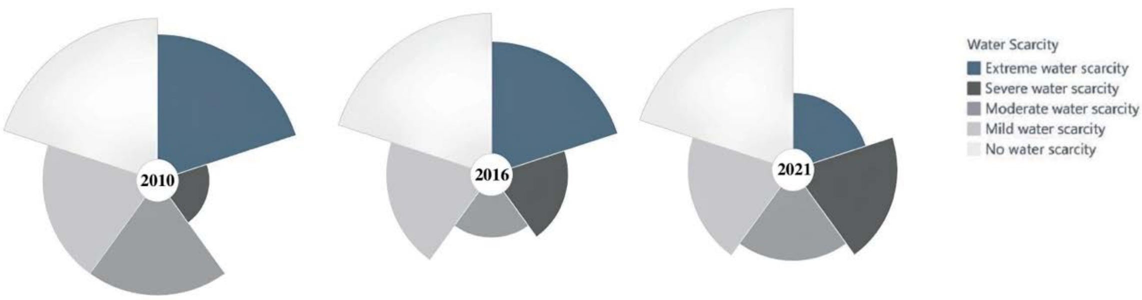

Fig. 1. Distribution of water scarcity in 31 Chinese Provinces (2010, 2016, and 2021).

Table 1
Detailed list of provinces with water scarcity in 31 Chinese Provinces (2010, 2016, and 2021)

Water scarcity	2010	2016	2021
Extreme water scarcity	Beijing, Tianjin, Hebei, Shanxi, Shanghai, Jiangsu, Shandong, Ningxia	Beijing, Tianjin, Hebei, Shanxi, Shanghai, Shandong, Henan, Ningxia	Beijing, Tianjin, Shanghai, Ningxia
Severe water scarcity	Henan, Gansu	Liaoning, Jiangsu, Shaanxi, Gansu	Hebei, Shanxi, Jiangsu, Shandong, Henan, Guangdong
Moderate water scarcity	Inner Mongolia, Liaoning, Anhui, Guangdong, Chongqing, Shaanxi	Inner Mongolia, Jilin, Chongqing	Liaoning, Jilin, Anhui, Fujian, Gansu
Mild water scarcity	Jilin, Heilongjiang, Zhejiang, Hubei, Hunan, Guizhou	Heilongjiang, Zhejiang, Anhui, Hubei, Guangdong, Sichuan	Zhejiang, Hubei, Hunan, Chongqing, Guizhou, Shaanxi
No water scarcity	Fujian, Jiangxi, Guangxi, Hainan, Sichuan, Yunnan, Tibet, Qinghai, Xinjiang	Fujian, Jiangxi, Hunan, Guangxi, Hainan, Guizhou, Yunnan, Tibet, Qinghai, Xinjiang	Inner Mongolia, Heilongjiang, Jiangxi, Guangxi, Hainan, Sichuan, Yunnan, Tibet, Qinghai, Xinjiang

Note: In the water scarcity classification, when water resource per capita are below 500 m^3, it is categorized as extreme water scarcity; below 1,000 m^3, it is considered severe water scarcity; below 2,000 m^3, it falls under moderate water scarcity; below 3,000 m^3, it is classified as mild water scarcity; and above 3,000 m^3 per capita is categorized as not experiencing water scarcity.

Table 2
Clarifications and important contents of the Hebei Province water resource fee-to-tax reform pilot

Clarifications	Important contents
Water resource taxpayers	Entities and individuals who directly utilize water resources from rivers, lakes (including reservoirs), and groundwater through water intake projects or facilities are considered water resource taxpayers. They are required to apply for water intake permits in accordance with regulations.
Taxable and exempt objects	Taxable objects: Surface water and groundwater Exempt objects: Emergency water utilization, agricultural production water utilization within prescribed limits, etc.
Taxation method	Taxation is based on the quantity of water used. However, significant increases in the tax rate apply to excessive water consumption beyond the planned allocation, with rates being doubled for use exceeding the planned allocation by 20% or less, 2.5 times for use exceeding the planned allocation by 20% to 40%, and 3 times for use exceeding the planned allocation by over 40%.
Tax rate standards	Tax rate standards are established separately for surface water and groundwater by industry. For agricultural producers exceeding the prescribed limits, the rate is set low at 0.1 RMB/m^3 for surface water. Specialized industries have a higher tax rate, set at 10 RMB/m^3. For groundwater, agricultural producers exceeding the prescribed limits are taxed at a rate of 0.2 RMB/m^3. For industrial, commercial, specialized industries, and other sectors, the rates vary based on non-overexploited areas, general overexploited areas, and severely overexploited areas, ranging from 1.4 to 6 RMB/m^3 for industrial and other sectors and from 20 to 80 RMB/m^3 for specialized industries.

