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Forty years of irrigation development and reform in China*

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This study reviews 40 years of irrigation development in China including the transformation of the institutional and incentive structures in irrigation management. After rural reforms in the 1970s, irrigation investments slowed until the late 1990s. In North China, farmers became major investors in groundwater irrigation, leading to property rights' transfer of tube wells from collective to private ownership. Despite positive effects in cropping patterns, farmer income and development of groundwater markets, privatisation has accelerated groundwater table deterioration. Since the middle of 1990s, Water User Associations have replaced village collective management of surface irrigation. This approach was adopted by most provinces by early 2001 with mixed results; only institutions with water-saving incentives realised efficient irrigation. The Government is reforming water price policies to provide water-saving incentives to farmers while not hurting their income. While China has focused on water rights and markets, and despite regulations and pilot projects, full implementation of water rights has been slow. Research reveals greater policy scope for expanding irrigation technologies that generate real water saving to rural areas. Given pressure associated with water scarcity and concern for food security, further effective reforms in irrigation and policy incentives are expected. The Government has also initiated some pilot projects to resolve increasing water scarcity problems through adjusting agricultural production activities.

Key words: China, incentive mechanisms, institutional innovation, irrigation development, irrigation technologies.

1. Introduction

Since the onset of the economic reforms and the implementation of the household responsibility system (HRS) in the late 1970s, China's rural

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economy has achieved impressive growth. From 1978 to 2017, grain production increased from 305 to 662 million tons, with an annual growth rate of 2.0 per cent (NBSC 2018). The value of agricultural products in real terms has grown at an even faster rate of by 5.4 per cent per year. Investment in irrigation is among the major factors that have contributed to the success of the economic reform in boosting rural growth (Huang and Rozelle 2018). By increasing crop yields as well as allowing more growing seasons, irrigation can double agricultural productivity relative to rainfed land (Wang *et al.* 2010). Although the amount of irrigation investment has fluctuated over the years, effective irrigated land that is equipped with irrigation facilities has increased significantly. By 2017, China's irrigated land has reached 67,816,000 ha, covering half of all cultivated land (NBSC 2018). Over 70 per cent of China's grain, 80 per cent of the nation's cotton and more than 90 per cent of the nation's vegetables are grown on irrigated land (Wang *et al.* 2017). However, increasing water scarcity has threatened the sustainability of irrigated agriculture. China's per capita water availability is only one-fourth of the global average (Wang *et al.* 2017). Moreover, water resource are not evenly distributed. With just 19 per cent of water endowment, Northern China supports more than 65 per cent of the national cultivated land and 50 per cent of grain production (NBSC 2018). From 1961 to 2011, river run-off in 60 per cent of large river basins has seen a decline, primarily in Northern China.[1] As surface water resource decrease, water users (particularly farmers) are turning to groundwater resource (Wang *et al.* 2006). Due to dry climatic conditions and high variability of precipitation, groundwater also acts as an important storage buffer in Northern China. However, the reliance on groundwater leads to overdraft and adverse environmental effects (Wang *et al.* 2017). Furthermore, water users in the agricultural sector are displaced by users in other sectors. From 1978 to 2017, the share of agricultural water use declined from 88 per cent to 62 per cent due to increasing industrial and domestic water use. In the most recent decade, the Government has started to recognise the importance of meeting ecological water requirements, which increases the demand for water. In future, climate change is expected to further aggravate the gap between the supply and demand of water, and enhance the supply variability (Wang *et al.* 2013; IPCC 2014).

Since food self-sufficiency has always been an important policy goal and irrigation is one of the key factors to maintain food security, China's Government has been active in pursuing solutions to the challenges of irrigated agriculture. Traditionally, the Government has focused on the supply side and relied on projects that augmented water supply such as

[1] The Northern China includes North China Plain (Beijing and Tianjin municipalities as well as Hebei, Shanxi, and Inner Mongolia provinces), northeast China (Liaoning, Jiling, and Heilongjiang provinces), northwest China (Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang provinces) and part of Henan Province.

building reservoirs to meet the growing water demand (Xie *et al.* 2009; Wang 2012). Over time, it has become clear that it is difficult to catch up with the expanding water demand and the demand side also needs to be managed. The Government started to advocate irrigation technologies to reduce irrigation withdrawal since the early 1990s (Lohmar *et al.* 2003). The government encouraged reforms of institutional arrangements in water management and provided economic incentives to save water (Huang *et al.* 2010b). The Government also experimented with market-based solutions such as the assignment and trading of water rights and developing water markets to improve allocative efficiency of water use (Speed 2009; Moore 2015). Irrigation pricing policy has always been on the policy agenda (Huang *et al.* 2010a). In recent years, the Government has renewed its efforts to reform irrigation water price (Sun *et al.* 2018).

The overall goal of this study is to review irrigation development in China and examine the trends, drivers, and effects of the 40-year transformation of the institutional arrangement and incentive mechanisms in irrigation management. No prior literature has reviewed Chinese irrigation over this period. In the last 2 years, China launched the multidimensional Rural Revitalization Development Strategy (Huang and Rozelle 2018). This strategy aims to absorb lessons from past development and policymaking to inform future development. There are significant policy implications and urgent policy requirement of reviewing 40 years of irrigation development and management; this is expected to support rural revitalisation. The fruits of this examination could also be useful to other countries facing water scarcity. The study focuses on North China since it is one of the most water-scarce areas in the world. A unique aspect of this study is that most information used comes from village and household survey data the authors have collected in rural China over more than two decades.

To this effect, we pursued the following objectives. First, we tracked the evolution of irrigation investment and development of irrigated areas over the past 40 years, and to understand the relevant policies. Second, we examined the trends in the institutional arrangement of groundwater and surface irrigation reforms, and then identified their effect on water use, agricultural production, and farmer income. Third, we analysed the trends, drivers and effects of reform in incentive mechanisms, including irrigation price policy, establishment of a water rights system, and development of water markets. Fourth, we summarised the adoption trends, influence factors, and effects of water-saving technologies, followed by a discussion of the challenges and opportunities for future reforms in irrigation sector.

The remaining paper is organised as follows. Section 2 summarises irrigation development and investment over 40 years. Section 3 presents the trend, drivers, and effects of surface and groundwater irrigation systems. Then, we analysed the progress of reform in irrigation price policy, water rights system, and water markets in Section 4. Section 5 presents the adoption status, influence factors, and effects of water-saving technologies. Section 6 includes the challenges and opportunities for irrigation development, as well as future reforms in management. The final section deals with new policies on controlling groundwater overdraft and the progress and major challenges of pilot projects in Hebei Province, followed by the concluding remarks.

