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Article

Exploring China's Farmer-Level Water-Saving Mechanisms: Analysis of an Experiment Conducted in Taocheng District, Hebei Province

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Abstract: Two types of farmer-level mechanisms have been traditionally adopted to increase agricultural water use efficiency in northern China: pricing mechanisms and tradable water rights systems. However, the reluctance of policymakers to exacerbate farmers' burdens has rendered pricing mechanisms politically infeasible, while tradable water rights systems involve prohibitively high transaction costs in rural China. An experiment conducted in 2005 in the Taocheng District of Hebei Province created a new kind of water-saving mechanism that involves a number of institutional innovations, including "flexible total management", "collect then refund" and "collect and subsidize, then refund". This paper evaluates the district's water-saving mechanisms based on efficiency, equity and operability criteria. The results of the analysis demonstrate that the "collect then refund" mechanism can more effectively enhance water use efficiency and reduce farmers' burdens than water pricing instruments, tradable water rights systems and flexible total management. Adequate infrastructure and trusted institutions are identified as necessary prerequisites for the successful implementation of the new water-saving mechanism. We believe the new mechanism has great potential to be scaled up.

Keywords: water saving; water pricing; water markets; agricultural water use; China

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1. Introduction

China is facing increasingly severe water scarcity, especially in the northern part of the country [1], where agriculture is the most water-intensive sector. In 2011, agriculture alone accounted for 73.8% of total water use [2]. However, irrigation water use efficiency is still low, and this is largely blamed for the severity of the region's water stress [3]. In response, two mechanisms are generally used to increase the efficiency of agricultural water use in China: pricing mechanisms and tradable water rights systems.

Among the various policies available to address intensifying water stress, pricing mechanisms have been prioritized worldwide [4–7]. The theoretical justification for water pricing is to provide the "right" signal of the value or cost of the water supply, such that farmers can make decisions by themselves that are appropriate for their own situation. However, the effective functioning of pricing mechanisms depends on the presence of such enabling conditions as clearly defined ownership rights and a well-functioning market, which has not been well established for water in rural China. Yang *et al.* [8] analyzes the potential for pricing mechanisms in China's current water management context and suggests that pricing irrigation water alone is not a sufficiently effective means of promoting water conservation. In recent years, a great deal of research dedicated to increasing China's agricultural water efficiency has focused on the reform of water management institutions, the promotion of water user associations (WUA) and irrigation water management transfer [9–13].

Although water management institutions have been considerably improved in China, the unwillingness of the government to increase farmers' burdens has further impeded the adoption of pricing mechanisms for agricultural water conservation. Since 2003, the Chinese government has started to subsidize the agricultural sector and pay more attention to farmers' incomes. Several existing studies have illustrated that increasing water prices not only yields water conservation benefits, but also negatively impacts farmers' incomes [14,15], which renders such policies politically unfeasible. Furthermore, some districts in China have gone so far as to abolish the collection of water fees, a practice that has expanded in recent years [16]. As pricing mechanism policies may be no longer present realistic options in China, other measures for improving agricultural water use efficiency must be considered.

Tradable water rights systems are viewed as essential to the proper functioning of water markets [17], and as a result, the development of a tradable water rights system is considered to be an attractive alternative to the adoption of water pricing mechanisms in China. Over the past decade, the Chinese government has tried to develop a water rights system to enable the allocation of water entitlements and the transfer of water rights [18]. However, a number of studies have described a variety of barriers to the establishment of open water markets [19–23]. The experience in China supports such findings. Attempts at adopting tradable water rights systems in China have been challenged by a number of practical issues related to market forces, technological conditions, risks and uncertainties and prohibitively high transaction costs [24,25]. Many studies have highlighted transaction costs as the major constraint for the success of water rights trading systems [26,27]. Water trading regime modeling studies that simulate the effects of transaction costs provide additional evidence that trans-jurisdictional water markets can lead to considerable potential benefits if transaction costs are not present; with transaction costs, water trading benefits increase as transaction costs decrease [23,28].

However, the practice in China suggests that the transaction costs are too large and the benefits are too small to motivate local governments and farmers to establish water markets for water reallocation [29].

