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Education level of farmers, market-oriented reforms, and the utilization efficiency of agricultural water resources in China

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Abstract
The utilization efficiency of agricultural water resources has an overall and long-term impact on agricultural development. However, owing to serious wastage of agricultural water resources for a long time, low utilization efficiency of such water resources has become a common problem in developing countries. Past studies have paid scant attention to the impact of soft factors, namely farmers' educational level and market-oriented reforms, especially in a quantified form, on the improvement of agricultural water utilization efficiency. This study adopted the system Generalized Method of Moments estimation method of a dynamic panel model and used provincial panel data from China for 2007–2020 period. The results show that the utilization efficiency of agricultural water resources can indeed be improved by either promoting farmers' education levels or deepening market-oriented reforms. However, with the advancement of market-oriented reforms, the influence of farmers' education level on the utilization efficiency of agricultural water resources gradually weakens, which is due to the "agricultural to non-agricultural" effect. Finally, this paper proposes policy suggestions to improve the utilization efficiency of agricultural water resources from three perspectives: improving the education level of farmers, optimizing the agricultural water pricing system, and improving the agricultural water rights trading system.

Keywords Farmers' education level · Market-oriented reforms · Agricultural water resource · China

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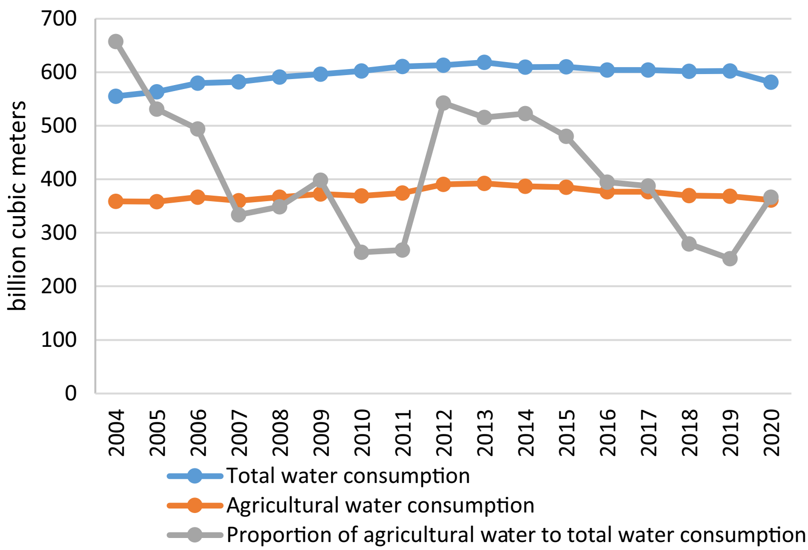

Fig. 1 China's agricultural water consumption and its proportion. *Source*: China's National Bureau of Statistics

1 Introduction

Water is a fundamental resource for agricultural development and plays a strategic role in China's agricultural sector (Pan and Ying 2012; Du et al. 2021). As water has increasingly become scarce (Shao et al. 2007; Wang and Xue 2013; Hao et al. 2022), it has an overall and long-term impact on China's food security and agricultural economic development (Du et al. 2021). However, with global climate change and the continuous promotion of "agricultural to non-agricultural,"[1] both the available water resources and agricultural water consumption in China generally exhibit a decreasing trend. According to the water consumption records of 2004 (Fig. 1), 358.57 billion cubic meters of water were consumed by agricultural activities, which formed 64.6% of the total water supply. However, in 2020, agricultural water consumption decreased to 62.1% of the total water supply. Despite the decreasing proportion of agricultural water consumption, it is still a major component of total water consumption in the society. Furthermore, it is worth noting that the water used for irrigation is the main contributor to total agricultural water consumption. However, due to inadequate water conservancy infrastructure, unscientific agricultural irrigation methods, and inefficient water distribution systems, large amounts of water resources are wasted during irrigation. For example, the overall area under irrigation

[1] Hu et al. (2019) pointed out that as the proportion of non-agricultural water consumption (including industrial water, domestic water, ecological water, etc.) increased consistently, it caused a shift in water consumption from agricultural to non-agricultural sectors, which is called "agricultural to non-agricultural.".

in China was 1.037 billion mu (74 million hectares) in 2020, of which water-saving measures were implemented in only 567 million mu, accounting for only 54.68%[2] of overall area under irrigation, far below the advanced level of developed countries which is 80%.