2. Irrigation development and investment in China

China has a long history of water capture and control, especially for flood control and irrigation (Calow *et al*. 2009). Before rural reforms, significant investments in water infrastructure helped China establish a robust rural irrigation system. At the founding of the People's Republic of China in 1949, the new nation struggled with low agricultural productivity, natural disasters (such as drought and floods), and poor farmers. As a primarily rural economy, the Government considered water infrastructure to be an important investment priority. This turned to be a smart development strategy that influenced China's long-term progress. From 1950 to 1978, China invested nearly 100 billion yuan into water infrastructure; this accounted for 6.9 per cent of the national total investment in infrastructure (MWR various years). Moreover, farmers also formed the labours force in the construction of this infrastructure (Lohmar *et al*. 2003). Thus, China's effective irrigated land areas increased from 16,000,000 ha in 1950 to 48,050,000 ha in 1978, with an annual growth rate of 4.01 per cent (Figure 1 and Table 1). The share of cultivated land areas equipped with irrigation facilities increased from 16 per cent in 1950 to 48 per cent in 1978. That is, before rural reforms in China, near half of the cultivated land areas had access to irrigation water.

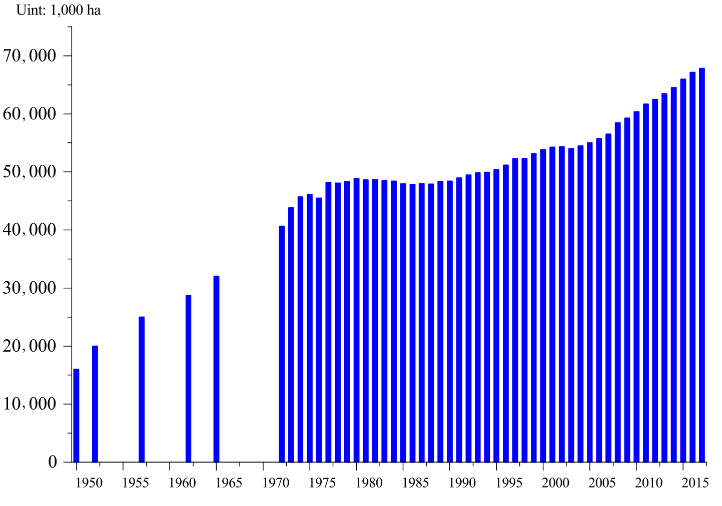

Figure 1 Development of effective irrigated land areas in China (1950 - 2017).
Data Sources: Various years of China Statistical Yearbooks. [Colour figure can be viewed at wileyonlinelibrary.com]

However, after the rural reforms, the expansion of irrigated land areas slowed down and even showed a declining trend in the early 10-year reform period. Since the late 1970s and early 1980s, de-collectivisation through rural reforms has increased agricultural productivity and production. From 1978 to 1984, the annual growth rate of grain productivity and output reached 6.12 per cent and 4.95 per cent, respectively (NBSC 2018). It is likely that this progress motivated Chinese policymakers to shift their investment focus from agriculture to industrial and other sectors (Lohmar *et al.* 2003). The Government not only reduced funding for developing new water infrastructure by a considerable margin, but also neglected funding for the operation and maintenance of existing irrigation facilities. The percentage of construction funds for water infrastructure over total infrastructure declined from 7.1 per cent in 1978 to a paltry 1.9 per cent in 1988. Correspondingly, irrigated land areas in this period decreased from 48,050,000 ha to 47,910,000 ha (Figure 1). Many irrigation facilities have also deteriorated or become dysfunctional because of low investments.

The decline in irrigated land areas and deterioration of the irrigation system negatively affected agricultural production. Post-reform grain production peaked in 1984; it then declined and stagnated in the late 1980s (NBSC 2018). From 1984 to 1988, grain production and productivity decreased by 3.2 per cent and 0.8 per cent, respectively, with annual growth rates of −0.82 per cent and −0.02 per cent, lower than those in the early reform period. The decrease in grain productivity reflects the diminished contribution of de-collectivisation in certain degree. However, the decline in irrigated land areas and weakened capacity to adapt to natural disasters likely explains this decrease in grain production. Wen (1993) blamed low investment in agriculture for this decline. Moreover, based on the estimation of the effect of irrigation investment on total factor productivity, Huang *et al.* (2000) found that China's irrigation system was losing its ability to increase output and productivity.

Table 1 Effective irrigated land areas and respective growth rate in China

	Effective irrigated land areas (1,000 ha)	Annual growth rate of effective irrigated land areas (%)	Share of effective irrigated land areas over cultivated land areas (%)
Pre-reform			
1950–1978	36,640	4.01	28
Reform period			
1978–1990	48,298	0.06	42
1990–2000	50,882	1.07	47
2000–2010	56,026	1.15	45
2010–2017	64,183	3.36	48
Average	53,869	0.89	45

Data sources: Authors' estimation based on various years' Statistical Yearbooks published by National Statistical Bureau.

Eventually, waning irrigation investments and associated issues attracted the attention of policymakers; the decline was reversed, and the area of land irrigated has increased since the late 1980s. In 1988, China's first *Water Law* was issued, and the decline in irrigated area is considered to be a primary reason for its passage (Lohmar *et al*. 2003). After 1988, Government investments in water infrastructure gradually increased to 2.9 per cent of total investments. This investment boom was partially triggered by the need to restore and maintain water infrastructure, but also by a renewed national commitment to all infrastructure investment. In 1990, irrigated land area rose to 48,390,000 ha, marginally higher than the level in 1978. In spite of this positive development, the annual growth rate of irrigated land areas from 1978 to 1990 was only 0.06 per cent; lower than the pre-reform rate (Table 1). In the 1990s, irrigated land areas continued to expand, but the annual growth rate was still a low 1.07 per cent.

From the late 1980s to most of the 1990s, water scarcity increased because of continuous expansion of irrigated areas and increasing water demands for industrial and domestic use. It was not until the late 1990s that the Chinese Government recognised this trend. In 1997, the lower reaches of the Yellow River (the second largest river in China) dried up for 226 days, which affected socio-economic activities in downstream river areas (Wang *et al*. 2009). During this period, the Government noted the disappearing prospects for tapping additional water resource for irrigation supply. Instead of further large-scale expansion of irrigated land areas, it became necessary to upgrade existing irrigation facilities and increase efficiency. Officials began to shift their investment priorities from new projects to renovations and maintenance of existing systems (Nyberg and Rozelle 1999). In the late 1990s, the Government launched massive programs to improve irrigation conditions and increase water-use efficiency. Two such programs included upgrading, renovating and investing in water-saving facilities of large-scale and middle-scale irrigation districts (IDs) and Agricultural Comprehensive Development. Consequently, irrigated land saw steady growth in the first decade of the twenty-first century, and the annual increase rate was 1.15 per cent, higher than that before 2000.