Since increasing agricultural water prices has proved infeasible and high transaction costs have discouraged the development of water markets, other farmer-level water-saving mechanisms must be explored. It is against this backdrop that we consider the experience of the local Water Resources Bureau of Taocheng District in Hebei Province, which inadvertently created an innovative new water-saving mechanism while attempting to replicate Zhangye City's tradable water rights system.

The next section of this paper describes the policy background and study area. The third section introduces the experiment conducted by the Water Resources Bureau of Taocheng District in Hebei Province. Various kinds of water-saving mechanisms are evaluated in the fourth section based on efficiency, equity and operability criteria. The last section concludes the study and proposes scaling up the farmer-level agricultural water-saving innovation.

2. Policy Background and Study Area

2.1. Policy Background

For political and equity considerations, the Chinese government prefers a "water rights transfer system" to water pricing in irrigation water management. A number of ministerial and regional guidelines and directives related to water transfers have been issued over the last decade or so [18]. The framework for the allocation and management of China's water resources was established by the 2002 Water Law [30]. China's 11th Five-Year Plan (2006–2010) [31] prioritizes the improvement of water resource management. It specifically requires the establishment of "an initial water rights allocation system and a water rights transfer system".

With the support of the Chinese government, water trading has been implemented at the basin, region and farm level [29]. The Yellow River Water Allocation Plan, approved by the State Council in 1987, is an example of a basin-level water rights allocation scheme, as it apportions water resources among the 10 provinces that utilize the river's water. By following this, the implementation of absolute regional water use control via a water rights system has gradually expanded throughout the basin [30]. Elsewhere, in 2000, Dongyang City and Yiwu City in Zhejiang Province of eastern China agreed to a region-level water transfer scheme, which is widely regarded as the first such arrangement in China. Several other similar contract-based regional transfer systems have subsequently occurred in Zhejiang Province [32]. Furthermore, the initiative to build a Water-Saving Society in 2002 in Zhangye, a northwestern inland city, is China's first case of a farmer-level water transfer scheme. The Liyuan Irrigation District of Zhangye City provides a typical example. Within the irrigation district, "water certificates" are issued to individual farmer households. These certificates show the household's water allotment and the conditions for the use of allocated water. Allocations are assigned by using a "water ticket" system on an annual basis. Individual farmers purchase water tickets from the irrigation district management agency (or the local water user association) for each irrigation cycle [33]. Since this paper explores micro-agricultural water-saving mechanisms that affect participants, we mainly focus on farmer-level water transfer.

2.2. Study Area

The Haihe River Basin is a major basin in northern China. The basin extends from the Bohai Sea in the east, to the Yellow River in the south, the Taihang Mountains in the west, the Inner Mongolian Plateau in the north and across eight provinces and municipalities, including Beijing, Tianjin, Hebei, Shanxi, Shandong, Henan, Liaoning and Inner Mongolia, with a total drainage area of 265,000 km^2. The study area of this paper is Taocheng District in Hebei Province, which is located near the center of the Haihe River Basin (Figure 1).

Figure 1. Location of the Haihe River Basin and the surveyed irrigation district.

Taocheng District is located in the southeast of Hebei Province, in the heart of Hengshui City. According to the Hengshui City Statistics Bureau [34], Taocheng District covers 590 km^2 and encompasses four street offices, two towns and four townships. The district has a population of 468,876 residents, of which 161,774 are located in rural areas. The study area is a typical irrigated district in northern China. The average annual rainfall is 522 mm. The water resources per capita of this area are 120 m^3, approximately 5.2% of the national average. For a long time, about 59.3% of irrigation water was obtained via deep groundwater exploitation. While the annual water use requirement in the region is 161 million m^3, the annual water availability is only 83 million m^3 (including deep groundwater resources). In order to maintain its current rate of social and economic development, the district has to over-exploit 78 million m^3 of groundwater each year. The over-exploitation of groundwater lowers the groundwater level at a rate of 2.3 m annually, with aquifer water levels in Taocheng District dropping from 15.92 m in 1972 to 94.06 m in 2006, causing land subsidence, saltwater intrusion and other ecological problems.