China is a country with both abundance and shortage of water resources, and the occurrence of water shortages is directly related to the efficiency of water utilization (Jia and Liu 2011). Therefore, improving the utilization efficiency of agricultural water resources is key to realizing their sustainability and ensuring China's food security (Yang et al. 2017; Zhang et al. 2019; Hao et al. 2022). Water utilization efficiency is naturally affected by water resource endowment; however, scarcity of water resources can induce technological changes in water saving. China's agricultural water-saving technologies have evolved from traditional agronomic measures, irrigation technologies, and engineering technologies to modern water-saving technologies such as genetic engineering, information technology, the Internet of Things, intelligent irrigation areas, and precision irrigation perception technology. Theoretically, continuous change in water-saving technologies can improve the utilization efficiency of agricultural water resources; however, it inevitably depends on the scientific and cultural quality of agricultural water users because they use these technologies in day-to-day farming. Scientific quality comes under hard science and technology that can improve farmers' water-saving skills in a short time. Cultural quality, however, is a soft factor. It not only provides intellectual support for the use of hard science and technology, but also affects farmers' water-saving consciousness imperceptibly and improves the sustainability of water consumption in agriculture. Improvement in scientific and cultural qualities depends on the improvement in farmers' education levels. Past studies mainly focused on the improvement in water utilization efficiency brought about by the progress in science and technology, while ignoring the impact of farmers' education on water utilization efficiency. The contributions of this paper are as follows: First, this paper provides a new perspective for improving agricultural water's utilization efficiency in China. Starting by constructing an econometric model based on China's provincial panel data, this paper explores the direct effect of farmers' education level on agricultural water's utilization efficiency in China and supplements the academic research on agricultural water's utilization efficiency. Second, since China is a transitional and emerging country which is undergoing market-oriented reforms, the study also investigates the moderating effect of market-oriented reforms on farmers' education level. Third, China's rural sustainable development policy has provided a good reference material for various countries, especially emerging countries, so our policy suggestions are conducive to formulating green recovery plans in the post-epidemic era. The results of the empirical study are interesting: with the advancement of market-oriented reforms, the marginal influence of farmers' educational levels on the utilization efficiency of agricultural water resources has gradually weakened. Addressing these issues will help design institutional arrangements to optimize the allocation of water resources and improve the utilization efficiency of agricultural water resources.

[2] The data came from the Ministry of Water Resources.

The rest of the paper is arranged as follows. Section 2 introduces literature review, Sect. 3 presents theoretical background and econometric model, introduces variables and data. Section 4 presents the empirical tests and their results. Section 5 is robustness test by adopting an instrumental variable, re-selecting the sample, and the grouping test. Finally, Sect. 6 summarizes the main findings and discusses policy recommendations.

2 Literature review

Utilization efficiency of resources has significant impact on green development and recovery of the economy, because it's improvement indicates economic development and recovery by minimizing input of resources. Many scholars pointed out that increasing consumption of resources cause a negative response of CO2 emissions (Saboori et al. 2017; Rasoulinezhad and Saboori 2018), and it is harmful to sustainable economic development. Accordingly, it is necessary to take some policy measures to solve problem caused by excessive consumption of resources (Rasoulinezhad 2020; Yoshino et al. 2021; Taghizadeh-Hesary 2021), and improvement of utilization efficiency of resources is feasible measures. Agricultural water is a scarce strategic resource, and its shortage can badly affect China's economic development and world food security (Brown and Halweil 1998; Xie et al. 2005; Wang and Zhao 2008). Improvement in water utilization efficiency can effectively alleviate the problem of water resource shortages (Jia and Liu 2011; Hu et al. 2019; Zhang and Weng 2022). Therefore, to some extent, utilization efficiency of agricultural water resources directly impacts not only China's food security strategy but also provides a solid foundation for the realization of China's economic internal circulation. As a result, improving the utilization efficiency of agricultural water resources has become a central field of academic research. Therefore, scholars have examined this issue from several perspectives.

First, the influence of technological progress on agricultural water resource utilization efficiency has been examined by scholars. According to Hayami's theory of induced technological change (Hayami 2000), the growth of a country's agricultural production is restricted by its resource endowment, but this restriction could be overcome through technological progress. Agricultural water resources are relatively scarce and their supply is inelastic. This inherent economic characteristic will lead to technological progress in saving water to improve its utilization efficiency. Irrigation and engineering water-saving technologies are important factors affecting the utilization efficiency of agricultural water resources. Senanayake et al. (2015), Wang and Lu (2015), Zhang et al. (2019) and Hao et al. (2022) found that wide application of water-saving technologies could significantly improve the utilization efficiency of agricultural water resources. In view of the shortage of freshwater resources in China, Lu (2011) proposed that artificial precipitation should be fully used to improve the temporal and spatial distribution of water resources, and air water resources must be developed as much as possible.

Second, past studies have analyzed the influence of agricultural production efficiency on the efficiency of agricultural water resource utilization. Ruttan

(2002), Xue and Hao (2012), Gadanakis et al. (2015), and others have shown that agricultural production efficiency is inversely proportional to the consumption of agricultural water resources. Higher agricultural production efficiency can ensure the completion of agricultural production tasks with zero or negative growth in agricultural water consumption. Agricultural water resources, thus saved, can be allocated to other production activities to improve their utilization efficiency. However, Jin et al. (2018) believed that the impact of agricultural production efficiency on agricultural water consumption is more complex than a simple linear relationship. Further, Jin et al. (2018) believed in the existence of a certain "threshold effect": when the agricultural production efficiency is low, improving it could prevent an increase in agricultural water consumption; however, when agricultural production efficiency improves consistently to reach a certain critical point, the "inhibition effect" of improving agricultural production efficiency on agricultural water consumption increases.