As China entered the second decade of this century, evidence indicated severe water scarcity has been increasing. This threatened China's resource base, agricultural production, and sustainable development. Recognising such serious challenges, the Government committed itself to more irrigation investments and expansion of irrigated land areas. In 2011, Document No 1. of the Central Committee expressly dealt with accelerating reform and development of water infrastructure, with special attention given to improving irrigation conditions. Consequently, under the central government's aegis, irrigated land areas rose from 60,348,000 ha in 2010 to 67,816,000 ha in 2017 (50 per cent of cultivated land areas), with an annual increase rate of 3.36 per cent. This was the first post-reform period in which the annual increase rate came close to pre-reform levels (Figure 1).

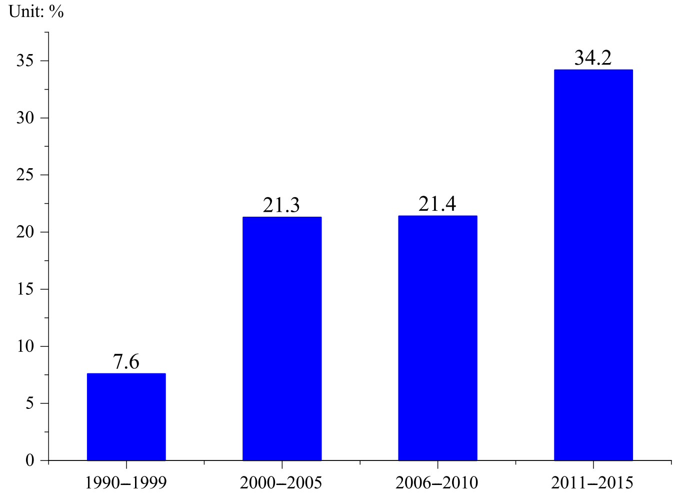

Figure 2 Annual growth rate of irrigation investment in rural villages in six provinces (Liaoning, Shaanxi, Shanxi, Inner Mongolia, Hebei, and Henan Provinces) in North China over various periods.
Data sources: North China Water Resources Survey (NCWRS), organised by China Center for Agricultural Policy, Peking University. [Colour figure can be viewed at wileyonlinelibrary.com]

Our field survey provides strong evidence to indicate the remarkable increase in irrigation investments in recent years, especially by the Government. Based on our NCWRS data,[2] in the 1990s, the annual growth rate of irrigation investment at the village level was 7.6 per cent; this number was 21.4 per cent in the first decade of the twenty-first century (Figure 2). However, from 2011 to 2016, the annual growth rate jumped to 34.2 per cent, higher than in other post-reform periods. We found that the percentage of government investments significantly increased after 2000. In the 1990s, 28 per cent percentage of irrigation in rural areas was under the central or local government. In the 2000s, this number increased to 49 per cent. After 2010, most rural irrigation investment was government-led; on average, it accounts for 74 per cent of total irrigation investment in Northern China.

3. Reform of institutional arrangement for managing irrigation

China has developed a vast and complex bureaucracy to manage its water resource. The primary state agency charged with managing the state's water is the MWR and its provincial counterparts. In areas that use surface water for irrigation, IDs, and local Water Resource Bureaus often manage the upper levels of irrigation systems (the main canals and branch canals) that transfer water out of major rivers (e.g. the Yellow River) or reservoirs and channel it

[2] The *North China Water Resource Survey* (NCWRS) Panel Survey was conducted in two rounds, 2004 and 2016. The survey tracked 400 randomly selected villages in six provinces (Inner Mongolia, Hebei, Henan, Liaoning, Shaanxi and Shanxi provinces) in Northern China.

to lower levels. Local irrigation systems (tertiary canals and below) are administered by county, township governments, and village committees (Xie *et al*. 2009). The canal network in the village is the responsibility of the village. In areas that use groundwater, both wells and groundwater irrigation are managed within the village. Both the groundwater sector and the surface water sector have experienced changes in institutional arrangements in the past several decades. This section describes these changes and discusses their impacts.

3.1. Reform of institutional arrangement for managing groundwater irrigation

Since the 1950s, China's irrigation investment was mainly targeted at exploiting surface water resource. The groundwater irrigation system only developed during the late sixties in Northern China. At this time, faced with increasing demand and limited surface water supply, farming communities in the region turned to groundwater; hence groundwater irrigated land areas rose to 30 per cent by 1970 (Figure 3; Wang *et al*. 2006). In addition, extensive surface irrigation has caused serious salinity issues in many IDs in Northern China. As a response, in the early 1970s, the Government began to financially support village collectives exploring groundwater. By 1980, groundwater irrigated areas had increased, with 55 per cent of irrigated land areas in Northern China extracting groundwater. Further, the number of agricultural wells increased from 0.2 million in 1965 to 2.3 million in 1980, while the amount of groundwater abstraction increased from almost zero to 75 bcum.

Unfortunately, the expansion of groundwater irrigation is not without cost. With increasingly intensive use of groundwater and insufficient recharge rate, the groundwater table began to decline in Northern China. The groundwater

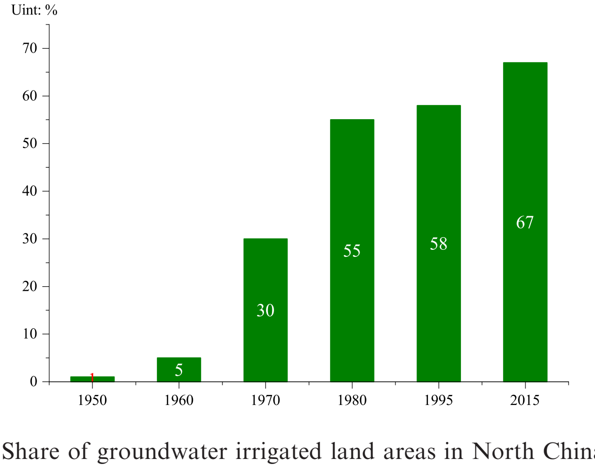

Figure 3 Share of groundwater irrigated land areas in North China.
Data sources: Wang *et al*. (2006), North China Water Resources Survey (NCWRS), organised by China Center for Agricultural Policy, Peking University. [Colour figure can be viewed at wileyonlinelibrary.com]

table first dropped in the 1970s, a problem that has become more serious since the 1980s (Wang *et al.* 2006). Excessive withdrawals and falling water tables have also caused land subsidence, cones of depression, and deterioration of water quality. Consequently, pumping costs have risen by 0.005 yuan per cubic metre. Because of poor pump and engine maintenance, agricultural tube wells in many regions have become unusable, requiring replacement with even deeper tube wells (Wang *et al.* 2007). The need for new investments to replace tube wells first arose in the early 1980s when de-collectivisation and the fiscal reforms left many villages without access to investment funds or command over labour to invest in tube wells (Lohmar *et al.* 2003).