Source of information: Compiled by the author based on "Implementation Measures for the Water Resource Tax Reform Pilot in Hebei Province" (Hebei Provincial Government [2016] No. 34).
Note: Values such as tax rates are presented in RMB (Chinese Yuan)/m^3).

improvement in the water shortage situation. However, it is important to note that these improvements cannot be solely attributed to the implementation of water resource fee-to-tax reform. They may also be influenced by certain common factors between pilot and non-pilot provinces. Therefore, empirical methods are needed to conduct a thorough analysis of the underlying reasons for these improvements.

3. Methodology and data

3.1. Influence path analysis

The theory of environmental regulation and the application of the fee-to-tax reform on water resources in Hebei Province suggests that the conversion of the fee-to-tax reform on water resources can affect the TWUE from three angles: the market, the government, and businesses and other social entities (Fig. 2).

Firstly, in particular, enterprises and other social entities may become more conscious of and proactive in water conservation as a result of the water resource fee-to-tax reform. Water resource taxes are more restrictive than fees because they force businesses and other social entities to use water resources more wisely and effectively. This prevents unreasonable demands for water resources, lessens water waste and misuse, and eventually encourages improvements in TWUE.

Furthermore, a tax on water resources might encourage the development and improvement of market mechanisms that encourage the trading of water rights. Hebei province's water resource fee-to-tax reform optimizes the water resource tax pricing system by using strategies like volumetric taxation, tax and fee translation, and limiting excessive water consumption. In order to guarantee that water pricing can more precisely reflect market changes and effectively use taxes to limit water resource use, hence promoting the improvement of TWUE, this seeks to build a standardized, rational, and efficient system for taxing water resources.

Finally, the water resource endowment of the various Chinese provinces varies significantly, as can be seen in Fig. 2. The government must control regional variations in water resources and handle externalities associated with water resources in order to safeguard the interests of water resource users and take fairness into account. The government requires enough financial support in order to carry out these programs and initiatives. One of the main sources of fiscal income for governments is taxation, and converting water resource fees into taxes can give local governments more funding. In the end, this improves TWUE by supporting the government's tasks in regulating and coordinating the allocation of regional water resources, in addition to helping local governments fulfill their financial spending demands.

3.2. Methodology

3.2.1. Super slack-based measure model

For the purpose of quantifying the TWUE in a more scientific way, we construct a non-radial, non-angular super SBM (Super Slack-Based Measure) model that takes undesirable outputs into account. Slack variables are introduced in this model to consider the degree of relaxation in resource utilization while also enabling a further comparison of regions that are DEA efficient in resource utilization to achieve a comprehensive identification of water-saving potential.

$$\varphi^* = \min_{\lambda, s^-, s^+} \frac{1 + \frac{1}{m}\sum_{i=1}^{m} \frac{s_i^-}{x_{io}^t}}{1 - \frac{1}{q+h}\left(\sum_{r=1}^{q} \frac{s_r^+}{y_{ro}^t} + \sum_{k=1}^{h} \frac{s_k^-}{b_{ko}^t}\right)}$$

$$\begin{aligned} s.t.\ x_{io}^t &\geq \sum_{t=1}^{T} \sum_{j=1, j\neq o}^{n} \lambda_j^t x_{ij}^t - s_i^- \quad i = 1,2,\ldots,m; \\ y_{ro}^t &\leq \sum_{t=1}^{T} \sum_{j=1, j\neq o}^{n} \lambda_j^t y_{rj}^t + s_r^+ \quad r = 1,2,\ldots,q; \\ b_{ko}^t &\geq \sum_{t=1}^{T} \sum_{j=1, j\neq o}^{n} \lambda_j^t b_{kj}^t - s_k^- \quad k = 1,2,\ldots,h; \\ \lambda_j^t &\geq (\forall j), s_i^- \geq (\forall i), s_r^+ \geq (\forall r), s_k^- \geq (\forall k) \end{aligned} \tag{1}$$

where φ is the calculated TWUE. When φ ≥ 1, it indicates that the decision-making unit is in a strong effective state; when φ < 1, it indicates that there is an efficiency loss in the decision-making unit. x,y,b represent input, expected output and undesired output, respectively. s_i,s_r,s_k are the slack variables of the three, respectively.