Third, scholars have examined the influence of system design on agricultural water utilization efficiency. Many scholars have discussed the utilization efficiency of agricultural water resources from the perspective of the system. They concluded that a lack of system design leads to low efficiency in agricultural water use. Wang (2010) proposed that improving irrigation methods, designating exclusive water rights and water price competition mechanisms, and improving irrigation management systems would help improve irrigation water utilization efficiency. In addition, institutional arrangements for improving citizen participation also help improve the utilization efficiency of water resources. Guo and Feng (2015) and Hao et al. (2022) believed that public participation is necessary, and there is an important relationship between farmers' cognition, satisfaction, and willingness to participate in water resource management, which ultimately affects the efficiency in water resource utilization.

Finally, past studies have analyzed the influence of the characteristics of farmers and farmlands on agricultural water utilization efficiency. The effect of rural households' characteristics on water utilization efficiency has attracted the attention of academia. Karagiannis et al. (2003) and Dehehibi (2007) found that farmers' age, education, agricultural training, and fertilizer application had significant effects on agricultural water utilization efficiency. Frija et al. (2009) believed that property rights of agricultural land, irrigation methods, land area, and irrigation technologies significantly affect efficiency in using water for irrigation. Wang and Zhao (2008) and Wang et al. (2016) believed that adjusting the planting mode of crops, reducing the planting area of crops with high water consumption, and planning and reforming water conservancy and irrigation systems are beneficial measures for improving the efficiency of agricultural water use. However, some scholars believed that a change in planting structures does not lead to an improvement in water utilization efficiency. For example, Zhang et al. (2019) believed that the planting structures conversion of different agricultural products does not promote the full utilization of agricultural water resources. Du et al. (2021) found complex impact of planting structures on water utilization efficiency.

Past studies have shown that improvements in agricultural water resource utilization efficiency are not only affected by the improvement in traditional technologies and agricultural production efficiency but are also restricted by system design and the characteristics of farmers and farmland. These studies have undoubtedly enriched path selection for improving the efficiency of agricultural water resource utilization. Whether in theory or in practice, improvement in agricultural water resource utilization efficiency is not only subject to the hard constraints of water-saving technologies, but also to the soft constraints of marketization level and farmers' quality. Past studies mainly focused on the improvement in water utilization efficiency brought about by the progress in science and technology, while ignoring the impact of farmers' education and market-oriented reforms on water utilization efficiency. As a result, certain questions remain unanswered. For example, does farmers' education level improve the utilization efficiency of agricultural water resources? Whether market-oriented reforms in the agricultural field improve the allocation and utilization efficiency of agricultural water resources? More importantly, as a transitional and emerging country, with the deepening of market-oriented reforms, how will the relationship between the education level of farmers and agricultural water utilization efficiency change in China? As previous studies did not address these questions, this study explores the impact of farmers' education level and market-oriented reforms on agricultural water utilization efficiency. Further, this study investigates the moderating effect of market-oriented reforms on farmers' education level.

3 Theoretical background and empirical research design

3.1 Theoretical background and econometric model

Since human capital has been included in the conceptual framework of generalized capital, the importance of human capital for economic development has aroused extensive attention. Lucas (1988) believed that human capital has an external effect, and took the external effect of human capital into the endogenous economic growth model as the main engine of economic growth. Human capital is regarded as an important source of productivity growth. Romer (1990), Barro (1990), Andersson et al. (2009) and other scholars also found that human capital can promote productivity growth. However, Endogenous Growth Theory based on human capital is a theoretical summary of western developed countries, which implies a precondition: the market economy system has been established. Acemoglu et al. (2014) discussed the possible nexus between institution, human capital and economic growth, and found that good institutions promote the accumulation of human capital and the improvement of total factor productivity, thus promoting the economic development of the country. In China, market-oriented reforms is an important change of economic system, and it plays a key role in promoting sustained and rapid economic growth (Fan et al. 2003). The market-oriented reform from a planned economy to a market economy includes series of large-scale institutional changes in economy, society, law, etc. Market-oriented reforms have adjusted the economic environment, and it will inevitably exert an important impact on the output effect of China's human capital (Fang and Zhao 2011).

According to above theories, we believe that utilization efficiency of agricultural water resources is a productivity that reflects the input–output relationship of agricultural water resources. Therefore, farmers' education level and regional market-oriented reform will inevitably affect utilization efficiency of agricultural water resources in China. Therefore, based on China's provincial panel data, an econometric model is constructed as follows:

$$\text{awe}_{i,t} = \alpha_0 + \alpha_1 \text{education}_{i,t} + \alpha_2 \text{marketization}_{i,t} + \alpha_3 \text{patent}_{i,t} + \varepsilon_{i,t} \tag{1}$$

In Eq. (1), i and t represent the selected province and period, respectively. The variable *awe* represents utilization efficiency of agricultural water resources, education represents farmers' education level, marketization is the degree of marketization. We added the number of agricultural patents as a control variable. According to Endogenous Growth Theory, R&D is also considered an important factor in promoting productivity growth (Romer 1990).