Thus, rural farmers took over the responsibilities of investing and managing agricultural tube wells, leading to a profound transformation of the institutional arrangement of groundwater irrigation. With the implementation of the HRS through rural reforms, farmers were allowed to independently manage land allocated to them and retain profits from agricultural production (Lin 1992). To earn higher profits, farmers would need to enhance agricultural productivity through reliable irrigation supply. To ease such issues, the Government relaxed constraints on individual investments. Therefore, responding to the growing number of inoperable tube wells and lack of collective investment and management, individual farmers began to drill tube wells. As a consequence, the property rights of tube wells dramatically shifted from collective to private ownership.

Since the early 1980s, individual farmers have become major investors of agricultural tube wells. After the mid-1990s, private ownership dominated tube well property rights. Our CWIM data reveal that farmers already made two-thirds of new investments in 1983, contributing 67 per cent of new tube well investments.[3] Even so, in this period, collective tube wells still accounted for 93 per cent of total tube wells (Wang *et al.* 2007). Since the late 1980s, collective tube wells sharply declined owing to private tube well ownership. In 1995, the share of collective tube wells dropped to 47 per cent, while private tube wells rose to 63 per cent (Figure 4). In the mid-2000s, the share of collective tube wells diminished to 17 per cent, and private tube wells dominated, accounting for 83 per cent of total tube wells. Our survey of six provinces in Northern China also confirmed this trend; private tube wells rose from 42 per cent in 1995 to 67 per cent in 2016, of which 56 per cent fell under individual ownership (investment by individual household) and 11 per cent under shareholding ownership (joint investment by several households).

However, after the mid-2000s, tube well ownership trends reversed; the share of private tube wells declined, and collective ownership increased. Our CWIM data demonstrated that, in 2007, private tube wells dropped to 69 per

[3] The *China Water Institutions and Management* (CWIM) Panel Survey was conducted in five rounds, 2001, 2004, 2007, 2012 and 2016. The survey tracked 370 households, 180 water managers in 88 randomly selected villages in three provinces (Ningxia, Henan and Hebei Provinces) in Northern China.

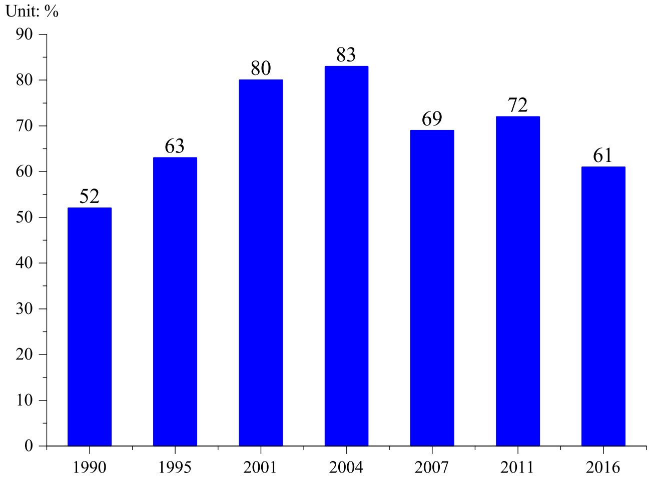

Figure 4 Share of private tube wells (per cent) in North China Plain.
Data sources: China Water Institutions and Management Survey (CWIM), North China Water Resources Survey (NCWRS), organised by China Center for Agricultural Policy, Peking University. [Colour figure can be viewed at wileyonlinelibrary.com]

cent (compared with 83 per cent in 2004) (Figure 4). Although this share increased by 2011 (72 per cent), in 2016, the percentage further declined to 61 per cent. There are three likely reasons for this. First, the government increased investments in irrigation development in the past decade. Second, farmers' investment incentives declined once farming income ceased to be a major source of income and farmers allocated more of their labour to non-agricultural activities. Third, pumping costs increased because of groundwater table lowering, thereby exceeding farmers' financial capability.

The privatisation of tube well ownership affected agricultural production and groundwater use. For instance, farmers expanded the sown area of less water-sensitive and high-value crops, such as maize, cotton, and non-cotton cash crops (mainly horticultural crops) (Wang *et al.* 2010). Their incomes increased from adjusting cropping patterns. Moreover, groundwater service markets have emerged transferring tube well services from tube well owners to non-owners (Zhang *et al.* 2008). Villages with active groundwater service markets increased from 5 per cent in 1990 to 80 per cent in NCP. Scholars found that farmers who buy water from local groundwater service markets use less water than farmers who have their own tube wells or use collective tube wells (Zhang *et al.* 2010).

Despite seemingly positive effects, there is a negative side to tube well privatisation. The empirical analysis showed that privatisation has accelerated groundwater table lowering (Wang *et al.* 2009). So, while a groundwater market improves water-use efficiency, it still cannot offset the negative effect of privatisation on the table. Therefore, farmers' initiatives that modify the institutional arrangement of groundwater management cannot resolve water scarcity. In fact, it has aggravated the scarcity. To promote sustainable utilisation of groundwater resource, it is necessary for policymakers to address the falling groundwater table.

The issues was neglected for a long time, however the Government began addressing groundwater management in the mid-2000s. Before the twenty-first century, management was firstly short-staffed, fragmented, and it was difficult to find specific government regulations by the centre on dealing with groundwater problems. Even when local regulations existed, implementation was ineffective (Wang *et al.* 2010; 2019). However, from 2004, the MWR began to publish a bulletin on groundwater resource and issue national policies for managing groundwater (such as, regulations on water quota management and water resource fee). In 2014, China launched a pilot project on comprehensive control of groundwater overdraft issues in Hebei Province. The main goal of the project is to control the total amount of groundwater withdrawal in the region. The project also promotes using measures such as irrigation technologies, crop mix adjustment, and land fallow programs to cut down groundwater use. In 2018, the pilot projects were extended to other provinces including Shanxi and Shandong Provinces. Although it is too early to have a conclusive assessment of the effects of these pilot projects, it is clear that groundwater management has become a priority for policymakers in China.