3.2.2. Synthetic control method

The Synthetic control method (SCM) is a non-parametric approach that improves upon the limitations of traditional policy evaluation methods. It helps reduce the bias in subjective selection and avoids endogeneity issues in policy assessments. In recent years, it has been widely used in settings where a single aggregate unit, such as a province or country, is exposed to a non-random event or policy.

In this context, based on panel data from Hebei province covering the years 2010–2020, we used SCM to assess the impact of Hebei province's water resource fee-to-tax reform on its TWUE. Since each province has unique characteristics due to differences in natural endowments, finding a highly similar control group to Hebei province is quite challenging. Therefore, following the "counterfactual" approach proposed by Abadie et al. [28], the study applies a data-driven approach to assign weights to 20 provinces that did not adopt the WRFR pilot[1]. These weights are used to synthesize a "synthetic Hebei" that closely resembles Hebei's characteristics. This ensures that the "Synthetic Hebei" can comprehensively simulate the situation in Hebei Province without the implementation of the water resource fee-to-tax reform. The difference in TWUE between the "Real Hebei" and the "Synthetic Hebei" can be interpreted as the net effect of the water resource fee-to-tax reform pilot on TWUE. The application of this approach makes it possible to separate the reform's effects from other causal factors.

The specific model is as follows. A total of $n + 1$ provinces are present, with Hebei (the province in which the water resource fee-to-tax reform pilot was executed) designated as province 1 and the remaining n provinces—where the reform was not conducted—as the other n provinces. Hebei Province's TWUE may be expressed as TWUE^1_{1r} when the water resource fee-to-tax reform pilot is implemented beginning in period T_0. On the contrary, Hebei Province's TWUE can be expressed as TWUE^0_{1r} when the water resource fee-to-tax reform pilot is not implemented. Eq. (2) may be used to indicate the effect of the water resource fee-to-tax reform pilot on the TWUE of Hebei Province after period T_0, which is represented as α_{it}.

$$\alpha_{1t} = \mathrm{TWUE}_{1t}^1 - \mathrm{TWUE}_{1t}^0 \tag{2}$$

However, due to the irreversibility of the fee-to-tax reform pilot implementation, we are unable to acquire

[1] This paper focuses on the policy effects of Hebei Province's WRFR pilot on TWUE. Since the TWUE of the 9 provinces where the pilot was conducted in 2017 would also be influenced by the water resource fee-to-tax policy, they are not suitable as a control group. Therefore, the control group solely contains the other 20 provinces that did not adopt the WRFR pilot (excluding the Hong Kong, Macau, and Taiwan) in order to appropriately represent the impact of Hebei Province's water resource tax reform.

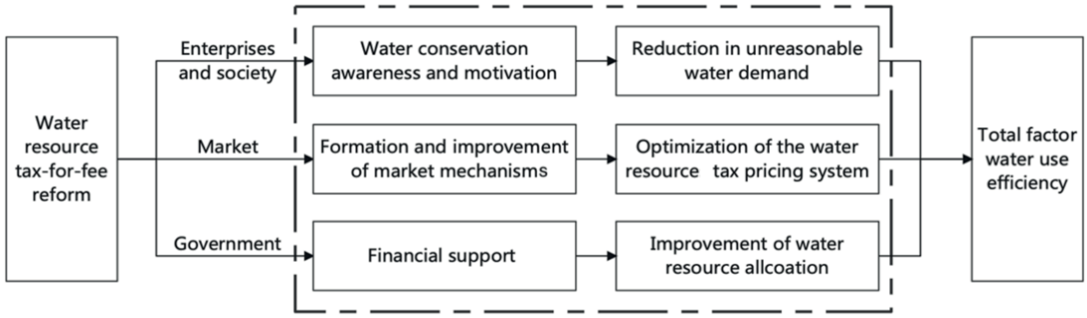

Fig. 2. Influence path of WRFR's impact on improving TWUE.