As a transitional and emerging country, China is undergoing advancement of market-oriented reforms. How will the relationship between the education level of farmers and agricultural water utilization efficiency change in China? In order to investigate it, we introduce the cross term of farmers' education level and degree of marketization, and build the following regression equation:

$$\begin{aligned} \text{awe}_{i,t} =& \alpha_0 + \varphi \text{education}_{i,t} * \text{marketization}_{i,t} + \alpha_1 \text{education}_{i,t} \\ &+ \alpha_2 \text{marketization}_{i,t} + \alpha_3 \text{patent}_{i,t} + \varepsilon_{i,t} \end{aligned} \tag{2}$$

In order to overcome the estimation error caused by missing variables, we add the lag term of dependent variables into Eq. (1) and Eq. (2), and obtain new equations:

$$\begin{aligned} \text{awe}_{i,t} = \alpha_0 + \beta_1 \text{awe}_{i,t-1} + \beta_2 \text{awe}_{i,t-2} + \alpha_1 \text{education}_{i,t} \\ + \alpha_2 \text{marketization}_{i,t} + \alpha_3 \text{patent}_{i,t} + \varepsilon_{i,t} \end{aligned} \tag{3}$$

$$\begin{aligned} \text{awe}_{i,t} = \alpha_0 + \beta_1 \text{awe}_{i,t-1} + \beta_2 \text{awe}_{i,t-2} + \varphi \text{education}_{i,t} * \text{marketization}_{i,t} \\ + \alpha_1 \text{education}_{i,t} + \alpha_2 \text{marketization}_{i,t} + \alpha_3 \text{patent}_{i,t} + \varepsilon_{i,t} \end{aligned} \tag{4}$$

We use Eq. (3) to examine the direct effect of farmers' education level on agricultural water's utilization efficiency. Equation (4) is used for investigating the moderating effect of market-oriented reforms on farmers' education level.

3.2 Variables and data

Improvements in agricultural water utilization efficiency are not only affected by water-saving technologies but also by farmers' water-saving consciousness and marketization mechanisms. To explore the impact of farmers' education level and market-oriented reforms on the utilization efficiency of agricultural water resources,

Table 1 Information of variables

Name	Symbol	Indicator	Data's source
Agricultural water resource utilization efficiency	awe	Total-factor's agricultural water resource utilization efficiency	Measured by DEA method
Education level of farmers	education	Average years of education per capita in rural areas	China's Rural Statistical Yearbook
Degree of marketization	marketization	Marketization index	Wang et al. (2021)
Number of agricultural patents	patent	Patents in agriculture, forestry, animal husbandry, hunting, trapping, and fishing	Website of the China Intellectual Property Office

this study uses the data of 31 provinces in China. From 2007, China's government puts forward a new target for developing modern agriculture by improving utilization efficiency of agricultural resources, so we select 2007–2020 as the time period of research. In this section, we introduce the variables and data. Table 1 collects names, symbols and sources of all variables.

3.2.1 Agricultural water resource utilization efficiency (awe)

The accurate quantification of agricultural water utilization efficiency is the basis in our study. We use single-factor and total-factor methods to scientifically evaluate agricultural water resource utilization efficiency. Considering multiple factor inputs in the agricultural production process, the total-factor method to assess agricultural water utilization efficiency is more practical (Yang et al. 2017). Stochastic frontier analysis (SFA) and data envelopment analysis (DEA) are two common methods when using total factors to measure utilization efficiency of agricultural water resources. Compared to SFA, the DEA method does not need to set the production function form, so it has advantages in simulating the production process (Wei and Shen 2014; Zhao et al. 2014). Therefore, based on the methodology adopted to measure water resource utilization efficiency by Thanassoulis (2000), Hu (2006), Yang and Liu (2015), and Yang et al. (2017), this study uses the DEA method to calculate agricultural water utilization efficiency, considering the amount of agricultural water consumption, labor force of the primary industry, power of agricultural machinery, use of agricultural fertilizer, and agricultural planting area as input variables, and the valued added by the primary industry as the output variable.

3.2.2 Education level of farmers (education)

Education level reflects farmers' cultural and technological literacy; the higher the education level, the higher the water-saving skills and awareness of farmers. We calculate the average years of education per capita in rural areas based on China's Rural Statistical Yearbook. People with primary and secondary school education, junior high school education, senior high school education, junior college school education and above are assigned 6, 9, 12, and 16 years, respectively, on the parameter of education.