3.2. Institutional arrangement for managing surface irrigation

Compared with the institutional innovation in groundwater irrigation in the early 1980s, similar reforms for surface irrigation developed later. Particularly, they were not promoted until the mid-1990s. Since the start of rural reform in the late 1970s, transfer of irrigation investment funds from the national to local governments fell significantly. The reform also led to ambiguous property rights over many local water delivery systems built in the collective period (1959 - 1979). The fiscal constraints and ambiguity over property rights produced weak incentives for local governments to invest in and maintain irrigation systems that deliver surface water resource. Thus, the irrigated land areas declined, and the facilities deteriorated in many IDs. While the central Government encouraged IDs to commercialise activities they could maintain themselves, the performance of the reforms was not satisfactory (Lohmar *et al.* 2003). During this period, deterioration of irrigation systems and increasing water supply challenges became a common problem in many developing and developed countries. To resolve these problems, some countries, such as Philippines, Thailand and Malaysia, began to reform the institutional arrangement of irrigation by involving farmers into management, from the late 1980s onward.

In the mid-1990s, the World Bank began to promote irrigation management reform in its funded IDs of Hubei and Hunan Provinces. This initiated the reform of China's surface irrigation institution. In the reform, management responsibilities were transferred from village collectives to Water User

Associations (WUAs). In theory, a WUA is farmer-based, participatory organisation. Because of The World Bank project's success, the Government began to promote the reform in other IDs by issuing regulations. For example, the central Government issued suggestions on reforming the management system of water infrastructure in 2002. This regulation encouraged the establishment of WUAs. Then, it issued two specific regulations guiding the effective development of WUAs in 2005 and 2014. Many local Governments (Water Resource Bureaus) helped establish WUAs. Surface irrigation management reforms rapidly expanded to many IDs. From 2001 to 2016, the number of WUAs increased from 1,000 to more than 80,000. Currently, WUAs provide irrigation services for 30 per cent of irrigated land areas covering all provinces in China (Li 2002; MWR 2016).

Though WUAs dominate institutional reforms in irrigation, they are not the only option that has been adopted by local governments. In practice, some village committees also established contracts with individual farmers to manage water issues in villages. For example, according to our field survey in Ningxia and Henan Provinces in the Yellow River Basin, before 2004, the percentage of villages establishing contracting management (30 per cent) was higher than those with WUAs (22 per cent) (Table 2). However, after 2004, the percentage of contracting management rapidly declined; in 2008, WUAs already became more dominant, covering 71.5 per cent of the villages. In 2016, WUAs provided irrigation services for 81.3 per cent of the villages, while this number was only 15.6 per cent for contracting management and 3.1 per cent for collective management.

Despite the efforts of policymakers and rapid development, not all institutional reforms have been implemented successfully. Wang *et al.* (2010) found that The World Bank-funded WUAs were successful because of large investments in irrigation facilities, building human capacity and strict regulations to guide their operation. However, visits to the field in rural China revealed cases in which local irrigation management changes had failed. For example, Wang *et al.* (2014; 2005; 2006) found that only institutions that established water-saving incentives were successful in reducing irrigation. In addition, the reduction of irrigation owing to an incentive mechanism declined from 40 per cent in the early 2000s to 20 per

Table 2 Institutional reform of surface irrigation management in the Yellow River Basin (Ningxia and Henan Provinces)

	Share of villages (%)						
	1990	1995	2001	2004	2008	2012	2016
Collective	91	87	64	48	19	15	3.1
Water User Association	3	6	14	22	71.4	75	81.3
Contracting	6	7	22	30	9.5	10	15.6

Data sources: China Water Institutions and Management Survey (CWIM), organised by China Center for Agricultural Policy, Peking University.

cent in recent years (Wang *et al.* 2005; Wang *et al.* 2014). Importantly, the reduction of irrigation negatively affected wheat yield (Wang *et al.* 2014). Therefore, more WUA managers gave up the opportunity to establish incentive mechanisms. Though extensively covered in extant literature, Wang *et al.* (2006) found that the participation role of farmers in improving the performance of the irrigation institution was limited. Mixed performance of irrigation management reform also can be found in other countries in Asia (Mukherji *et al.* 2012).

Moreover, reform of the surface irrigation institution faces challenges of financial sustainability, besides other issues. As a farmers' organisation, most WUAs do not have fixed sources to support operations and maintenance. In some regions, WUAs add extra fees to irrigation charges. However, considering farmers' cooperation and participation, not all WUAs can opt for this method. Further, in some IDs, local Government provide financial subsidies for the operation of WUAs. Besides financial sustainability, effective operation of WUAs is also plagued by issues such as lack of capacity building for farmers, lack of appropriate legal backup, unreliable water supply, and nominally turning over responsibilities and power to irrigators. In spite of progress, the reform of surface irrigation institution is far from successful. It still requires formal and informal efforts towards improvements.

4. Movement towards marker-based mechanisms for water allocation

China's movement towards market-based mechanisms to allocate water partly came with the recognition that it is equally or more important to manage water from the demand side. It is also in line with the essence of China's economic reform: the use of economic incentives to boost performance in the industrial and agricultural sectors. China's Government has been focusing on two economic instruments: irrigation water price and tradable water rights. This section describes the progress of the government's efforts in promoting the use of both instruments to manage irrigation water over the past 40 years, as well as challenges encountered in these reforms.

4.1. Irrigation prices

Over the past 40 years, the reform of China's irrigation price policy has made some progress, though mainly in terms of cost recovery rather than demand management. After the first water-fee regulation in 1985, irrigation supply transformed from being fully subsidised to incurring a supply cost fee. In 1992, price bureaus took over the management responsibilities of irrigation fee from the Water Resource Bureaus, changing the nature of the fee from an administrative issue to a commodity. Then, the irrigation fee further changed from a single to a two-part structure in the last two decades. The two parts include a basic fee charged by area and a volumetric fee charged by the amount of irrigation. The scarcity value of water resource was added as a component of irrigation fee by collecting water resource fee in the past decade. In addition, from 2016, the central Government began selecting regions to set up pilot projects to shift from water resource fees to water resource taxes. Finally, irrigation price changed from a single component to a comprehensive package in the last decade. The Government consequently realised that irrigation price reform should be supported by improving the conditions of irrigation facilities and institutional innovation (such as establishing WUAs).

