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Water markets and water rebounds: China's water rights trading policy

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ABSTRACT

Water markets aim to achieve water conservation and efficient allocation through market transactions. However, the presence of water rebounds may counteract this effect. Water markets and water rebounds have a complex interaction that has not been adequately explored in current studies. This study fills this research gap by developing an analytical framework connecting water markets and water rebounds and scrutinizing the causal linkage between them and the potential mechanisms involved within the context of China's water rights trading (WRT) policy. The findings have the potential to significantly impact water management strategies. We argue that water markets and water rebound mitigation—which is frequently linked with the capacity of water markets to improve water quality—are causally related. Furthermore, deploying water markets may also slow technological progress, resulting in reduced water efficiency and hence, an indirect mitigation of water rebounds. Lastly, the impact of water markets on water rebounds varies according to water availability and socioeconomic levels.

1. Introduction

Water is a vital natural and economic resource for human livelihoods and national security due to its scarcity and public good qualities (Rodina and Chan, 2019). The world economy is at risk from water pollution and unequal distribution due to rising economic activity and population growth worldwide (Weinzettel and Pfister, 2019). One viable option to deal with water scarcity is to utilize market systems to manage water effectively and equitably (Delorit and Block, 2018). The water market refers to allocating and optimizing water through market mechanisms to deal with water shortages (Bakker, 2014). As a result, water markets have drawn widespread interest and application in many countries and regions worldwide. For instance, the California water market in the United States (Colby, 1990), the Murray-Darling Basin in Australia (Crase et al., 2013), and the water markets in Chile and Mexico (Rosegrant and Binswanger, 1994) are considered models of water markets. Afterward, water markets began to be established in India, South Africa, Peru, and other nations (Bauer, 1997; Veettil et al., 2011). China also launched a pilot water market in 2014, known as the Water Rights Trading (WRT) policy. The WRT aims to maximize the efficiency of water allocation and encourage the rational use and conservation of water through market mechanisms.

Changes in water use efficiency (WUE) can also be brought about by water markets that employ market mechanisms to optimize the efficiency of water distribution (Liu et al., 2022). Water markets would make up for the original allotment of water rights (Molinos-Senante et al., 2016). Water users would be able to rationalize the allocation of resources through market instruments to increase WUE and ultimately save water (Shi et al., 2022). However, due to the water rebound effect (Ward and Pulido-Velazquez, 2008), water conservation from water efficiency improvements brought about by water markets may be substantially or even totally negated by the consequent new water demand (Greening et al., 2000; Xu and Song, 2022). The water rebound refers to the fact that water conservation due to increased WUE may be offset by additional water demand (Song et al., 2018). Unlike WUE and water conservation, water rebound focuses on unintended water use behaviors triggered by increased WUE. The intricate relationships between water markets and rebound effects have received limited attention in the literature. For example, water markets have been shown to improve efficiency while also exacerbating water demand through market

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behavior in the Murray-Darling Basin in Australia and in California in the United States (Crase et al., 2013; Lu et al., 2021).

Although research has explored the role of water markets in enhancing WUE (Bajaj et al., 2022; Delorit and Block, 2018; Zhang et al., 2024), less focus has been placed on the possible rebound effects triggered by water markets and their underlying mechanisms. As a result, the existing literature remains extremely limited and one-sided in its understanding of the utility of water markets. To develop a conceptual framework for understanding the causal link between water markets and rebound effects, this study compares and contrasts the body of research on water markets (Beck et al., 2010; Liu et al., 2022) with the literature on water rebounds (Fei et al., 2021; Song et al., 2018). The development of this conceptual work involves a thorough case analysis of China's WRT policy. This study makes the case that water markets and water rebound mitigation—which is frequently linked with the capacity of water markets to improve water quality—are causally related. Furthermore, the deployment of water markets may also slow technological progress, resulting in reduced water efficiency and hence, an indirect mitigation of water rebounds. Lastly, the impact of water markets on water rebounds varies according to water availability and socioeconomic levels.

The contributions are twofold. First, while an increasing amount of research has noted the influences of water markets on WUE (Liu et al., 2022; Pan et al., 2023) and the complicated association between WUE and water rebound effect (Freire-González, 2019), a limited number of studies have scrutinized the relationship between water markets and rebound effects. This study provides new evidence for the debate on the complex association between the two. Second, this study constructed a conceptual framework for the linkage between water markets and rebound effects to investigate potential processes by which water markets influence water rebounds from the perspectives of technological progress and water quality improvement. Thus, this study offers an initial conceptual framework for understanding the internal linkages between the two.

2. Theoretical framework and hypothesis development

Previous research has taken into account the possible mediation pathways of water markets for water rebounds, acknowledging the significance of technological progress. Water markets can utilize market mechanisms to reuse and efficiently allocate water (Jiang et al., 2016). Water markets encourage water users to adopt efficient water conservation techniques to shift water from low-value to high-value applications, thereby boosting WUE (Pan et al., 2023). However, increased WUE could potentially lead to higher water use as a result of decreased water scarcity, thus exacerbating the rebound effect (Berbel et al., 2015; Freire-González, 2019). Thus, water markets may promote advances in water conservation technologies, which in turn exacerbate water rebound. Based on the aforementioned analysis, this study suggests the following hypothesis:

Hypothesis 1. Water rebounds are exacerbated by water markets, which encourage technological progress in water conservation.