$TWUE^0_{1t}$ directly. Therefore, following the "counterfactual" approach, we derive an estimate model for $TWUE^0_{1t}$ as displayed in Eq. (3).

$$\mathrm{TWUE}^0_{1t} = \delta_t + \theta_t P_i + \lambda_t \eta_i + \varepsilon_{it} \quad (3)$$

where δ_t represents the influence of the time trend, P_t is the characteristic variable unaffected by the water resource fee-to-tax reform, and $E(\varepsilon_{it}) = 0$.

Construct a weight vector with dimensions of $m \times 1$, denoted as $W = (w_2, w_3, \ldots, w_{m+1})$, where w represents the proportion of the performance of the control group in simulating the impact of the water resource fee-to-tax reform in Hebei Province. All w values are greater than or equal to 0, and $w_2 + w_3 + \ldots + w_{m+1} = 1$.

In this context, $TWUE^0_{1t}$ can be further expressed as shown in Eq. (4).

$$\sum_{m=2}^{m+1} w_m \mathrm{TWUE}^0_{1t} = \delta_t + \theta_t \sum_{m=2}^{m+1} w_m P_m + \lambda_t \sum_{m=2}^{m+1} w_m \eta_i + \sum_{m=2}^{m+1} w_m \varepsilon_{it} \quad (4)$$

The ideal weight vector $W^* = \left(w_2^*, w_3^*, \ldots, w_{m+1}^*\right)'$ may be obtained if the period before policy implementation is greater than the period after implementation. This puts $TWUE^0_{1t}$ and n extremely near to $\sum_{m=2}^{m+1} w_m \mathrm{TWUE}^n_{it}$ [29].

Consequently, the estimated effect of the water resource fee-to-tax reform pilot on the TWUE of Hebei Province $\left(\widehat{\alpha_{1t}}\right)$ can be expressed as Eq. (5).

$$\widehat{\alpha_{1t}} = \mathrm{TWUE}^1_{1t} - \mathrm{TWUE}^0_{1t} = \mathrm{TWUE}^1_{1t} - \sum_{m=2}^{m+1} w_m \mathrm{TWUE}^n_{it} \quad (5)$$

Table 3
TWUE evaluation index system

		Index
Input	Labor input	Employment at the end of the year (10,000 people)
	Capital input	Capital stock (100 million yuan)
	Resource input	Total water consumption (100 million m^3)
Output	Desirable output	Real GDP (100 million yuan)
	Undesirable output	Chemical oxygen demand (10 thousand tons)
		Carbon dioxide emissions (10 thousand tons)

Note: Real GDP was calculated at constant prices in 2010 as the desirable output of each province.

3.3. Variable selection

This study investigates the impact of WRFR pilot on TWUE in Hebei Province, with a particular emphasis on the consequences of pilot policy implementation. The objective here is to ensure that synthetic Hebei can comprehensively mimic Hebei's TWUE. Therefore, TWUE was created as the dependent variable. Some external factors that may potentially influence TWUE had been identified, namely resource endowment, economic development and technological progress. These factors were designated as predictor variables.

3.3.1. Dependent variable

TWUE (as outlined in Table 3), which was gauged as the dependent variable, had been measured by a non-radial, non-angular Super SBM model, was calculated using indications from dimensions such as labor input, capital input, resource input, desirable output, and undesirable output.

3.3.2. Predictor variables

3.3.2.1. Resource endowment

Water resource per capita (WATERP) and effective irrigated area (EIA) were selected.

- Water resource per capita (WATERP, m^3 per person). Regional TWUE is strongly influenced by the amount of available water resources. Generally speaking, the "resource curse" hypothesis is also applicable to water resources, suggesting that an abundance of water resources might be linked to a decrease in TWUE since residents would be less aware of water conservation [30].

- Effective irrigated area (EIA, 1,000 hectares). Agriculture accounts for more than 70% of the total water consumption in Hebei Province. Water conservation in agriculture is therefore essential. EIA is a useful indicator for gauging the amount of water consumed in agricultural production units and areas since it may represent the irrigation water demand in agriculture.

3.3.2.2. Economic development

Real GDP per capita (RGDP), Urbanization level (URBAN) and Percentage of primary industry (PI) were selected.