These reforms mainly relate to prices of surface water resource for irrigation, not for groundwater. For groundwater irrigation, farmers pay for electricity or diesel for pumping water but do not need to pay a resource fee. Collecting groundwater resource fees is Government's expectation. However, due to high implementation costs this has not happened. In addition to the electricity or diesel charges, farmers also bear some fixed costs associated with groundwater pumping, either through investing in tube wells or paying a management fee for those tube wells funded by village collectives. In addition, due to lack of government control, two-part structure of irrigation price also does not apply for groundwater. Therefore, groundwater irrigation costs are mainly influenced by energy prices and the cost of drilling tube wells.

Despite the Government's efforts to reform irrigation charges, the current charges are far from satisfactory and do not facilitate efficient water-use by farmers. Effective reforms must first address the challenges outlined below.

First, in spite of a modest increase, the current irrigation price is still low, which makes it difficult to cover the supply cost and reflect the scarcity value of water resource. As shown in Figure 5, the surface irrigation price in Zhangye Prefecture increased 35 times from 0.006 yuan/m^3 in 1981 to 0.216 yuan/m^3 in 2016. Even so, the current irrigation price only covers 70 per cent of the supply cost. Sun *et al.* (2018) found that the value of the marginal product of irrigation water in Zhangye is 0.48 yuan/m^3, higher than the irrigation price. That is, the current irrigation price doesnot reflect the scarcity value of water. Huang *et al.* (2010a) also revealed similar evidence for NCP.

Second, because of poor measurement facilities and high implementation cost, it is hard to implement volumetric irrigation fees in the field. Our CWIM data show that 83 per cent of the plots were charged a surface irrigation fee by area in 2001; this number declined to 65 per cent in 2015. In some regions, irrigation fee by area was replaced by time, and in 2015, 27 per cent of the plots charged fees using this approach. Charging an irrigation fee by time is closer to by volume, dramatically improves the collection of irrigation fees. Compared with surface irrigation, charging an irrigation fee by time for groundwater was higher; it reached 36 per cent in 2015. Since most tube wells include electricity measurement, it is common to collect groundwater irrigation fees based on electricity use (59 per cent in 2015). In the past two decades, some local Governments have set up pilot projects to install

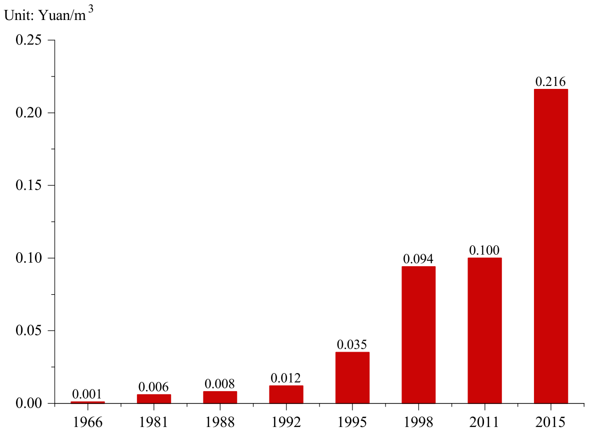

Figure 5 Surface irrigation price over time in Zhangye District, Gansu Province (1966 - 2015). [Colour figure can be viewed at wileyonlinelibrary.com]

integrated circuit cards (IC) to directly regulate the pump rates of individual farmers. However, because of high transaction costs (such as facility investment, maintenance, and monitoring cost), IC cards were not extended to non-pilot project sites (Wang *et al.* 2019).

Finally, increasing irrigation fee conflicts with the policy goal of raising farmer income. Based on empirical studies, we found that the irrigation demand price elasticity for wheat was −0.18 and −0.35 for maize, in the Northern China. The low demand elasticity for irrigation is also common in globally (Moore *et al.* 1994; Scheierling *et al.* 2006). Therefore, to encourage farmers to decrease irrigation by a percentage, policymakers must increase the irrigation price by a larger percentage. However, doing so would negatively affect farmers' income, leading to a policy conflict (Huang *et al.* 2010a; Wang *et al.* 2016). In fact, with the implementation of the agriculture tax exemption and the grain subsidy policy from 2004, some developed regions in China have even exempted farmers from irrigation fees to further reduce their financial burden (Wang 2012). Without a rational irrigation price, farmers have no incentives to make intensive and extensive adjustment to their production behaviour in order to increase irrigation efficiency (Dinar and Mody 2004; Huang *et al.* 2010a; Wang *et al.* 2016). Thus, Huang *et al.* (2010a) proposed developing a subsidy program that transfers income to households as compensation for farmers' lost income from irrigation price reform.

Consistent with prior scholarship, the Hebei pilot reform indicates that designing a suitable subsidy program could enable a win-win strategy of agricultural pricing reform (Wang *et al.* 2016). Since 2005, as the national pilot project site of 'Establishing Water Saving Society', Taocheng District in Hebei Province has been implementing the 'Increase Price and Provide Subsidy' reform for groundwater irrigation reform. Prices of groundwater for irrigation were raised in the villages that implemented the program. As a result, the villages generally would collect a higher amount of total irrigation fees. The additional irrigation fees collected (compared to the before-program period) were reallocated back to all farmers equally based on the size of their irrigated land and are not tied to the amount of groundwater used. Since groundwater is volumetrically priced, higher prices would incentivise farmers to reduce withdrawal of groundwater. The subsidies (reallocated irrigation fees) buffer against the negative impacts of higher irrigation costs. In those villages that implemented the program, irrigational application rates were reduced by 21 per cent for both wheat and cotton, partly because farmers were more likely to adopt water-saving technologies (Wang *et al.* 2016).

Despite the notable success of Hebei's irrigation price reform in the pilot site, it has not been extended to other regions since its initiation in 2005. Wang *et al.* (2016) found that, in Taocheng District, considering the time-consuming management and low financial subsidy, a few villages ceased their participation in the reform. In the pilot reform, wheat farmers received, on average, a subsidy of 181 yuan per ha, that is only 11 per cent of the agricultural subsidy in China. There is also no specific financial source to provide subsidy for farmers in the long-term. Therefore, if the Government would like to extend this price mechanism to other regions, a financial support system should be designed and established. In addition, such pilot project has not been set up for reforming surface irrigation price. Compared with groundwater that can link its irrigation fee with electricity use due to availability of electricity measurements, it is even harder to reform surface irrigation price.