Studies that have already been done have acknowledged the significance of improving water quality while examining the relationship between water markets and rebound effects. Water markets are essentially market-oriented environmental regulations encouraging water pollution control behavior among water users (Sheng and Webber, 2021). Consequently, the valuation of water increases due to improved water quality (Shortle, 2017), which can discourage inefficient water use and waste (Bakker, 2014). For example, implementing a water market in China encouraged firms to implement end-of-pipe treatment, which ultimately significantly reduced water pollution and increased water productivity (Du et al., 2023). This increase in water availability and reduction in water wastage due to water pollution control has significantly dampened new water demand, which may help to curb water rebound. The following hypothesis is proposed as a result of the foregoing analysis:

Hypothesis 2. Water markets contribute to improved water quality and thus inhibit water rebounds.

Consideration must also be given to regional variations in water availability in order to comprehend the current discourse about the significance of water markets in water rebounds. Differences in water availability can also lead to differences in water prices between regions, which trigger differences in the water use behavior of local users (Liu et al., 2022). High-water availability areas usually have lower water prices compared to low-water availability areas. This could potentially discourage residential users from utilizing water-saving technologies (Tang et al., 2013) and impede the progress of water-saving production technologies (Qian et al., 2021). All these measures reduce WUE (Auty and Gelb, 2001), resulting in less significant water rebounds in high-water availability areas than in low-water availability areas. The following hypothesis is proposed as a result of the foregoing analysis:

Hypothesis 3. Water markets contribute more to suppressing water rebound in high-water availability areas than in low-water availability areas.

Lastly, the effect of the economic level is an inevitable part of the debate of water rebounds for water markets. Due to insufficient marketization, water markets in underdeveloped areas cannot allocate water as effectively as those in developed ones (Thirlwall, 1972). This also results in the typically higher cost of deploying water-saving technologies in underdeveloped areas, which inhibits water users from innovating in water-saving technologies (Nuruzzaman et al., 2019). Ultimately, underdeveloped areas may have more noticeable water rebounds than developed ones. In addition, water markets in underdeveloped areas also tend to be less efficient than in developed areas, predisposing them to higher water prices (Ge, 2009). This can dampen the water demand triggered by reconfiguring water markets, thereby increasing actual water conservation and ultimately suppressing water rebounds. Based on the aforementioned analysis, this study proposes the following hypothesis:

Hypothesis 4. Water markets help dampen water rebounds in underdeveloped areas more than in developed areas.

The study will explore the relationship between water markets and rebound effects and possible internal processes based on the previously indicated analytical framework. First, however, the case and methodology will be briefly described.

3. Materials and methods

In this section, the study will first describe China's WRT policy as a specific application of the water market. After that, the study will explain the estimation methodology for water rebounds and the empirical strategy to analyze the causal link between WRT and water rebounds. Finally, it will describe data sources.

3.1. China's WRT policy

As a typical water-scarce state, China's per capita water is barely 25 % of the global average. In China, water scarcity is a recurrent occurrence due to the unequal distribution of water among regions and years (Lu et al., 2021). China started attempting to trade water rights early on in an effort to reduce water consumption and save water. China's first WRT treaty was signed by Dongyang City and Yiwu City in 2000, raising awareness of the problem of water rights markets (Wang et al., 2017). In 2006, China's State Council issued a specialized WRT regulation, which explicitly stipulated that institutions and people with permits for water abstraction can transfer their water resources for a fee (State Council, 2006).

In an effort to bring previously fragmented WRT to a national scale, China launched a large-scale, formalized national pilot to conduct a water rights identification and trading program in 2014, thereby formalizing the WRT market. Seven provinces were selected as national pilot regions for the program. These pilot areas are spread throughout three regions of China: Inner Mongolia, Ningxia, and Gansu in the west; Guangdong in the east; and Henan, Hubei, and Jiangxi in the center (see Fig. 1). The availability of water, the use of water-saving technologies, and farming practices vary significantly between these regions. In addition, ten provinces in China are trying to establish provincial-level WRT markets (Liu et al., 2022). Subsequently, China established the China Water Exchange (CWE) in Beijing in 2016 with the goal of consolidating provincial and national WRTs into this single platform. The CWE acts as an intermediary in the purchase and sale of water rights and is able to commoditize water by enabling those who own water rights to transform them into a commodity that has value in the market (Bakker, 2014).

Currently, CWE transactions contain three types of transactions, including local WRT, abstraction WRT, and irrigation WRT (MWR, 2014). Currently, WRT in China mainly consists of irrigation, water abstraction, and local water rights trading. Local water rights trading is mainly carried out between counties and cities, while water abstraction rights trading involves the transfer of direct abstraction rights from water sources, and irrigation water rights trading is mainly for agricultural water usage (Sheng et al., 2024). In accordance with the National Water Rights Trading System (https://uc.cwexs.com/), as of the end of March 2024, China's WRT had accumulated 11,439 transactions, with 4.307 billion cubic meters of water traded.