Although the study area suffers from severe water scarcity, it possesses a number of advantageous characteristics that are necessary for effective water governance, including good irrigation infrastructure, sophisticated flow measurement equipment and some institutions, such as trusted WUA.

Unfortunately, a lack of farmer-level water-saving incentives has stymied efforts at promoting effective water governance. The efficiency of agricultural water use is still low, and the technology promoted by the local water resources bureau has not been largely adopted by the farmers. This is why the Taocheng Water Resources Bureau began to explore alternative water-saving mechanisms starting in 2004.

3. Irrigation Management Experiments in Taocheng District

3.1. Phase One: Implementation of Tradable Water Rights System

The original objective of the Taocheng Water Resources Bureau was to replicate the water-saving model pioneered by Zhangye City. Taocheng District was identified as a provincial pilot water-saving society by the Water Resources Department of Hebei Province in April 2004. Over the following three months, a delegation from Taocheng Water Resources Bureau visited Zhangye City to learn from their experience. On 1 October 2004, the Bureau selected Chonggao Village of Heyan Town as the first pilot to implement the farmer-level water transfer regime. It was at this point that the experiment conducted by the local bureau officially began [35].

Within the village, "water certificates" that specify the allocation assigned to the household and the conditions for the water's use were issued to individual households by the local water resources bureau. Allocations are assigned using a "water ticket" system on an annual basis. During each irrigation cycle, farmers purchase water tickets from the local water user association, which was originally established with the aid of local officials, but which is currently operated by farmers themselves. The volume available to be purchased is limited to the amount listed on the water certificate and the total volume available to the district for the year, which is determined by the Taocheng Water Resources Bureau, according to local cultivation habits, average annual water consumption and the region's water resource planning. The village's comprehensive irrigation infrastructure and sophisticated measurement equipment helped to facilitate the establishment of the water ticket system.

The water certificates are submitted to the water user association before each delivery of the water via pipes to the farmer's land. The volume designated by the water ticket is the total amount a farmer can use that year. If that amount does not satisfy the farmer's requirements, he has no choice but to purchase an extra water ticket from another farmer. Water tickets can be traded freely, and the price of water tickets is determined by mutual bargaining. The proper functioning and self-governed operation of the local water user association promotes the farmers' receptiveness to the scheme, thereby enabling its implementation.

The Taocheng Water Resources Bureau determined the water volume of Chonggao Village to be 0.41 m^3/m^2 in the first irrigation cycle. Unfortunately, there have been few instances of water ticket trading in practice, besides some anecdotal evidence of the sale of water tickets between neighbors, as a means of adjusting in the event of over-ordering in the first few months. The Taocheng Water Resources Bureau later identified two impediments to the successful implementation of the water transfer scheme: first, the volume of water consumed is too hard to estimate before the irrigation cycle. As the 0.41 m^3/m^2 estimate was based on the average annual consumption during a year characterized by especially abundant rainfall, it could not meet the farmers' needs during years that experienced typical levels of rainfall. Second, the transaction costs associated with trading water exceeded the benefits. China's agriculture is characterized by large numbers of smallholders and a great many individual water users. Land fragmentation and the small volumes of water rights made the allocation and management of water rights a significant administrative challenge. As a result, the benefits of trading water were excessively small and the transaction costs associated with price seeking and bargaining between farmers were prohibitively high.

3.2. Phase Two: Flexible Total Management

Chonggao Village's difficulties with water transfer policies are not unlike those experienced by Zhangye City [29,36] and illustrate the problems that are common to farmer-level water transfer projects in China. After the failure of the Chonggao Village pilot, the Taocheng Water Resources Bureau created a new mechanism called "flexible total management" and chose Beisuzha Village as the new pilot site. Following this, the Bureau renamed the tradable water rights system applied in Chonggao Village, "fixed total management". In the Chonggao pilot, the local authority needed to determine the total annual volume available to the district before the irrigation cycle. The volume was always set beneath the average annual water consumption amount, in order to promote water use efficiency. However, this assessment was complicated by a variety of uncertainties and the vastness of the amount of information that the local authority needed to collect and process.