4.2. Water rights system and water markets

China's Government has been trying to set up a water rights system and allocate water through market mechanisms since the early 2000s (Calow *et al.* 2009). In theory, regulatory caps on total water use within a given region in a rational water rights system can lead to socially optimal allocation of water resource; thus, water can be used by those who value it most (Howe *et al.* 1986; Debaere *et al.* 2014). Considering the potential benefit, the central Government has been issuing regulations to promote the development of a water rights system over the last two decades. The first two important regulations were issued in 2005: *Some Opinions on Water Rights Transfer* and *Establishing Framework of Water Rights System*. In 2014, the Government launched formal pilot projects in seven provinces to further accelerate development. These provinces included Ninxia, Jiangxi, Hubei, Inner Mongolia, Henan, Gansu and Guangdong. To support the implementation of pilot projects and encourage water rights transaction among regions, sectors and individual water users, the MWR issued the *Temporary Management Regulation on Water Rights' Transfer* in 2016. In the same year, the first national *Transaction Institute of Water Rights* was established in Beijing.

So far, only a few pilot projects of water rights transfer have been considered successful, especially for trade among regions and industries. For example, there are two prominent water rights transfer projects (Speed 2009; Moore 2015); between Dongyang and Yiwu in Zhejiang Province, and between agricultural and industrial sectors in Inner Mongolia and Ningxia Provinces. Though successful, they are mainly coordinated by local governments; water users in these regions have not been directly involved in the transaction.

It is more difficult to establish a water rights system to promote rights transfer among irrigation water users in rural areas. At the ID level, water rights have only been granted to farmers at a few select pilot sites, where water rights transactions among individual farmers are not always effective (Sun *et al.* 2016). Our field surveys in China seldom found evidence of water rights' transfer among farmers. In fact, many farmers are unaware of their water-use rights or that they can be traded. A typical example for establishing a water rights system in rural areas is the institutional reform in Zhangye Prefecture in Gansu Province. Here, water rights have been granted to individual farmers in the form of water rights certificates. These certificates state the upper limit of the amount of water a household can buy, which is computed by the water rights area and crop irrigation quota. Even so, transactions involving water rights are rare in Zhangye. Importantly, because of poor implementation and high monitoring cost, water rights certificates do not have a sustainable function in reducing irrigation. They only played a significant role in the early stages of reform, where irrigation of wheat reduced by 23 per cent (before 2010). Our survey also found that farmers paid almost no penalty for exceeding their water rights, which encouraged them to use yet more water.

Despite progress made in establishing a water rights system and developing water markets, China still faces challenges in expanding reforms. There has been heated debate on the suitability of water markets in rural areas. The major issue is that initial water rights have not yet been allocated to various water users in most regions (Wang *et al.* 2017). It is thus impossible to develop water markets without a fully established water rights system. Recently, a water quota system has been suggested for allocating initial water rights to users. However, there is no clear agreement on the relationship between the water rights system and the water quota policy. In addition, the implementation of a water quota policy in rural areas has been slow because of lack of measurement facilities and the high cost of monitoring the large number of small-scale farmers. Therefore, some officials and scholars question the suitability of water markets in rural China, at least at the individual farmer level. If possible, it is better to encourage trade at the level of WUAs or IDs. Lewis and Zheng (2018) noted that promoting water trade at the WUA level requires strong efforts to encourage farmers to participate in the activities of WUAs. Finally, the potential effects of water rights transfer on disadvantaged water users and on the environment also need to be seriously considered (Johansson *et al*. 2002; Heaney *et al*. 2005; Etchells *et al*. 2006). For example, if rights are based on diversions rather than consumptive use, there is a risk that other users and uses of water depending on return flows will be impacted (Table 3).

5. Adopting irrigation technologies to save water

One of the potential solutions China's Government can consider to address water shortage problems is higher on-farm irrigation efficiency. The use of irrigation technologies is considered as the main tool to boost irrigation efficiency. Traditional irrigation technologies that are used for saving water, such as field levelling and border and furrow irrigation (Blanke *et al*. 2007), were already in use by farmer before reforms. Paradoxically, their adoption slowed after reforms. These technologies are divisible; that is, one farm household can adopt the practice independent of the action of its neighbours. They have relatively low fixed costs and their major investment is the labour input. The ease and low cost of organising rural labour by a village collective, it is not surprising to find wide adoption of technologies even before the 1980s. Our NCWRS data found that, by 1978, 59 per cent of villages had adopted traditional technologies, and 75 per cent by 2016. Regarding adoption intensity, less than half the crop sown areas used traditional technologies in 2016.

Conversely, household-based technologies came into use only after the 1980s, with higher adoption rates in the last two decades. Such technologies include surface pipes, drought-resistant crop, plastic sheeting, and retaining stub/low till (Blanke *et al*. 2007). Like traditional technologies, these technologies do not require large capital investment upfront and they can be easily used by individual households. Before rural reforms, household-based technology adoption was non-existent. Then, in the early 1990s, it accelerated. By the 1980s, only 5 per cent of villages in Northern China had adopted these technologies, which increased to 19 per cent by 1990 and 74 per cent by 2016. Regarding adoption intensity, half the crop sown areas used

Table 3 Collecting approaches of irrigation price in North China, share of wheat plots (%)

Year	Surface water			Groundwater			
	Area	Time	Electricity or Diesel	Area	Time	Electricity	Diesel
2001	82.9	6.1	11.0	8.9	27.2	33.0	30. 9
2004	80.4	11. 6	8.0	9.0	33.7	32.0	25.3
2007	74.6	21.7	3.7	2.5	28.4	36.8	32.3
2011	76.6	15.6	7.8	3.9	29.5	51.7	15.0
2015	64.8	27.2	8.1	1.4	36.4	58.9	3.3

Note: *Area*, *Time*, *Electricity* and *Diesel* refer to water price charged by plot area, irrigation time, electricity consumption, and diesel consumption, respectively.Data sources: China Water Institutions and Management Survey (CWIM), organised by China Center for Agricultural Policy, Peking University.

household-based technologies. These adoption trends reflect farmers' response to increasing pressures of irrigation supply.