3.2. *Measurement of water rebound*

Each province is first taken into account as a decision unit, according to Oh and Lee (2010). Assume that over the period $t = 1, 2, \ldots, T$. there are K ($i = 1, 2, \ldots, K$) provinces and that each province is able to produce M kinds of desired products ($y \in R_+^M$) and L kinds of non-desired products ($b \in R_+^L$) through the use of N kinds of inputs ($x, y \in R_+^N$). The following is the designation for the set of environmental production technologies:

$$P(x) = \{(y,b) : x \text{ can produce } (y,b)\} \tag{1}$$

where $P(x)$ is the set of environmental production technologies.

According to Chung et al. (1997), this study chooses to define $g = (g_y, -g_b)$ as a direction vector. Therefore, the equation as follows can be found:

$$D(x,y,b;g) = sup\{\beta : (y+\beta g_y, b-\beta g_b\Big) \in P(x)\} \tag{2}$$

where $D(\cdot)$ is the directional distance function. According to Oh Oh and Lee (2010), to get the technical efficiency of each province, the sum of each period is used as the global set of environmental production technologies and expressed as follows:

$$P^G = P^1 \bigcup P^2 \bigcup \cdots \bigcup P^T \tag{3}$$

The total factor productivity (TFP) index from time t to $t+1$ is expressed as follows:

$$GML^{t,t+1}\left(x^t, y^t, b^t, x^{t+1}, y^{t+1}, b^{t+1}\right) = \frac{1 + D^G\left(x^t, y^t, b^t\right)}{1 + D^G\left(x^{t+1}, y^{t+1}, b^{t+1}\right)} \tag{4}$$

where GML represents the TFP index. Thus, the rate of technological progress (σ) is as follows:

Fig. 1. China's WRT pilot.

$$\sigma_{i,t+1} = \frac{TFP_{i,t+1} - TFP_{i,t}}{TFP_{i,t}} = \frac{TFP_{i,t+1}}{TFP_{i,t}} - 1 = GML_i^{i,t+1} - 1 \tag{5}$$

Chang (2014) defines the water use intensity as follows:

$$WI = \frac{W}{Y} \tag{6}$$

where W represents water use, Y represents total output, and WI denotes water use intensity.

In addition, the potential water conservation gained from increased WUE (S) in each province can be explained below:

$$S_{i,t+1} = \left(WI_{i,t} - WI_{i,t+1}\right)Y_{i,t+1} \tag{7}$$

Improving WUE may contribute to economic growth, leading to additional water demand. The additional water demand due to economic growth can be described as follows:

$$Q_{i,t+1} = \sigma_{i,t+1}\left(Y_{i,t+1} - Y_{i,t}\right)WI_{i,t+1} \tag{8}$$

Ultimately, water rebounds can be described as follows:

$$\begin{aligned} rebound_{i,t+1} &= \frac{\sigma_{i,t+1}\left(Y_{i,t+1} - Y_{i,t}\right)WI_{i,t+1}}{\left(WI_{i,t} - WI_{i,t+1}\right)Y_{i,t+1}} \times 100\% \\ &= \frac{\left(GML_i^{i,t+1} - 1\right)\left(Y_{i,t+1} - Y_{i,t}\right)WI_{i,t+1}}{\left(WI_{i,t} - WI_{i,t+1}\right)Y_{i,t+1}} \times 100\% \end{aligned} \tag{9}$$

where *rebound* denotes water rebounds.

3.3. The empirical strategy

In order to assess the impact of the pilot on water rebounds, this study treats China's WRT pilot as a quasi-natural experiment. Specifically, the treatment group consists of 17 water rights pilot provinces (including seven national WRT pilot provinces and ten provincial WRT pilot provinces), whereas the control group consists of the remaining 14 provinces. This study employs the difference-in-differences (DID) approach to identify causal associations between WRT pilots and water rebounds. The following is the benchmark regression model:

$$rebound_{it} = \alpha_0 + \beta trade_{it} + \varphi X_{it} + \gamma_t + \mu_i + \varepsilon_{it} \tag{10}$$

where i stands for province and t for time. The independent variable ($trade_{it}$) equals one if WRT was implemented in the ith province in 2014, and zero otherwise. A vector of control variables and a random error term are represented by X_{it} and ε_{it}, respectively. The time- and province-fixed effects are indicated by γ_t and μ_i. α represents the intercept term, and β is the rebound effect of the WRT to be estimated.

The DID approach is chosen for this study because of its suitability for assessing differences in the impacts of WRT policies in pilot and non-pilot areas. The DID approach has the ability to effectively control time-invariant provincial characteristics, thereby enhancing the validity of causal inference. However, the limitation of the DID approach is the assumption of parallel trends in pilot and non-pilot provinces, which is tested in this study to ensure that the assumptions are reasonable.