3.2.3 Degree of marketization (marketization)

Market-oriented reforms provide an accurate price signal for water resource allocation and operations. The higher the degree of marketization, the more obvious the leverage effect of price on resource allocation and the more prominent the water education efficiency. According to China's marketization index released by Wang et al. (2021), the degree of marketization includes 25 indicators in five aspects: relationship between the government and market, development of a non-state-owned economy, development of a product market, development of a factor market, market intermediary organization development and legal system environment. Wang et al. (2021) reported the marketization index from 2008 to 2019, and we obtain the data for 2020 using the trend extrapolation method. Specifically, we calculate the growth rate from 2018 to 2019, then multiply the value in 2019 by calculated growth rate to get the value in 2020.

3.2.4 Number of agricultural patents (patent)

The number of agricultural patents reflects not only the scientific and technological level of agricultural development but also the marginal contribution of agricultural science and technology in improving agricultural water resource utilization efficiency. According to the website of the China Intellectual Property Office (IPC),[3] the IPC classification number of agricultural patents is A01, which includes patents in agriculture, forestry, animal husbandry, hunting, trapping, and fishing. We collect the number of agricultural patents based on this classification number.

Generally, when discussing the influence relationship between economic variables, traditional econometric tools such as Ordinary Least Squares (OLS) can also be used to obtain unbiased estimators of a regression coefficient. However, when a regression equation has serious endogeneity, especially when panel data are used, a biased regression coefficient can be obtained using traditional methods such as OLS. Therefore, considering the possible adverse effects of endogenous economic variables on empirical results, this study adopts the panel Generalized Method of Moments (GMM) estimation method. In this study, we use a one-step robust GMM estimation method.

4 Empirical results and analysis

This study examines the feasibility of improving agricultural water resource utilization efficiency with the help of two factors—farmers' education level and market-oriented reforms. The objective is to provide support in formulating policies to improve water resource utilization efficiency.

4.1 Preliminary test on the influence of farmers' education level and market-oriented reforms on utilization efficiency of agricultural water resources

To examine the influence of farmers' education level and market-oriented reforms on agricultural water utilization efficiency, the incremental regression method is used to conduct empirical tests. Moreover, to ensure the robustness of empirical results, we first use the panel fixed-effects model for analysis and finally use the system GMM method for testing. Columns I, II, and III in Table 2 show the estimated results using panel fixed effects (FE). In Column I, only farmers' education level is the main explanatory variable; we add the market-oriented reform variable in Column II, and

[3] http://epub.sipo.gov.cn/index.action.

Table 2 Impact of farmers' education level and market-oriented reforms on utilization efficiency of agricultural water resources

	I FE	II FE	III FE	IV sys-GMM
awe_{-1}	−0.0571 (0.0673)	−0.0649 (0.0672)	−0.1127 (0.0752)	−0.0683 (0.0767)
awe_{-2}	−0.1268* (0.0710)	−0.1263* (0.0708)	−0.1414 (0.0697)	−0.0831 (0.0895)
education	0.0636** (0.0286)	0.0673* (0.0286)	0.0612** (0.0279)	0.0929** (0.0389)
marketization		0.0210 (0.0134)	0.0321** (0.0145)	0.0492** (0.0209)
patent			0.0298 (0.0246)	0.0279 (0.0288)
R^2	0.4398	0.4464	0.4485	
AR(2)				0.610
Hansen				0.922
Obs	31 × 13	31 × 13	31 × 13	31 × 13

***, **, and * indicate the significance of coefficients at the 1, 5, and 10% levels, respectively; the numbers in parentheses show standard error; AR (2) and Hansen test provide *p*-values

the number of agricultural patents is introduced as a control variable in Column III. Column IV shows the corresponding system GMM estimation results.

As shown in Table 2, farmers' education level has a positive effect on the utilization efficiency of agricultural water resources. More specifically, when using FE, considering the education level of farmers alone, it is observed that farmers' education level is conducive for improving agricultural water resource utilization efficiency, and the impact coefficient was 0.0636, which passed the significance test. When market-oriented reforms and farmers' patents (control variable) are added to the model, farmers' education level again has a positive effect on agricultural water resource utilization efficiency, and the impact coefficients are 0.0673 and 0.0612, respectively. Even when using the system GMM method, farmers' education level has a significant positive effect on agricultural water utilization efficiency, with a coefficient of 0.0929. This indicates a positive impact of farmers' education level on agricultural water resource utilization efficiency; besides, improvements in farmers' education level can improve sustainable utilization efficiency of agricultural water resources, which is consistent with findings of studies in other countries. Existing research has found that in rural areas of Nepal, education level is an important factor in improving residents' active participation in water resource utilization (Whittington et al. 2002). In Thailand, the higher the education level of residents, the more evident is their water-saving awareness, resulting in improving water use efficiency (Purnama et al. 2016). This can be achieved in two ways. First, in the process of receiving education, farmers deeply recognize the importance of water resource scarcity, which makes them voluntarily and actively participate in water resource management and reduce water wastage. Second, improvements in education level increase farmers' human capital, enabling them to use water-saving technologies. It can improve the spatial and temporal effects of water resource allocation and promote the utilization efficiency of agricultural water resources.