- Real GDP per capita (RGDP, yuan per person). To eliminate the influence of price factors on regional GDP, we calculate RGDP for each province from 2010 to 2020, taking 2010 as the base year. Depending on the economic situation, the effects of economic growth on environmental quality can be complicated and variable. Diverse economic circumstances give rise to differences in the government's priorities and approaches to economic growth. Consequently, the degree of this influence is rather uncertain [31,32]. A higher GDP per capita might lead to two possible outcomes. On the one hand, increasing wealth may be associated with the overusing natural resources, which would lead to lower sensitivity to water prices and weaker water conservation awareness. On the other hand, there might be a progressive decrease in the readiness to exchange natural resources for economic growth in more developed countries, and citizens in these places may be more conscious of the need to save water. Regarding TWUE, there are both positive and negative forces, so the overall findings require further investigation.
- Urbanization level (URBAN, %). The proportion of the urban population to the total population in province was represented as URBAN. Compared to rural residents, urban residents tend to use water-intensive appliances more frequently. As a result, URBAN dramatically raises water consumption, thus affecting TWUE [33].
- Industry structure (Percentage of primary industry, PI, %; Percentage of secondary industry, SI, %; Percentage of tertiary industry, TI, %). Industrial structure is a key factor influencing TWUE in different provinces. The industrial structure of each province was measured using the percentages of primary, secondary, and tertiary industries.

3.3.2.3. Technological progress

Research and development expenditure by large-scale industrial enterprises (R&D, 10 thousand yuan). Water resource taxes, as a market-based environmental regulatory mechanism, can influence an enterprise's investment in technological innovation and research and development improvements. The improvement of TWUE is closely intertwined with technological progress. Technological progress can maximize the reduction of resource inputs, water consumption, and the release of undesirable outputs, including wastewater [34]. Thus, research and development expenditure by large-scale industrial enterprises (R&D) was selected to represent technological progress.

3.4. Data sources and descriptive statistics for the variables

The annual China Statistical Yearbook, the China Water Resources Bulletin, the China Economic Information (CEI) database and the Exome Sequencing Project (EPS) database are the main sources of data used in the study. Our study covers the period from 2000 to 2020, with the pretreatment period spanning from 2000 to 2015 and the post-treatment period ranging from 2016 to 2020.

Table 4 presents the descriptive statistics results of the organized variables.

It is clear from Table 4 that the 21 provinces' average TWUE for the study period was 0.3465. The wide variation between the lowest and greatest scores suggests that China's TWUE still needs big progress. Furthermore, there is a considerable variation of around 192 times in the water resource per capita, ranging from 89.12 to 17,107.35, indicating the unequal distribution of water resources in China.

4. Results

4.1. Impact of water resource fee-to-tax reform pilot on TWUE in Hebei

We employed STATA 17.0 software and used the SCM to construct the counterfactual "Synthetic Hebei". Table 5

Table 4
Descriptive statistics results

Variable	Observation	Mean	Std.	Min.	Max.
TWUE	231	0.3465	0.2582	0.1327	1.2738
WATERP	231	2,785.699	2,829.205	89.12	17,107.35
EIA	231	2,161.26	1,546.654	165.05	6,177.59
RGDP	231	51,255.99	25,373.54	13,119	157,279
URBAN	231	57.0176	11.4281	33.81	89.2749
PI	231	10.8855	5.4854	0.27	25.80
SI	231	41.5483	7.4670	19.30	54.71
TI	231	47.5626	7.1539	33.40	73.40
R&D	231	348.1371	482.4527	1.8334	2,499.953

reports the weight combination for "Synthetic Hebei", which consists of five provinces. Heilongjiang (34.50%) carries the highest weight, followed by Gansu (26.1%), Jiangsu (24.70%), and Anhui (13.9%), with Guangdong (0.8%) having the lowest weight.

Predictor variable balance is shown in Table 6.

The changes between TWUE in 2010 and 2015, when viewed in combination with Table 6, are merely 0.0017 and 0.0018, respectively. Additionally, there aren't many differences between the synthetic and genuine values of the other predictive variables. Thus, from 2010 to 2015, "Synthetic Hebei" was able to effectively match the circumstances of "Real Hebei".