This study includes a number of control variables to cover provincial features to make sure that provincial heterogeneity does not influence the results: (i) economic level (*gdp*), as determined by GDP; (ii) the proportion of industrial water to total water use (*ind*); (iii) the proportion of domestic water to total water use (*dom*); (iv) industrial structure (*stru*), as determined by the proportion of service sector output to manufacturing output; (v) science and technology investment (*tec*), as determined by the ratio of GDP to fiscal spending on science and technology to GDP; (vi) education investment (*edu*), as determined by the ratio of fiscal spending on education to GDP; (vii) employment density (*employ*), as determined by the number of employed persons divided by the area; (viii) research and development (R&D) intensity (*rd*), as determined by the proportion of R&D spending to GDP; (ix) urbanization (*urban*), as determined by the ratio of the urban population to the total population; (x) population density (*density*), as determined by the ratio of the total people to the area; (xi) water supply (*supply*); and (12) trade openness (*ope*), as determined by the ratio of the imports and exports of goods to GDP.

3.4. Data

According to Huang et al. (2021), the total water consumption (C), total labor force (L), and fixed capital stock (K) are selected as inputs, real GDP (Y) as the desired output, and sewage discharges (S) as the undesired output. The fixed capital stock can be calculated using the perpetual inventory approach by following Shan (2008).

In this study, the WRT pilot implementation is set to 2014. Due to data availability, this study uses 2007 as the initial year. Data from 31 Chinese provinces between 2007 and 2019 were eventually chosen to make up the original sample. The *China Environmental Statistical Yearbook* and *the China Statistical Yearbook* are the data sources. Table 1 describes the variables in detail.

4. Results

This study employs Eq. (10) to determine the influence of the WRT pilot on water rebounds after first estimating the water rebound for each sample province.

4.1. Water rebound estimates

This study calculates the water rebounds based on Eq. (9). Figs. 2 and 3 show the average water rebounds before and after the WRT pilot.

Figs. 2 and 3 show that water rebounds increased in most provinces after the WRT pilot. The non-pilot provinces increased by 8.03 while the pilot provinces increased by 1.12. Since the increase in the pilot provinces was less than in the non-pilot provinces, it suggests that the WRT pilot may have slowed down the rise in water rebounds.

4.2. Benchmark regression estimates

This study examines the WRT pilot's influence on water rebounds in accordance with Eq. (10). The results are shown in Table 2. While control variables are taken into consideration in column (2), no control variables are introduced in column (1).

The WRT pilot greatly suppresses water rebounds in the pilot provinces, as seen by Table 2's markedly negative coefficient of *trade* in column (1). Even after controlling for other variables, column (2)'s coefficient of *trade* is still significantly negative, proving yet again that the WRT pilot inhibits rebound effects in the pilot provinces. Furthermore, the coefficient of *trade* rises with the addition of control variables, suggesting that additional potential factors influencing water rebounds should be taken into consideration. Otherwise, the effect of the WRT pilot on water rebounds will be underestimated.

4.3. Robustness checks

To minimize estimate bias resulting from endogeneity and verify the reliability of the findings, the parallel trend test, the placebo test, propensity matching scores, and the exclusion of additional policy interferences are the four ways used in this study to check robustness.

4.3.1. Parallel trend test

The samples must fulfill the parallel trend assumption in order for the DID approach to work (Xue et al., 2023). This means that without the WRT pilot, the water rebound of the treatment and control groups ought to be roughly parallel. This study employs the event study approach to determine if the parallel trend assumption is satisfied. The model is configured in this way:

Table 1
An overview of the variables.

Variable	Descriptions	Unit	Obs.	Mean	Std. Dev.	Min	Max
K	Fixed capital stock	billion CNY	372	6574.74	5775.89	124.46	32,295.37
L	Total labor force	million person	372	24.89	16.64	1.64	69.95
C	Total water consumption	billion m^3	372	90.38	95.18	0.81	474.99
Y	Real GDP	billion CNY	372	2026.53	1841.48	39.82	10,798.69
S	Sewage discharge	million m^3	372	1430.95	1286.19	64.03	8085.35
employ	Employment density	people/ km^2	372	247.66	363.84	1.33	2170.66
density	Population density	people/ km^2	372	2788.65	1193.25	515.00	5967.00
supply	Water supply	billion m^3	372	1.78	1.66	0.07	9.48
gdp	Economic level	billion CNY	372	2026.53	1841.48	39.82	10,798.69
rebound	Water rebound	%	372	0.89	34.26	−361.56	239.78
stru	Industrial structure	%	372	123.95	68.07	52.71	523.40
urban	Urbanization	%	372	55.44	14.00	21.90	89.60
edu	Education investment	%	372	4.34	2.32	1.91	16.84
tec	Science and technology investment	%	372	0.44	0.25	0.15	1.37
ind	The proportion of industrial water to total water use	%	372	21.07	13.24	1.85	67.22
dom	The proportion of domestic water to total water use	%	372	14.91	8.06	2.00	46.82
ope	Trade openness	%	372	27.78	32.70	1.27	169.76
rd	R&D intensity	%	372	1.52	1.10	0. 19	6.31

Fig. 2. Average water rebounds before the WRT pilot (2008–2013): initial state of water rebounds.

$$rebound_{it} = \beta_0 + \sum\nolimits_{k=-6}^{k=5} \theta_k trade_{it}^k + \beta_1 X_{it} + \gamma_t + \mu_i + \varepsilon_{it} \tag{11}$$

where θ_k represents the water rebound variation between the treatment and control groups pre- and post-WRT pilot. The variables that remain align with the values found in Eq. (10).