"Flexible total management" alleviated these administrative burdens for the local authority. After the irrigation cycle, the water user association of Beisuzha Village conducted a detailed registration of the total volume used by the village. They then calculated the average amount of the water consumed per square meter. This amount served as the metric used to either reward or punish farmers. If the volume of water a farmer consumed per square meter exceeded the designated amount, he would be punished at a rate of 0.1 RMB/m^3; otherwise he would be rewarded at a rate of 0.1 RMB/m^3. This flexible total management is significantly different from the tradable water rights system. It uses the average water consumption after the irrigation cycle as the baseline of the water-saving incentive scheme. Since no farmer knows the average amount of water consumption before the irrigation cycle ends, all farmers attempt to consume less water than their neighbors do.

An accurate water measurement and control system is essential to the proper functioning of the flexible total management scheme. Without a fair measurement system and a trusted local water user association, the new mechanism cannot be implemented. Unfortunately, despite the bureau's innovation and their good water governance, the water user association's lack of sufficient enforcement authority resulted in farmers' payment delinquency. Furthermore, many local governments in China now lack adequate water fee enforcement power in rural areas, due to policy and structural changes in these areas [16]. This new problem pushed the Taocheng Water Resources Bureau to implement further reforms.

3.3. Phase Three: "Collect then Refund"

In 2005, the vice director of the Taocheng Water Resources Bureau decided to address the payment delinquency issue by letting farmers pay the required amount of money before an irrigation cycle and then refunding the appropriate amount according to the water volume they used after the irrigation cycle ends.

Based on this idea, the Bureau created a new mechanism called "collect then refund", which involved, first, establishing the water price, then collecting the water funds through raising water prices during the irrigation cycle, and, last, the WUA divided the water funds by the total land area of the village and determined the refund amount per square meter and distributed the remainder accordingly. The reward and punishment for each farmer was also published in the village.

The Taocheng Water Resources Bureau realized that with this mechanism, those farmers whose water consumption was above the average level were punished, while the other farmers were rewarded. If an institution gets 50% support and 50% opposition in a village, it will be hard to implement. Therefore, the Taocheng Water Resources Bureau planned to subsidize the water adjustment fund in order to carry out the new mechanism.

As a result, a revised version of the mechanism was innovated and called "collect and subsidize, then refund". On 1 August 2005, the Taocheng Water Resources Bureau chose Guojiazhuang Village as the pilot site of the new mechanism. They raised the agricultural water price from 0.35 RMB/m^3 to 0.5 RMB/m^3, and the Bureau offered a subsidy of 0.05 RMB/m^3. The surcharge and subsidy were managed by the local water user association during the irrigation cycle. After the irrigation cycle, the local WUA divided the surcharge and the subsidy amounts by the total land area of the village and determined the refund amount per square meter and distributed it accordingly. Due to the subsidy, the mechanism was supported by the majority of the farmers in Guojiazhuang Village. Compared with the tradable water rights system, the new mechanism is simpler to implement and its transaction costs are smaller.

Evidence indicates that given the favorable water governance policy context of Guojiazhuang Village, in terms of the good condition of their irrigation infrastructure and their trusted water user association, the new mechanism managed to achieve an average water saving rate of about 18.85% [37]. The researchers choose ten control villages (which had not implemented any new mechanisms) near the pilot village that has similar natural conditions and populations.

The water-saving effect can be observed in farmers' behavior. Farmers started to adopt new methods of irrigation and new water-saving technologies. They even voluntarily undertook investments to improve their irrigation infrastructure. An evaluation conducted by the Taocheng Water Resources Bureau reveals that the number of villages that adopted this new mechanism reached 83 by the end of 2012. It is estimated that on average, the new mechanism can save about 7 million m^3 of water, 4.5 million kW h of electricity and 2.6 million RMB each year in that district. Taocheng District's policy innovation has achieved national recognition for their effective management of water resources. In 2012, the Taocheng Water Resources Bureau was given an award by the Ministry of Water Resources [38].