Furthermore, by combining Figs. 3 and 4, it becomes more apparent that, firstly, before the water resource fee-to-tax reform pilot in 2016, the difference in TWUE between "real Hebei" and "synthetic Hebei" was extremely small, fluctuating within the range of –0.008 to 0.005. This suggests that synthetic Hebei provides close reproductions of the real Hebei. Then, after 2016, real Hebei exhibited a significantly higher TWUE compared to the synthetic one. This widening gap between the two indicates the existence of a promotion impact of the WRFR pilot in Hebei. Therefore, it can be concluded that WRFR has contributed to improving Hebei's TWUE. However, it is noteworthy that there is a declining trend in TWUE, implying that the policy's effectiveness may be diminishing, and a "fatigue" phenomenon is evident. Ensuring the continuity of the policy's impact is a pressing concern for the future. Moreover, it's important to highlight that the policy effect of the WRFR pilot in Hebei demonstrates a clear "policy-precedence" characteristic. Since Hebei was designated as the sole pilot province for WRFR by the central government in March 2016, it has consistently shown a statistically significant positive impact on TWUE at the 95% confidence level. This can be attributed to the proactive approach of the local government in Hebei, which has taken early measures to explore various aspects of the water resources management system and taxation system establishment. This proactive stance has allowed Hebei to serve as a leading example, amplifying the policy's demonstrative effect and facilitating the realization of desired outcomes.

Table 5
Weights of control groups in "Synthetic Hebei"

Province	Weight (%)
Heilongjiang	34.50
Gansu	26.10
Jiangsu	24.70
Anhui	13.90
Guangdong	0.80

4.2. Robustness test

The above study indicates that after the implementation of the water resource fee-to-tax reform pilot in Hebei in 2016, there is a difference in TWUE between "Real Hebei" and "Synthetic Hebei". However, the robustness and scientific validity of the results require further examination.

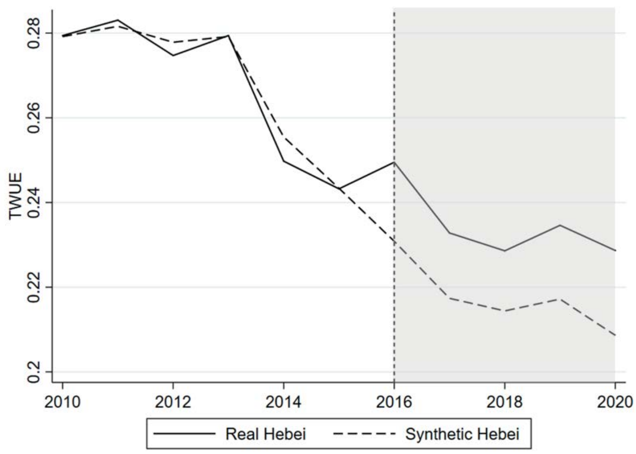

Fig. 3. Trends in TWUE: real Hebei and synthetic Hebei. Note: The shaded area represents the period of implementation of the pilot WRFR. The vertical dotted line represents time when Hebei takes to implement WRTR (2016).

Table 6
Predictor variable balance

Variable	Real Hebei	Synthetic Hebei
TWUE (2010)	0.2794	0.2777
TWUE (2015)	0.2432	0.2450
Water resource per capita (WATERP, m^3/person)	217.4283	392.292
Effective irrigated area (EIA, 1,000 hectares)	4,491.487	4,422.738
Real GDP per capita (RGDP, yuan/person)	36,394.83	33,386.65
Urbanization level (URBAN, %)	47.8596	50.2113
Percentage of primary industry (PI, %)	12.7	12.7033
Percentage of secondary industry (SI, %)	46.2667	46.2655
Percentage of tertiary industry (TI, %)	41.0167	41.0300
Research and development expenditure by large-scale industrial enterprises (R&D, thousand yuan)	207.3027	199.4863

4.2.1. Pre-event test

Pre-event test is carried out under the assumption that the water resource fee-to-tax reform pilot's start date was advanced to 2015.

Fig. 5 displays the test's outcomes. The patterns in "real Hebei" and "synthetic Hebei" may be shown to be closely linked prior to 2015, suggesting a strong fit. However, the difference fluctuated after 2015. This indicates that the water resource fee-to-tax pilot's net policy effect is, in fact, influencing the trend of change in TWUE in Hebei Province, provided that pertinent macroeconomic circumstances are under control.