The WRT pilot's implementation in 2014 serves as the event study's base year. θ_k shouldn't be much different from 0 prior to the WRT pilot in 2014 if the control and treatment groups fulfill the parallel trend assumption. Table 3 presents the outcomes. *pre_k* and *post_k* denote the *k*th year before and after implementing the WRT pilot.

Table 3 indicates that the coefficients of *pre_k* do not show a significant downward trend prior to the WRT pilot. This suggests that the model has fulfilled the parallel trend assumption. Two years after the WRT pilot, the coefficients of *post_k* start to be significantly negative. This indicates a lag impact of the WRT pilot on water rebounds. This is

Fig. 3. Average water rebounds after the WRT pilot (2014–2019): water rebounds increased in most provinces after the pilot.

Table 2
The effect of the WRT pilot on water rebounds.

Variables	(1)	(2)
	rebound	*rebound*
trade	−9.9094*	−13.5036**
	(5.8176)	(5.4349)
gdp		−0.0007
		(0.0021)
stru		−0.1536**
		(0.0625)
employ		−0.0709**
		(0.0267)
urban		−2.2451**
		(0.8563)
edu		8.3566**
		(3.2365)
tec		11.4565
		(14.3169)
ind		0.3573
		(0.5342)
dom		1.0661
		(0.6328)
density		−0.0004
		(0.0047)
supply		−11.1591*
		(6.0318)
ope		0.1499
		(0.1933)
rd		10.1369
		(8.2135)
Year-fixed effect	Yes	Yes
Province-fixed effect	Yes	Yes
Obs.	372	372

Note: *, **, and *** represent significance at 10 %, 5 %, and 1 % levels, respectively.

Table 3
Results of the parallel trend test.

Variables	(1)
	rebound
pre_6	−15.4343
	(9.8130)
pre_5	−10.8938
	(9.5728)
pre_4	11.4547
	(18.3466)
pre_3	−10.3899
	(9.0594)
pre_2	9.2712
	(18.1534)
pre_1	−22.2122
	(13.5052)
0	−3.5326
	(7.9290)
post_1	−39.2986
	(30.9765)
post_2	−23.9241*
	(13.2736)
post_4	−26.2460**
	(12.3249)
post_5	−19.9753***
	(6.1130)
Year-fixed effect	Yes
Province-fixed effect	Yes
Obs.	372

Note: *, **, and *** represent significance at 10 %, 5 %, and 1 % levels, respectively.

likely due to the time lag between the preparation and formal operation of the WRT.

4.3.2. Placebo test

In order to eliminate the possibility that other random factors could have an impact on the estimation results, this study uses pseudo-treatment groups to administer the placebo test. This work uses simulations to randomly split the sample provinces into treatment and control groups. During each simulation, DID regressions using the constructed pseudo-sample are performed. To make the effect of the WRT pilot on particular provinces more randomized and to prevent other small probability occurrences from interfering with the estimated outcomes, this simulation process is performed 500 times.

Because the pseudo-sample is created at random, the dependent variable has no significant impact on the variable *trade*, i.e., $\theta^{false} = 0$. This implies that the coefficients do not deviate considerably from zero without significant omitted variable bias. Conversely, an identification bias would be indicated by a statistically significant departure of θ^{false} θfalse from zero. Fig. 4 illustrates the kernel density estimates for each of the 500 randomly selected treatment groups.

Fig. 4 shows that the kernel density estimates are distributed around zero. This distribution is insignificant compared to the actual regression's coefficient values. This demonstrates that no significant estimation bias is caused by missing variables in the regression findings. Thus, other unobservable elements do not drive the influence of the WRT pilot on water rebounds.

4.3.3. Other robustness checks

To avoid systematic differences in the trend of changes between pilot and non-pilot provinces, this study first employs the PSM-DID approach to mitigate possible selectivity bias, which helps identify the true effect of the WRT pilot on water rebounds. After the treatment and control groups have been matched, this study repeats the DID estimation using the matched samples.

The balance test results for PSM are shown in Panel A of Table 4, whereas the estimated outcomes for the matched samples are displayed in Panel B.

By matching provinces with similar characteristics, PSM reduces the deviation, which quantifies the disparities in variables between

Table 4
Robustness check outcomes (PSM-DID).