Some important studies have promoted the concept of "real water saving" in recent years. They have proven that most of the water loss in irrigation returns to the stream or the aquifer through runoff or return flow, which can be used by downstream users or pumped out in the future. Those are not real water losses. The real water loss should be measured based on an accurate accounting of basin-wide water use [39,40]. We believe since the new water saving mechanisms aim to incentivize water saving behavior, they can still contribute to real water saving. Policymakers must determine a set of indicators that can comprehensively define and accurately measure "real water saving".

4. Evaluation of Alternative Irrigation Management Mechanisms

Although the new mechanism functions well in practice, there are some issues that remain to be explored, such as the differences between and commonalities among different mechanisms and the efficiency, equity and operability outcomes of different mechanisms. In this section, we evaluate alternative water-saving mechanisms according to efficiency, equity and operability criteria. The following four kinds of water pricing mechanisms are considered: increasing irrigation water prices, tradable water rights systems, flexible total management and a "collect then refund" mechanism.

"Efficiency" in this paper refers to the marginal productivity of irrigation water. The objective is to compare changes in water use, which will be reflected in changes in the marginal productivity of water. If the marginal productivity of irrigation water is high, water can be regarded as being used efficiently. Thus, water saving refers to improvements in marginal productivity per unit of irrigation water. In this paper, a profit maximization model is used to evaluate water-saving mechanisms in a manner similar to that of Duan and Yang [41]. Considering the influences of different mechanisms on individual behavior, our discussion of efficiency focuses on the behavior of individual farmers.

Since farmers constitute an economically disadvantaged social group in China, "equity" in this paper refers to the financial burden a mechanism puts on farmers. "Operability" refers to the feasibility of the practical operation of a mechanism, which can be measured by the transaction costs associated with the mechanism. We will discuss the "operability" of four kinds of mechanisms adopted in Taocheng District in a separate section.

Before the evaluation, we first assume a representative farmer, z, behaves rationally, by following the profit-maximization principle, and the farmer plants s m^2 of a particular crop. In this paper, we use a single-crop model to simplify how these mechanisms actually work, and while the single-crop model is limited in that it cannot address the impact of crop mix or crop choices on water use, adopting a single-crop model is a necessary simplification, which is helpful to illustrate the functioning of the water consumption mechanism and can be regarded as a baseline for further analysis.

The water-saving investment in capital and labor by farmer z is i. The water loss during the irrigation process is g_0 before making the water-saving investment and g_1 after making the water-saving investment. The water volume saved is g, $g = g_0 - g_1$. The investment, i, is a function of water-saving, namely $i = i(g)$, and $i' > 0$. Crop water consumption is w. Considering water loss, total water consumption of the farmer, z, is d_1, with $d_1 = w + g_1 = w + g_0 - g$. Crop production is given as $q = f(w,s)$, which has a diminishing marginal return to applied irrigation water, w. Crop price is p_f. Without loss of generality, we assume the number of farmers of the entire village is N, and the land area of every farmer is equal and represented as one unit. Under this assumption, the total land area of the whole village is also N. The total water consumption of the entire village is D, which is the sum of irrigation water consumption by individual farmer households d_1, d_2, d_3, …, d_n. The total water fee paid by all the farmers in the village is F.

4.1. Increasing Irrigation Water Price

4.1.1. Efficiency

When we increase the agricultural water price to save water, we assume the price a farmer has to pay in cubic meter is p_w. Assuming the farmer is risk-neutral, the profit function of the typical farmer z is:

$$\pi = p_f f(w,s) - p_w(w+g_0-g) - i(g) \tag{1}$$

The first order optimality conditions of the profit maximization are:

$$\pi_w = p_f f_w - p_w = 0 \tag{2}$$

$$\pi_g = p_w - i' = 0 \tag{3}$$

Thus, the equilibrium condition of water use is:

$$p_f f_w = i' = p_w \tag{4}$$

The above equation implies that at optimal water-saving investment level, the marginal economic return of irrigated crop production equals the marginal cost of water-saving investment, which is equivalent to the water price. If the water fee amount is area-based, farmers will use as much water as needed or wanted, because payment for water is fixed no matter how much water is used. The water use efficiency of charging water fees by volume is higher, due to $p_w > 0$. At this time, the water use efficiency is determined by p_w. If the p_w is high enough, water use efficiency will be achieved by the efficiency criterion of this paper.