4.2.2. Placebo test

For the robustness check, we performed placebo tests according to the permutation test proposed by Abadie et al. [28], which mainly be focused on the top four weighted provinces (refer to Table 5). Fig. 6a, b and d illustrate that the pre-2015 synthetic provinces closely align with the trajectory of TWUE changes in real provinces before WRFR

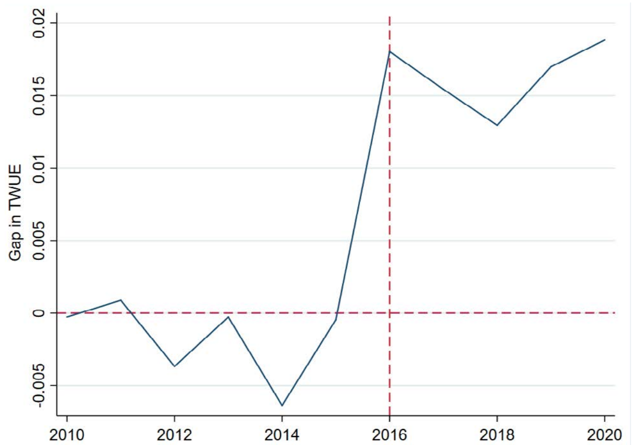

Fig. 4. Difference in TWUE between real Hebei and synthetic Hebei.

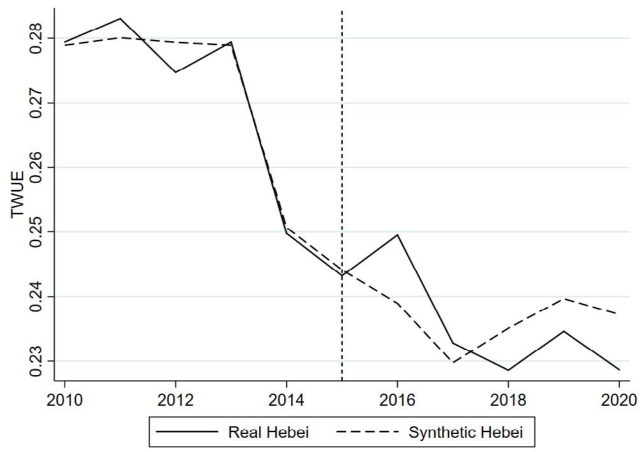

Fig. 5. Pre-event test result.