The empirical results in Table 2 also show that market-oriented reforms have a positive effect on the efficiency of agricultural water resource utilization. In Columns II and III, using the FE method, improvement in marketization degree and number of agricultural patents are conducive to improvement in agricultural water utilization efficiency, and the impact coefficients are 0.0210 and 0.0321, respectively, which are statistically significant. In column IV, using the system GMM method, the impact of marketization on agricultural water utilization efficiency is still positive, with a coefficient of 0.0492. This indicates that reforms pertaining to water rights and water prices under marketization can exert a positive impact on the utilization efficiency of water resources through allocation and transaction links. For example, allocation of water rights clarifies the amount of water resources available to water users. When strict limits are imposed on water consumption, it makes users consume water more efficiently. Similarly, water price reforms help optimize water use decisions by changing economic costs of water. In particular, price mechanisms can be applied to incentivize water conservation and improve water utilization efficiency (Dinar and Mody 2004; Liu et al. 2015; Yi et al. 2019; Ma et al. 2021) to improve sustainability in water use. Studies have also found that market-oriented reforms based on price mechanisms have a positive impact on water resource utilization efficiency. For example, Wichelns et al. (2002), Bithas (2008), and Finger (2012) used the examples of the United States, United Kingdom, and Switzerland, respectively, and found that raising water prices could improve the utilization efficiency of agricultural water resources and achieve sustainable development of water resources. This shows that market-oriented reforms have played a role in improving agricultural water utilization efficiency.

4.2 Moderating effect of farmers' education level and market-oriented reforms on utilization efficiency of agricultural water resources

The results in subSect. 4.1 show that farmers' education level and degree of marketization can improve the utilization efficiency of agricultural water resources. In other words, improvements in agricultural water use efficiency are a function of the intertwined influence of farmers' education level and degree of marketization. However, China is experiencing rapid marketization, with the vertical promotion of.

346 market-oriented reforms, does the effect of farmers' education level on agricultural water utilization efficiency change? To answer this question, this study further constructs the cross term of farmers' education level and market-oriented reforms to investigate the influence of farmers' education level on agricultural water utilization efficiency in the background of market-oriented reforms. Table 3 presents the estimation results of the relevant models. In Column I, the cross term of farmers' education level and market-oriented reforms is significantly negative, with a coefficient of-0.0189. In Column II, when we control for agricultural patents in the model, the coefficient of the cross term is still significantly negative. In Columns III and IV, using the system GMM method, the coefficients of the cross term are also

Table 3 Moderation effect test of market-oriented reforms

	I FE	II FE	III sys-GMM	IV sys-GMM
awe_{-1}	−0.0777 (0.0659)	−0.1421 (0.0738)	−0.0313 (0.0544)	−0.0961 (0.0630)
awe_{-2}	−0.1241* (0.0692)	−0.1450** (0.0682)	−0.0537 (0.0688)	−0.0921 (0.0718)
education ∗ marketization	−0.0189*** (0.0060)	−0.0210*** (0.0071)	−0.0254*** (0.0054)	−0.0269*** (0.0094)
marketization	−0.1656*** (0.0473)	0.1928*** (0.0559)	0.2328*** (0.0435)	0.2541*** (0.0742)
education	0.2121*** (0.0534)	0.2229*** (0.0609)	0.2853*** (0.0455)	0.2956*** (0.0791)
patent		0.0319 (0.0241)		0.0343 (0.0284)
R^2	0.4725	0.4752		
AR(2)			0.599	0.659
Hansen			0.997	0.965
Obs	31 × 13	31 × 13	31 × 13	31 × 13

***, **, and * indicate the significance of coefficients at 1, 5, and 10% levels, respectively; the numbers in parentheses show standard error; AR (2) and Hansen test provide *p*-values

significantly negative, which is consistent with the results of the FE model. Obviously, the cross term of farmers' education level and market-oriented reforms is significantly negative, which shows that with continuous advancement in market-oriented reforms, the marginal impact of educational attainment on agricultural water utilization efficiency is declining. This is due to the promotion of market-oriented reforms, especially reforms pertaining to factors like water, which make farmers consider costs and benefits of water; as a result, water conservation efforts have become a bigger function of market mechanisms than an individual's subjective consciousness. When market-oriented reforms that use price to regulate farmers' water-saving awareness are used, they reduce the spillover effects of education. This may also be due to the fact that, with the advancement of market-oriented reforms, farmers with higher education may shift agricultural water to non-agricultural uses considering the costs and benefits of water use. This results in inconsistencies between nominal agricultural water utilization and actual agricultural water utilization (Li et al. 2021), causing a decline in statistical agricultural water utilization efficiency, which also leads to a decline in the marginal impact of educational attainment on agricultural water utilization efficiency in the process of market-oriented reforms.