Panel A: The balance test

Variables	Unmatched (U)/Matched (M)	Treatment group mean	Control group mean	Deviation (%)
gdp	U	2893.20	1694.70	62.8
	M	2610.40	2203.20	21.3
stru	U	114.14	127.70	−23.6
	M	112.78	110.61	3.8
employ	U	164.60	279.46	−37.4
	M	158.58	108.25	16.4
urban	U	58.73	54.19	37.2
	M	57.04	55.80	10.2
edu	U	4.01	4.47	−22.4
	M	4.10	4.43	−15.7
tec	U	0.42	0.45	−12.8
	M	0.39	0.39	0.6
ind	U	17.92	22.74	−36.3
	M	18.28	16.21	17.3
dom	U	13.96	15.27	−17.2
	M	13.36	11.11	29.6
density	U	2967.80	2720.00	21.1
	M	3035.00	3266.80	−19.7
supply	U	2.11	1.65	26.4
	M	1.95	1.78	9.7
ope	U	19.61	30.91	−39.0
	M	18.21	15.85	8.1
rd	U	1.51	1.52	−0.6
	M	1.43	1.29	14.7

Panel B: PSM outcomes

Variables	*rebound*
trade	−23.9867* (13.2711)
Controls	
Year-fixed effect	Yes
Province-fixed effect	Yes
Obs.	151

Note: *, **, and *** represent significance at 10 %, 5 %, and 1 % levels, respectively.

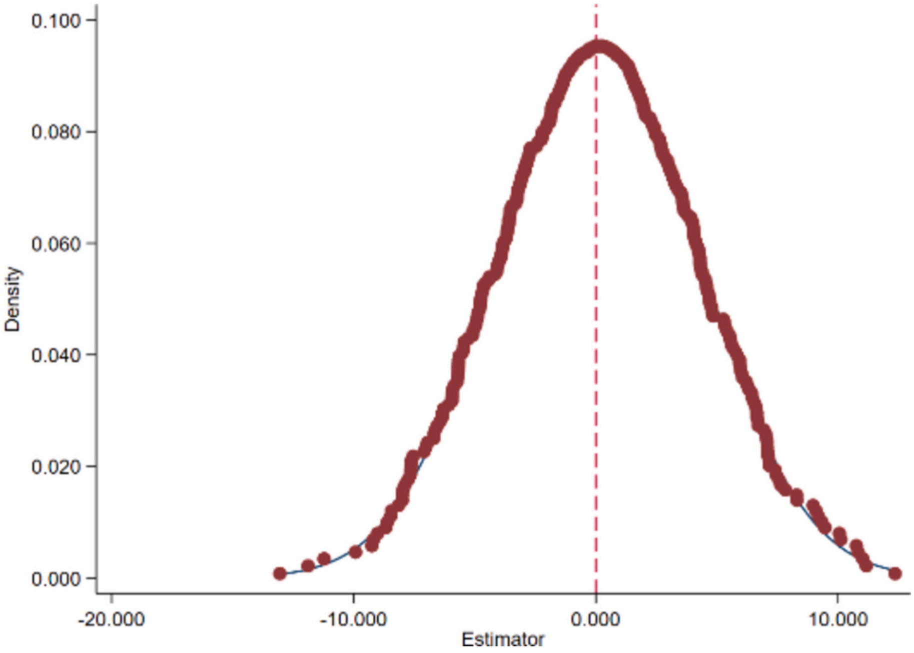

Fig. 4. The kernel density estimates.

treatment and control groups. The improvement in balance can be observed by calculating the standardized deviation before and after matching. Panel A of Table 4 illustrates how matching greatly reduces the standardized deviation of most variables, with the average bias dropping from 28.07 % to 13.93 %. This suggests that the sample selection bias is effectively resolved by the PSM approach. Panel B demonstrates that all of the coefficients of *trade* are considerably negative, which is consistent with the findings in Table 2.

In addition, the WRT pilot is likely to be influenced by China's water fee reform. Water fee reform was first implemented in Hebei in 2016, and it aims to encourage efficient water development and decrease water wastage. In 2017, China further added ten provinces—Beijing, Tianjin, Hebei, Sichuan, Henan, Inner Mongolia, Ningxia, Shandong, Shanxi, and Shaanxi—as pilot regions for water fee reform. Therefore, the DID regression is repeated by excluding the provinces participating in the water fee reform from the sample. Table 5 summarizes the outcome.

Table 5 indicates that the WRT pilot significantly suppresses water rebounds, as evidenced by the coefficient of *trade* remaining significantly negative even after controlling for the impact of water fee reform.

5. Additional analyses

5.1. Mediation mechanisms

According to the aforementioned findings, the WRT pilot would greatly reduce water rebounds.

The previous theoretical framework hypothesized that the water market may exacerbate water rebounds by promoting technological progress in water conservation. In addition, this study also hypothesized that the water market would suppress water rebounds by improving water quality. The following equations are employed to examine these hypotheses:

$$rebound_{it} = \alpha + \beta trade_{it} + \varphi X_{it} + \gamma_t + \mu_i + \varepsilon_{it} \tag{12}$$

$$mediation_{it} = \rho + \lambda trade_{it} + \kappa X_{it} + \gamma_t + \mu_j + \omega_{it} \tag{13}$$

where $mediation_{it}$ is the mediation variable, which denotes water-saving technological progress and water quality, respectively. This study evaluates water-saving technological progress by employing the logarithm of the quantity of water-related patent applications received (*innovate*). In addition, this study also uses the daily urban wastewater treatment capacity (*regulation*) to measure water quality. The estimation outcomes are displayed in Table 6, where column (1) reports the estimated results of the WRT pilot on water rebounds, and columns (2)–(3) report the estimation outcomes of water-saving technological progress and water quality as the mediation variables.