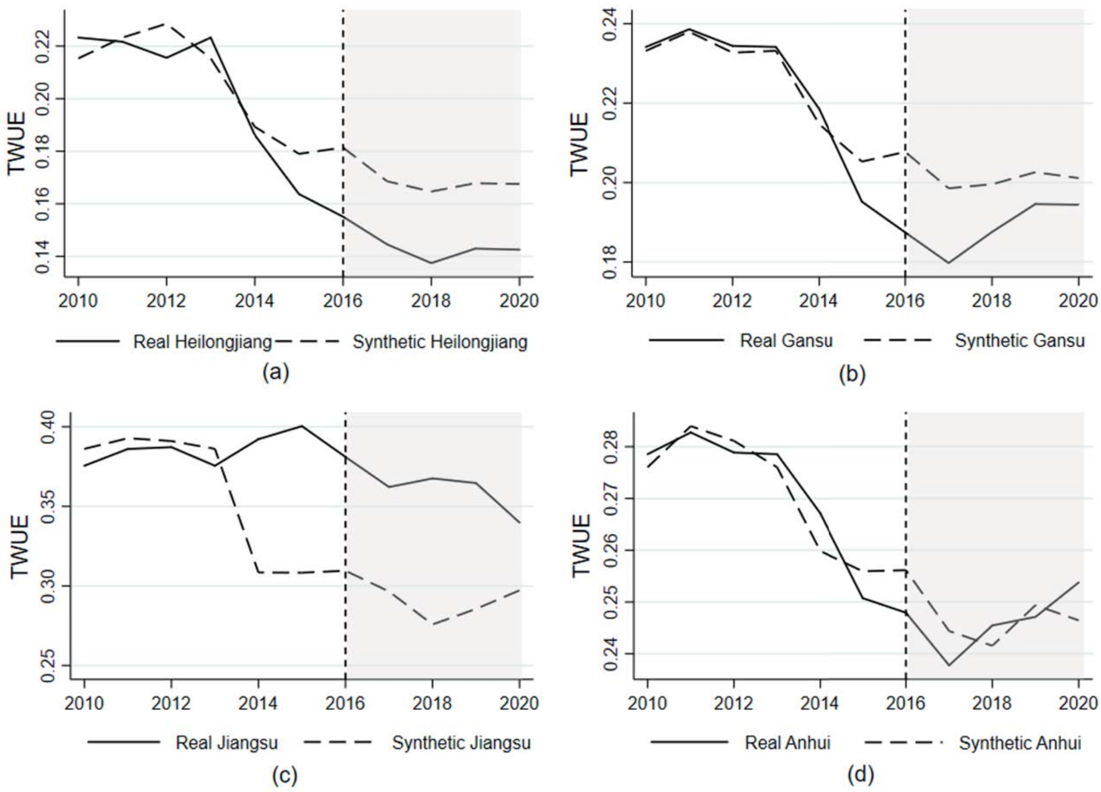

Fig. 6. Placebo tests results.

pilot, respectively. However, following the "hypothetical reforms", the TWUE of synthetic Heilongjiang and synthetic Gansu surpass their real values, while synthetic Guangdong exhibits only marginal divergence from the real value. All these contrast with Hebei, underscoring the robustness of the impact of WRFR on promoting TWUE in Hebei. Additionally, Fig. 6c reveals a notable disparity in TWUE between real Jiangsu and synthetic Jiangsu after the 2016 pilot program. Nevertheless, the pre-pilot fit is less satisfactory, suggesting that the difference in TWUE between real Jiangsu and synthetic Jiangsu is not necessarily attributable to the hypothetical WRFR.

The placebo test conducted above underscores that even provinces similar to Hebei do not experience an uptick in TWUE while implementing the pilot WRFR. Consequently, it can be inferred that WRSR in Hebei indeed contributes to an improvement in TWUE, rather than being a result of coincidental factors affecting other provinces simultaneously.

5. Conclusions and policy implications

The natural experiment of the water resource fee-to-tax reform pilot program in Hebei Province in July 2016 served as the basis for this article. The study uses the Synthetic Control Method to examine how the WRFR pilot affected Hebei's TWUE, with the other 20 provinces that did not execute the WRFR serving as the control group. Empirical findings suggest that, WRFR pilot in Hebei indeed contributes to its TWUE. Additionally, the decreasing trend in TWUE indicates a potential "fatigue" in its implementation, which highlights the need for further refinement and optimization of WRT policy and tax collection and management. Furthermore, it is noteworthy that WRFR pilot program in Hebei exhibits a pronounced "policy-precedence" characteristic. Further improvements and optimizations are needed in water resource tax policies and tax collection and management.

Based on the previous research findings and drawing from international experiences with water resource taxes, we have derived the following policy implications to enhance water resource management and improve TWUE in China. (1) Promote pilot experiences in Hebei. Encourage the promotion of successful pilot experiences in WRFR, particularly from Hebei province, to other regions in China, which can serve as a model for optimizing the water resource tax system. (2) Differential water resource fee-to-tax reforms. Consider implementing differential water resource fee-to-tax reforms that take into account the unique characteristics and resource endowments of different regions. Tailoring tax policies to local conditions may contribute to higher TWUE. (3) Expand the scope of pilot programs and grant provincial-level autonomy in designing their own water resource fee-to-tax reform plans. The government should expand the scope of pilot programs to help establish a robust economic system for green and circular development. And as water resource fee-to-tax reform is a governance policy at the provincial level, it allows each pilot province to develop its own water resource fee-to-tax reform plan based on local resource endowment, industry structure, and economic foundation. Given the limited binding nature of pilot policies, the varying policy effects across different provinces, and the real-time assessment of policy outcomes, the tax rate should be adjusted based on the scientific tax system design to achieve enhanced TWUE. (4) keep assessing and consolidate the trend of increasing policy effects in the tax rate design process. By continuously monitoring the impact of water resource fee-to-tax reforms, policymakers can make necessary adjustments to achieve improved TWUE and sustainable resource management.

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Data availability

Data will be made available on request.

Author contribution

All authors contributed to the study conception and design.

Duyun Peng: Conceptualization, Methodology, Validation, Data curation, Writing – original draft, Writing – review & editing.

Xiaoyu Liu: Conceptualization, Methodology, Writing – review & editing.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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