5 Robustness test

The relationship between farmers' education level, market-oriented reforms, and utilization efficiency of agricultural water resources was examined in Sect. 4. The results show that farmers' educational level and market-oriented reforms are both

Table 4 Robustness test results of adopting an instrumental variable

	I First stage estimated results	II Second stage estimation results	III Third stage estimation results
awe_{-1}	0.3559 (0.3896)	−0.1264 (0.0781)	−0.1079 (0.0789)
awe_{-2}	−0.1449 (0.3617)	−0.1358* (0.0699)	−0.1534** (0.0715)
education * marketization			−0.0183** (0.0092)
marketization		0.0704*** (0.0270)	0.1110*** (0.0371)
education	−0.1285 (0.1448)	0.0661 (0.0252)	0.1941*** (0.0650)
patent	−0.0466 (0.1278)	0.0316 (0.0252)	0.0288 (0.0254)
east	3.8759 (0.2165)		
R^2	0.4725	0.4297	0.4203
Obs	31 × 13	31 × 13	31 × 13

***, **, and * indicate the significance of coefficients at the 1, 5, and 10% levels, respectively; the numbers in parentheses show standard error

conducive to improving agricultural water utilization efficiency, but the marginal impact of educational attainment on agricultural water utilization efficiency declines with continuous advancement of market-oriented reforms. However, the robustness of the above mapping relationship needs to be examined. In this section, we re-examine the effects of farmers' education level and market-oriented reforms on the utilization efficiency of agricultural water resources using three strategies: adopting an instrumental variable, re-selecting the sample, and the grouping test.

5.1 Robustness test of adopting an instrumental variable

While examining the impact of the relationship between farmers' education level and market-oriented reforms on the utilization efficiency of agricultural water resources, we noticed that the data pertaining to the market-oriented reform index are more abstract in nature. This index in its quantified form is available for the 2008–2019 period, thanks to the study by Wang et al. (2021). Meanwhile, the data for 2020 are based on the trend extrapolation method. This may result in errors in measuring the degree of marketization. The degree of marketization in the eastern region of China is much higher than in the central and western regions; therefore, the eastern dummy variable is used as the instrumental variable for the degree of marketization. We conduct a robustness test based on the two-stage instrumental variable method. The

Table 5 Robustness test of deleting data in 2020

	I FE	II FE	III sys-GMM	IV sys-GMM
awe_{-1}	−0.1781** (0.0795)	−0.1832** (0.0788)	−0.0256 (0.1174)	−0.0876 (0.0917)
awe_{-2}	−0.1016 (0.0678)	−0.1051 (0.0672)	−0.0855 (0.0884)	−0.0966 (0.0705)
education * marketization		−0.0149* (0.0076)		−0.0325** (0.0147)
marketization	0.0355** (0.0137)	0.1494** (0.0597)	0.0138 (0.0239)	0.2672** (0.1178)
education	0.0427 (0.0282)	0.1623** (0.0672)	0.0946** (0.0345)	0.3528*** (0.1030)
patent	0.0508** (0.0242)	0.0470* (0.0240)	0.0352 (0.0302)	0.0476 (0.0280)
R^2	0.4221	0.4371		
AR(2)			0.614	0.790
Hansen			0.999	1.000
Obs	31×12	31×12	31×12	31×12

***, **, and * indicate the significance of coefficients at the 1, 5, and 10% levels, respectively; the numbers in parentheses show standard error; AR(2) and Hansen test provide *p*-values

results are presented in Table 4 and show that farmers' education level and marketization reforms have significant positive effects on the utilization efficiency of agricultural water resources, with coefficients of 0.1941 and 0.1110, respectively. However, the cross term of education level and market-oriented reforms is significantly negative. The conclusions are consistent with empirical results discussed in Sect. 4, showing the reliability of those results.

5.2 Robustness test of deleting data in 2020

The reliability of the empirical results depends not only on the test method but also on the sample selected. In the empirical analysis discussed in Sect. 4, the marketization index mainly came from two sources. The data from 2008 to 2019 were obtained from the marketization index prepared by Wang et al. (2021), and the data for 2020 were obtained using the trend extrapolation method. Therefore, to test the reliability of findings in Sect. 4, we exclude the data for 2020 and re-examine the impact of farmers' education level and market-oriented reforms on the utilization efficiency of agricultural water resources. Table 5 reports the results, showing that the impact coefficients of farmers' education level and market-oriented reforms on agricultural water utilization efficiency are significantly positive, and the coefficient of the cross-terms is also significantly negative, which is consistent with the findings in Sect. 4.