4.1.2. Equity

When we raise agricultural water prices to save water and the water fee is charged by volume, the water fee of the whole village is:

$$F = \sum_{n=1}^{N} p_w d_n = p_w D \tag{5}$$

It has been proven that agricultural water use is inelastic in low price zones [42]. Therefore, higher p_w leads to higher revenue from water fees, F. That is to say, when the water price is higher, the burden put on the farmers is heavier. In considering equity, it is important to note that agriculture is a weak sector and that farmers are a vulnerable group in China. As a result, the current policy tends to discourage raising agricultural water prices.

4.2. The Tradable Water Rights System

4.2.1. Efficiency

When assessing the tradable water rights system as a water-saving mechanism, we take the Chonggao Village as an example. Prior to the irrigation cycle, the bureau determines a fixed quota or amount each farmer can use, x, while the water price within the quota is p_w. If a farmer needs to use more water than he has been allocated, he is allowed to buy water from other farmers who are willing to sell a portion of their quota. The water trading price is determined through a bargaining process. With a fixed total water quota at the village level, the profit function problem faced by a representative farmer z is:

$$\pi = p_f f(w,s) + p_a a - p_w(w + g_0 - g) - i(g) \tag{6}$$

In the formula above, a is the quantity of the water that farmer z purchases from or sells to other farmers in the village, where $a = x - d_1 = x - w - g_0 + g$. P_a is the price of the water traded per cubic meter. Here, a can be positive, zero or negative. If farmer z saves water, then $d_1 < x$ and a is positive, and farmer z is the water seller. If farmer z does not save water, *i.e.*, $d_1 > x$, a is negative, and farmer z is the water buyer.

The first order optimality conditions of the profit maximization problem are:

$$\pi_w = p_f f_w - p_a - p_w = 0 \tag{7}$$

$$\pi_g = p_a + p_w - i^{'} = 0 \tag{8}$$

Thus, the equilibrium condition of water use is:

$$p_f f_w = i^{'} = p_a + p_w \tag{9}$$

The equation above implies that when the allocation of water resources achieves equilibrium, the marginal productivity of water of farmer z should reach $p_a + p_w$. The water use efficiency of the tradable water rights system is higher than that of the increasing of the water price, as $p_a > 0$.

4.2.2. Equity

When we apply the tradable water rights mechanism and since the total water allocation is fixed during the irrigation season, the water traded between farmers has no impact on the water fee for the entire village. The change in the water fee for the entire village is:

$$\Delta F = \sum_{n=1}^{N}(p_a a_n + p_w d_n) - p_w D = p_w D - p_w D = 0 \tag{10}$$

In terms of equity, the tradable water rights system puts no extra burden on all the farmers of the village. The total water fee is determined by p_w and D.

4.3. Flexible Total Management

4.3.1. Efficiency

In assessing the flexible total management mechanism, we analyzed the Beisuzha village scheme and assumed the threshold quota per square meter used to determine whether to reward or penalize a farmer to be x, and $x = \frac{(d_1 + d_2 + ... + d_n)}{N}$. If the volume of water a farmer consumed per square meter exceeds the designated amount, he will be penalized by paying a price of p_b; if the volume of water a farmer consumed per square meter does not reach the designated amount, he will be rewarded

p_b RMB/m^3 for the unused amount. $y = D - d_1$, w and $\frac{D}{N}$ do not fit certain mathematical relationships. Under these circumstances, the profit function of a typical farmer z is:

$$\pi = p_f f(w,s) - p_b(w + g_0 - g - x) - i(g) = p_f f(w,s) - p_b[w + g_0 - g - \frac{(d_1 + y)}{N}] - i(g) \quad (11)$$

The first order conditions of the profit maximization are:

$$\pi_w = p_f f_w - p_b \frac{(N-1)}{N} = 0 \quad (12)$$

$$\pi_g = p_b \frac{(N-1)}{N} - i' = 0 \quad (13)$$

Thus, the water use equilibrium condition is:

$$p_f f_w = i' = p_b \frac{(N-1)}{N} \quad (14)$$

If N is large, as is characteristic in China's smallholder agricultural system, then:

$$\lim_{N \to \infty} P_b \frac{(N-1)}{N} = P_b \quad (15)$$

In this mechanism, the individual farmer's water use efficiency depends on p_b. If p_b is higher, the marginal productivity of water is higher; otherwise, it will be lower.