Table 6 shows that the coefficient of *trade* in column (2) is notably negative, indicating that the WRT pilot greatly slows down water-saving technological progress and thus inhibits water rebounds. Thus, Hypothesis 1 is falsified.

Table 5
Robustness check outcomes (exclusion of other policy interferences).

Variables	(1) *rebound*
trade	−17.1009*** (5.0737)
Controls	Yes
Year-fixed effect	Yes
Province-fixed effect	Yes
Obs.	276

Note: *, **, and *** represent significance at 10 %, 5 %, and 1 % levels, respectively.

Table 6
Outcomes of the mediation mechanism test.

Variables	(1) *rebound*	(2) *innovate*	(3) *regulation*
trade	−13.5036** (5.4349)	−0.2218* (0.1302)	54.9707** (25.0584)
Controls	Yes	Yes	Yes
Year-fixed effect	Yes	Yes	Yes
Province-fixed effect	Yes	Yes	Yes
Obs.	372	372	368

Note: *, **, and *** represent significance at 10 %, 5 %, and 1 % levels, respectively.

Column (3)'s coefficient of *trade* is noticeably positive, suggesting that the WRT pilot improved water quality and thus suppressed water rebounds. Therefore, Hypothesis 2 is confirmed.

5.2. Heterogeneity analyses

First, based on median per capita water resources, this study splits the sample into low- and high-water availability areas in order to evaluate Hypothesis 3. The findings are displayed in Table 7's columns (1)–(2).

Table 7 demonstrates that the coefficient of *trade* is noticeably negative in column (1) but insignificant in column (2). This implies that the WRT pilot successfully reduces the rebound effect in the high-water availability area, while it does not have a significant effect on water rebounds in the low-water availability area. As a result, Hypothesis 3 is verified.

Second, in order to investigate Hypothesis 4, the sample is divided into developed and underdeveloped areas according to the average GDP per capita. The findings are shown in Table 7's columns (3)–(4).

Column (3) has negligible coefficients of *trade*, whereas column (4) has significantly negative coefficients of *trade*. This indicates that the WRT pilot significantly inhibits water rebounds in underdeveloped areas more than in developed ones. Thus, Hypothesis 4 is verified.

6. Discussion

water markets and water rebound mitigation—which is frequently linked with the capacity of water markets to improve water quality—are causally related. As this study showed, Hypothesis 2 was confirmed: the WRT pilot resulted in a 13.50 % decrease in water rebounds, and there was a significant causal association between the two. An important factor contributing to this association is improved water quality (Sheng et al., 2022). A rise in water valuation triggered by water markets encourages water users to control water pollution, effectively improving water quality (Duvivier and Xiong, 2013). In China, with the rise and prosperity of water markets, the state has devised "promotion

Table 7
Results of heterogeneity analyses.

Variables	(1) *High-water availability area*	(2) *Low-water availability area*	(3) *Developed area*	(4) *Underdeveloped area*
trade	−21.1334** (8.6008)	−12.0943 (13.1242)	−12.3350 (26.3938)	−13.4727** (6.3610)
Controls	Yes	Yes	Yes	Yes
Year-fixed effect	Yes	Yes	Yes	Yes
City-fixed effect	Yes	Yes	Yes	Yes
Obs.	186	186	34	338

Note: *, **, and *** represent significance at 10 %, 5 %, and 1 % levels, respectively.

tournaments" aimed at improving water quality in order to link the promotion of local officials to the reduction of water pollution (Sheng and Webber, 2017). Ultimately, water markets have resulted in more stringent environmental regulations, which have improved water quality (Sheng and Yang, 2024). Furthermore, the water rights traded in water markets are usually clean water with drinking or production value (Zanjanian et al., 2018). Consequently, expanding water markets also promotes actions aimed at improving water quality (Shortle, 2017). This motivates water users to treat more water to make it more commoditized and tradeable (Du et al., 2017; Goetz et al., 2017). Ultimately, water pollution control leads to increased water availability and decreased water waste, which can hedge against new water demand and mitigate water rebounds.

The deployment of water markets may slow technological progress, resulting in a decline in WUE and thus indirectly mitigating water rebounds. As demonstrated in this study, Hypothesis 1 is falsified. This study reveals findings contrary to existing research: water markets can slow down technological progress in water conservation and thus dampen water rebounds. The existence of water markets gives water a commodity attribute, allowing water users to purchase water rights to meet additional water needs without having to rely on water-saving technologies. In this case, water users are more inclined to invest in WRT than in high-cost, high-risk water-saving technology development and application, especially in areas where water prices are low (Wang, 2012). As a result, this substitutive role of water markets may lead to a lag in the innovation of water-saving technologies and hinder the improvement of overall water efficiency. In addition, a booming water market may encourage the development of numerous water transfer projects, which may be the reason why water consumers prefer water transfers over the use of water conservation technologies to meet demand (Sheng and Webber, 2023). For example, due to abundant water resources, Turkey has built two water transfer projects, the Peace Pipeline and the Friendship Pipeline, to sell water from the southern Ceyhan River to eight neighboring Arab countries (Yildiz, 2018). The development of water markets further facilitated the construction of water transfer projects so that water could flow to high-demand water users under market regulation, reducing the incentives for demand for water-saving technologies. As a result, water user preference shifts triggered by water markets discourage technological innovation by water users (Dinar et al., 1997), ultimately resulting in a decline in WUE and the mitigation of water rebound. Thus, water markets are likely to slow the technological progress in water conservation and ultimately inhibit water rebounds.