Table 6 Robust test of the grouping test

	I High marketization group FE	II Low marketization group FE	III High marketization group sys – GMM	IV Low marketization group sys – GMM
awe_{-1}	−0.0732 (0.1099)	−0.1773 (0.1088)	−0.0283 (0.0970)	−0.1306 (0.1192)
awe_{-2}	−0.2639*** (0.0892)	−0.0333 (0.1156)	−0.2227*** (0.0502)	0.0363 (0.1302)
marketizaiton	0.0632*** (0.0223)	0.0177 (0.0201)	0.0789* (0.0387)	0.0358 (0.0290)
education	0.0304 (0.0376)	0.1106** (0.0442)	0.0478* (0.0260)	0.1404* (0.0755)
patent	0.0269 (0.0361)	0.0353 (0.0383)	0.0363 (0.0346)	0.0183 (0.0498)
R^2	0.5366	0.4316		
AR(2)			0.706	0.472
Hansen			1.000	0.999
Obs	15 × 13	16 × 13	15 × 13	16 × 13

***, **, and * indicate the significance of coefficients at the 1, 5, and 10% levels, respectively; the numbers in parentheses show standard error; AR(2) and Hansen test provide p-values

5.3 Robustness test of the grouping test

According to the provincial ranking of factor marketization degree provided by Wang et al. (2021), the provinces are divided into two groups: a high marketization level group (15 provinces) and a low marketization level group (16 provinces). Table 6 shows that the impact of farmers' education level and marketization reform on the utilization efficiency of agricultural water resources is positive in both the low and high marketization groups, which illustrates that the improvement in farmers' education level and marketization degree helps improve agricultural water resource utilization efficiency. This is consistent with the results in Sect. 4, indicating the reliability of the empirical results of this study. However, the improvement effect of farmers' education level on agricultural water resource utilization efficiency shows heterogeneity in different marketization groups. The influence coefficient of education level on water resource utilization efficiency in the low marketization group is 0.1404, which is higher than that in the high marketization group (0.0478). This also verifies the reverse adjustment effect of the degree of marketization and education level, indicating that the empirical results of the study are robust.

6 Conclusion and policy recommendations

As water resources become increasingly scarce, their availability can have a huge impact on agricultural development. Agriculture is not only important for food production and economic development but is also the largest water consuming sector. However, for a long time, low utilization efficiency of water in agriculture has become a common problem in developing countries. Based on inter-provincial panel data from 2007 to 2020 in China, this study examines the effects of farmers' education levels and market-oriented reforms on agricultural water utilization efficiency. The results show that improving farmers' education level and deepening market-oriented reforms can help improve the utilization efficiency of agricultural water resources. However, with the advancement of market-oriented reforms, the marginal influence of farmers' educational levels on the utilization efficiency of agricultural water resources has gradually weakened. When we retested the results by adopting an instrumental variable, reselecting the sample, and grouping tests, the empirical results remained robust.

Based on empirical research, we make the following policy recommendations. First, in order to attain green recovery of the economy, it is important to improve the education level of farmers, enhance their water use skills, and cultivate the concept of water saving. Utilization efficiency of resources has significant impact on green development and recovery of the economy, so it is important to improve utilization efficiency of resources. Farmers are not only the main users of water resources but also play a pivotal role in water saving. Therefore, it is necessary to educate farmers to improve their awareness of water conservation practices. At the same time, it is necessary to make efforts toward farmers' skill training, providing education regarding water conservation and storage, and optimizing temporal and spatial distribution of water resources. Second, an agricultural water price system that matches market-oriented reforms should be established. At present, reforms in agricultural water prices have not achieved much. Besides, irrigation-related expenses do not form a high proportion of overall agricultural expenditure. Therefore, farmers have little incentives to save water. An agricultural water price system that considers factors like marketization and farmers' paying capacity for water should be established as soon as possible. It will require scientific stock-taking of water resources and establish a water price formation mechanism that reflects the supply and demand of water. Especially, with public budget deficits increased medical costs to cope with COVID-19, and a decline in tax revenues caused by slower economic growth, it is keen to bring private sector into agricultural water supply market in the process of market-oriented reforms. Third, it is necessary to improve the agricultural water rights trading market and adopt appropriate government controls. With advancement of market-oriented reforms, some farmers have shifted water resources that they used to utilize in agriculture to non-agricultural uses considering the costs and benefits of doing the same. Therefore, for farmers' welfare, it is necessary to build a basic system of non-agricultural utilization of agricultural water and establish a trading market for agricultural water rights with diversified subjects such as farmers and irrigation areas. Of course, to avoid the massive loss of agricultural water, non-agricultural utilization of agricultural water needs to be carried out under appropriate government control and effective supervision.

Our study fills an important gap in the literature by examines the effects of farmers' education levels and market-oriented reforms on agricultural water utilization efficiency. However, partly due to data limitations, there is still much related work to continue in future. For example, this study takes China's province as samples. If we can obtain micro-data on farmers' reactions in future, we will be able to analyze the impact of those two factors on utilization efficiency of agricultural water resources in a more comprehensive manner. Besides, if we get the degree of marketization in rural area, we will have more valuable conclusions and policy implications.

Authors' contributions The manuscript is a joint effort of all authors. MZ took part in conceptualization; MZ and JQ took part in methodology; HT and HM involved in literature review; HM and XT involved in writing original draft preparation; JJ took part in writing review and editing.

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Data availability The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors declare that they have no competing interests.

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