4.3.2. Equity

In terms of equity, the flexible total management mechanism adjusts individual farmer water use efficiency preferences, but the water fee of the entire village does not increase, which can be expressed by the formula:

$$\Delta F = \sum_{n=1}^{N} p_b(d_n - x) = 0 \quad (16)$$

4.4. The "Collect Then Refund" Mechanism

4.4.1. Efficiency

In the case of the "collect then refund" mechanism, after establishing the water price, the WUA collects the water funds by raising water prices during the irrigation cycle, then refunds the money. The original water price is p_w; the price surcharge amount is c and the final water price farmers have to pay is $p_w + c$. $d_1 = w + g_1 = w + g_0 - g$. The surcharge amount is used as the water fund. The WUA divides the water fund by the total land area of the village and determines the amount of money shared per square meter. In this case, the profit function of a typical farmer z is:

$$\pi = p_f f(w,s) - (p_w + c)(w + g_0 - g) - i(g) + c\frac{(d_1 + d_2 + \ldots\ldots + d_n)}{N} \quad (17)$$

The first order conditions of the profit maximization are:

$$\pi_w = p_f f_w + c\frac{(1-N)}{N} - p_w = 0 \tag{18}$$

$$\pi_g = p_w - \frac{(1-N)}{N}c - i' = 0 \tag{19}$$

Thus, the water use equilibrium condition is:

$$p_f f_w = i' = p_w - \frac{(1-N)}{N}c \tag{20}$$

If N is large, as is characteristic in China's smallholder agricultural system, then:

$$\lim_{N\to\infty}[P_w - \frac{(1-N)}{N}c] = P_w + c \tag{21}$$

The formula above proves that when the allocation of water resources achieves equilibrium, the water use efficiency of the individual farmer depends on p_w and c. If we apply the "collect then refund" mechanism when N is large, the real effect will be similar to increasing the water price to $p_w + c$.

If we consider the revised version of the mechanism, "collect and subsidize, then refund", we assume the subsidy amount provided by the government per cubic meter is e. Then, the profit function of a typical farmer z is:

$$\pi = p_f f(w,s) - (p_w + c)(w + g_0 - g) - i(g) + (c+e)\frac{(d_1 + d_2 + ... + d_n)}{N} \tag{22}$$

The first order conditions of the profit maximization are:

$$\pi_w = p_f f_w + c\frac{(1-N)}{N} + \frac{e}{N} - p_w = 0 \tag{23}$$

$$\pi_g = p_w - \frac{(1-N)}{N}c - \frac{e}{N} - i' = 0 \tag{24}$$

Thus, the equilibrium condition of water use is:

$$p_f f_w = i' = p_w - \frac{(1-N)}{N}c - \frac{e}{N} \tag{25}$$

If N is large, as is characteristic in China's smallholder agricultural system, then:

$$\lim_{N\to\infty}[p_w - \frac{(1-N)}{N}c - \frac{e}{N}] = p_w + c \tag{26}$$

The formula above implies that in the revised mechanism, the individual farmer's water use efficiency still depends on p_w and c. When N is large, the subsidy of the government has little impact on water use efficiency, and the real effect is still similar to increasing the water price to $p_w + c$.

4.4.2. Equity

In regards to equity, when the "collect then refund" mechanism is applied, the change in the whole village's water fee is:

$$\Delta F=\sum_{n=1}^{N}(p_w+c)d_n-cD-p_wD=p_wD+cD-cD-p_wD=0 \tag{27}$$

The "collect then refund" mechanism itself does not put any extra burden on the village's farmers.

When the "collect and subsidize, then refund" mechanism is applied, the change in the whole village's water fee is:

$$\Delta F=\sum_{n=1}^{N}(p_w+c)d_n-(c+e)D-p_wD=p_wD+cD-cD-dD=-dD \tag{28}$$

The benefit to the whole village is improved, thanks to the government's subsidy. Therefore, the "collect and subsidize, then refund" mechanism raises water use efficiency without burdening farmers.