The way that water markets affect water rebounds varies based on regional variations in water availability. As this study showed, Hypothesis 3 is confirmed: in high-water availability areas, water markets can dampen water rebounds, while the effect in low-water availability areas is insignificant. Since water availability tends to be closely related to water prices, regional differences in water availability trigger different water prices and, consequently, different water use behaviors (Liu et al., 2022). Low-water availability areas tend to have higher water prices due to water scarcity (Pan et al., 2023). However, the rise of water markets can lead water users to innovate water conservation technologies and water management systems, leading to an increase in commercialized water (Bakker, 2014). Conversely, high-water availability areas usually have lower water prices, which discourages the spread of water conservation measures (Tang et al., 2013). For example, Nuruzzaman et al. (2019) argued that firms are reluctant to invest in deploying advanced water-saving technologies in high-water availability areas, leading to inefficient water use. Thus, water markets tend to dampen or mitigate water rebounds in high-water availability areas.

Due to regional economic disparities, the effect of water markets on water rebounds may also vary. This study has confirmed Hypothesis 4, which states that water markets inhibit water rebounding in underdeveloped areas, while the effect on developed areas is insignificant. Water markets in underdeveloped areas tend to have lower efficiency (Ge, 2009), which may increase transaction costs in water markets and hinder efficient water allocation (Thirlwall, 1972). As a result, reducing WUE triggered by high transaction costs can also inhibit water rebounds. Furthermore, compared to developed areas, underdeveloped areas typically utilize water more inefficiently and incur higher adaptation costs for water-saving technologies, which does not incentivize water users to innovate and ultimately inhibit water rebounds (Dinar et al., 1997). Therefore, water markets are more likely to help curb water rebounds in underdeveloped areas than developed ones.

Finally, based on the findings of this study, it is recommended that incentives for technological innovation be strengthened in implementing water market policies to ensure that water markets do not trigger a rebound effect because of lowering the application of water-saving technologies. Specifically, the government should first provide subsidies or tax incentives for water-saving technology research and development and application to reduce the technological costs for water users, thereby enhancing their incentives to adopt water-saving technologies. Second, it should formulate a water price adjustment mechanism and gradually increase the price of water in water markets. Therefore, water users will have more economic incentives to choose water-saving technologies instead of relying on water rights trading to fulfill their needs. In addition, a WUE assessment system can be introduced to reward water users with remarkable water conservation results. Water conservation results can be incorporated into regional performance evaluation systems, prompting localities to encourage the popularization and adoption of water conservation technologies. These measures will help curb water rebounds brought about by water markets and realize sustainable development.

7. Conclusions

A conceptual framework for the water market-water rebound is developed in this study. It explores the causal link between the two and the potential mechanisms at play, using the example of the WRT pilot in China. This study makes the case that water markets and water rebound mitigation—which is frequently linked with the capacity of water markets to improve water quality—are causally related. Furthermore, deploying water markets may also slow technological progress, resulting in reduced water efficiency and, hence, an indirect mitigation of water rebounds. Lastly, the impact of water markets on water rebounds varies according to water availability and socioeconomic levels. These findings offer a theoretical foundation for the development of water management policies, i.e., future water market policies need to balance technological innovation with the long-term impacts of water markets.

By incorporating the case of WRT in China, this study also offers a fresh empirical justification for the study of water rebound effects in water markets. Even while the body of research critically examining water rebounds has been steadily growing, it has yet to causally link water markets to water rebounds to problematize it. New contributions to this literature could come from understanding how to mitigate water rebounds by undermining innovation and improving water quality. The capacity of water markets to counteract technological progress and enhance water quality, as this study has shown, may offer fresh evidence for observing the moderating impacts of water markets on water rebounds.

This paper focuses primarily on the linkage between water markets and rebound effects, but does not analyze in depth other mechanisms that may affect the association between the two, such as individual end-user behavior. Future research could consider in more detail the relationships between water markets and rebound effects. Understanding these water-use patterns and the political and economic rationales behind them might be aided by looking at the potential effects of water markets on the actions of individual end-users. In this sense, additional case studies are required to confirm the negative link between water markets and rebound effects. This would deepen our knowledge of the water rebound itself, as well as add to the cross-scale comprehension of the complexity of the water market-water rebound connection.

CRediT authorship contribution statement

Jichuan Sheng: Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Ruzhu Zhang:** Writing – original draft, Software, Data curation. **Hongqiang Yang:** Funding acquisition, Resources, Writing – review & editing. **Cheng Chen:** Funding acquisition, Resources, Writing – review & editing.

Declaration of competing 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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Data availability

Data will be made available on request.

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