In the last two decades, the Government has seriously emphasised adoption of irrigation technologies in rural China. To improve irrigation efficiency and help release saved water for other uses and users, beginning with the late 1990s, the government launched a large program for upgrading, renovating and investing in water-saving facilities of large-scale and middle-scale IDs. The most important investment of this program is to line the main and branch canals with concrete and install underground pipes to improve delivery efficiency of irrigation supply. In 2009, the General Office of the State Council of China issued a document on 'National Water-saving Irrigation Planning'. It specified that, by 2020, the area irrigated under water-saving irrigation projects should reach 80 per cent of the nation's effective irrigated land area. This plan will encourage and subsidise the adoption of modern irrigation technologies (such as sprinklers, drip irrigation, and micro-irrigation). China's central and local governments have also set up pilot projects to demonstrate and expand irrigation technologies to new areas. From 2000 to 2017, irrigated land areas adopting irrigation technologies doubled, and the share of overall irrigated land increased from 31 per cent to 50 per cent (Table 4). The significance of financial subsidies, pilot projects and extension services provided by the Government to encourage farmers to adopt irrigation technologies is confirmed by our empirical analysis (Cremades *et al*. 2015). The analysis also reveals the importance of increasing irrigation fees so farmers adopt irrigation technologies (Cremades *et al*. 2015; Wang *et al*. 2016).

With more government investments, adoption of community-based irrigation technologies has increased since 2000. As Blanke *et al*. (2007) noted, because of high investment cost and indivisible characteristics, canal lining, underground pipe, sprinklers, drip irrigation, and micro-irrigation belong to community-based irrigation technologies. Constrained by their

Table 4 Irrigated land areas with water-saving technologies in China

Year	Irrigated land areas with water-saving technologies (1,000 ha)	Share of irrigated land areas with water-saving technologies (%)	Share of irrigated land areas adopting (%)			
			Sprinkler irrigation	Drip irrigation (%)	Underground pipe (%)	Canal lining (%)
2000	16,389	30.5	4.0	0.3	6.6	11.8
2010	27,314	45.3	5.0	3.5	11.1	19.2
2015	31,060	47.1	5.7	8.0	13.5	n.a.
2017	34,319	50.6	6.3	9.3	14.7	n.a.

Note: n.a. refers to no data availability.Data sources: Authors' estimation based on data in Water Resource Bulletin (various year in 1999 - 2018), MWR.

characteristics, such technologies are always adopted at the village level or at least group level, but not by individual households. Like household-based technologies, in the early reform period, adoption of community-based technologies was non-existent, an increasing trend seen after 2000. From 2000 to 2016, the share of villages adopting community-based technologies increased from 13 per cent to 53 per cent in Northern China. According to statistical data of the MWR, canal lining and underground pipes are two major community-based technologies adopted in China. However, the adoption of sprinkler and drip irrigation was low, <10 per cent of irrigated land (Table 4).

Despite policymakers stressing on the importance of water conservation, the effects of adopting irrigation technologies have been debatable. In theory, such technologies should reduce water use and improve irrigation efficiency by reducing water loss during delivery processes in the canal and field. However, as Peterson and Ding (2005) and Ward and Pulido-Velazquez (2008), among others, have noted, adopting these technologies may or may not reduce water use, depending on a variety of economic and hydrologic factors. In addition, after adopting irrigation technologies with better efficiency, profit-maximising producers may respond by expanding irrigated acreage or move to more water-intensive crops (Huffaker and Whittlesey 1995; Ward and Pulido-Velazquez 2008). The econometric analysis in Northern China by Huang *et al.* (2017) found that adopting household and community-based technologies can reduce crop water use and improve the productivity of water. However, there were no significant effects on crop mix, irrigated area sown, or the share of a crop area that is irrigated.

6. Looking forward in the future: challenges and opportunities

China has made remarkable progress in the irrigation sector in the past 40 years. In spite of stagnation in the 1980s, irrigated land areas have expanded, with half the cultivated land being equipped with irrigation facilities. Nevertheless, the increase of total withdrawal for agricultural water resource is not substantial. One reason for this is the improvement of irrigation efficiency. Further, investments in water infrastructure are now a policy priority. Both surface and groundwater irrigation systems have also experienced a profound transformation from collective ownership to ownership by individuals or farmers' organisation. Farmers have not only become major investors in some rural irrigation facilities (such as tube wells), but they have also taken over full or partial responsibility for irrigation management. Moreover, reforms in irrigation price have been gradually promoted and improved as an incentive mechanism. Finally, the general legal framework of and regulations on the establishment of a water rights system has been designed, and pilot projects on water trade have been implemented.

Despite numerous achievements, policymakers still face many challenges. First, reforms during the last 40 years have not led to significant mitigation of water scarcity. Second, sustainable irrigation in agriculture continues to be a major challenge. Therefore, the Government should continue to tackle impending resource scarcity. Third, innovations in the groundwater irrigation system by farmers have increased groundwater depletion. Declining groundwater levels suggest the Government act with urgency to sustain groundwater stocks. Fourth, the resulting performance of surface irrigation institutions is inconclusive and requires greater public scrutiny. Moreover, irrigation price reforms have been far from satisfactory given their expected outcomes. In the context of inelastic irrigation demand and low farmer income, policymakers can be improved with win–win irrigation price policies and regulatory reforms that effectively 'cap' withdrawals within sustainable limits. Another issue fraught with uncertainty is whether it is possible to establish a rational water rights system that encourages farmers to participate in water markets. Finally, despite progress, the adoption of irrigation technologies and methods that generate real water savings is not sufficient. Given the slow progress of improved irrigation price policies, farmers' have faced few incentives to adopt improved irrigation technologies. Nevertheless, there are some opportunities that would allow the Chinese Government to cope with the challenges outlined herein.

First, policymakers are already keen on sustainability of water use. The Rural Revitalization Strategy issued by the central government in 2018 particularly focuses on implementation of rural water-saving actions and establishing water-saving societies in rural areas. It clearly directs reform towards an effective water-saving mechanism and corresponding subsidy policies.

Second, China's Government has relaxed its food security goal; conflicts between food security and sustainable development of irrigation water could be mitigated to an extent. Recently, the Government has also begun to implement land fallow subsidy policies to resolve groundwater overdraft issues in Northern China. This is a highly important policy change with the potential to significantly reduce the consumption of water resource and realise water saving.

Finally, the Government is encouraging farmers to rent their lands to farmers with better capacity to manage large areas. That is, in the future, farming management will have transferred from small to larger farm sizes. This transition will have a significant effect on adoption of irrigation technologies, reforms in the irrigation institution and incentive mechanisms. According to extant studies, larger farms are more likely to adopt modern irrigation technologies than are small farms. Possibly it also benefits for organising effective WUAs, implementing irrigation price reforms and establishing a water rights system also possibly benefits the effective organising of WUAs. These areas require scholars to conduct further theoretical and empirical studies.

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