4.5. The Discussion on Operability of the above Mechanisms

In terms of operability, there are several necessary preconditions, such as adequate infrastructure and good water management, needed to apply the mechanism of increasing the water price. Worldwide, water markets are more prevalent than increasing water prices. However, water markets have one critical limitation under China's current context. The institutional costs of implementing this mechanism may exceed its benefits, as witnessed in Zhangye City and Taocheng District [24].

The institutional cost of flexible total management is much smaller than that of the tradable water rights system. In the mechanism of flexible total management, the local authority does not have to determine the fixed quota before the irrigation cycle and the farmers do not have to spend time trading water. The biggest obstacle to implementing this mechanism is that the local WUA lacks the necessary enforcement capability to penalize those who refuse to pay the fine. The flexible total management still requires monitoring each individual farmer's water use to determine his punishment or reward; however, these can be easily calculated based on the accurate measurement infrastructure, due to the delicate design of "flexible total management" itself.

The "collect then refund" mechanism is designed to address the problems associated with the flexible total management mechanism. In terms of operability, "collect then refund" solves the enforcement dilemma. Additionally, the revised mechanism, "collect and subsidize, then refund," obtains the necessary support from the majority of the farmers. The "collect then refund" mechanism, when implemented in areas with the proper irrigation infrastructure and a trusted water user association, holds great potential for promoting good water governance.

5. Conclusions

This paper evaluates four agricultural water-saving mechanisms. Among them, the implementation of increasing the water price seems to be the easiest and most well-known mechanism. The motivation, economic principles and welfare consequences of the pricing mechanism have been illustrated by economic texts. However, the effective functioning of the pricing mechanism depends on some assumptions that cannot be fully met in rural China. Given China's current policy-making environment, increasing the agricultural water price seems to be more infeasible. Tradable water rights systems, which can be viewed as a further reform to enforce the price mechanism, are more effective in promoting water use efficiency and do not necessarily put any additional burden on farmers.

Unfortunately, this mechanism usually involves prohibitively high transaction costs, due to the high land fragmentation in rural China.

"Flexible total management" is a newly innovated mechanism, which uses average water consumption during an irrigation season as the reference for rewarding or penalizing farmers. This mechanism is similar to raising water prices in achieving the efficiency goal, but puts no additional burden on farmers at the village level. This mechanism groups farmers into those to be rewarded and those to be penalized, with the latter potentially regarding the mechanism as unfavorable, especially where the local WUAs lack necessary enforcement capability.

The "collect then refund" mechanism was originally established for collecting the fine before the irrigation season starts. The revised version manages to obtain majority support through the provision of a subsidy. The "collect then refund" mechanism and its revised version can lead to an improvement of water use efficiency similar to that of increasing the water price. However, this new mechanism puts no additional burden on farmers at the village level. Its revised version, "collect and subsidize, then refund", can even increase the welfare of farmers through subsidization. Subsidy not only makes implementation of the new mechanism easier, but also corresponds with the current policy environment in China. Therefore, the new mechanism appears to be a more promising alternative than increasing agricultural water prices or introducing water marketing, the main farmer-level agricultural water-saving mechanisms currently adopted in northern China.

Although the Taocheng Water Resources Bureau originally intended to replicate the Zhangye City model, the experiment in Taocheng led to a new water-saving mechanism instead. Despite severe water stress in Taocheng, it possesses several characteristics favorable for sound water governance, including good irrigation infrastructure, advanced measurement equipment and some institutions, such as trusted WUA, all of which were critical to the innovation's success. Therefore, good infrastructure and institutions should be considered necessary preconditions for the effective implementation of this new water-saving mechanism. As agricultural water management becomes increasingly important and water infrastructure and water management institutions further develop, it is reasonable to believe that the "collect then refund" mechanism can potentially be scaled up to more regions.

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Author Contributions

Sicheng Chen: idea, field trip, model construction and paper writing. Yahua Wang: basic idea, research design, paper writing and revision. Tingju Zhu: valuable discussion, model correction and paper revision.

Conflicts of Interest

The authors declare no conflict of interest.

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