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Water saving technology and saving water in China

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ABSTRACT

Rapid expansion of irrigated agricultural and increasing urban demands for water have important implications for the economy of China, especially for the agricultural sector in the northern part of the nation. In response to the water crisis, China's government has begun in recent years to invest in research on techniques to save water in the agricultural sector, although there is a debate about the extent of success in adoption by farmers. Top policy makers have publicly stated they would allocate billions of dollars in funding if they knew it would succeed in saving water. Unfortunately, there has been relatively little research in China on the economics of water saving technology and there is almost no systematic information on the extent to which the technologies have been adopted, if they are appearing to save water, and the characteristics of the communities that have been adopting them. Our goal is to sketch a picture of the state of water saving technology in northern China to increase awareness of past trends and current status. In simplest terms, we seek to establish a set of first order facts about the role that water saving technology has been playing in China's agricultural sector. We pursue three specific objectives: (1) to illustrate progress in adoption over the past two decades, (2) to identify the characteristics of technologies that have been most successful and those that have not, and (3) to explain factors that might be promoting water saving technology and factors that might be holding back adoption. We find that, although water saving technologies have expanded rapidly in recent years—especially those that can be adopted by individual households (as opposed to those that require the collective action of an entire community), there is still considerable room for water saving technology to be expanded.

Although China's water resources rank sixth in the world by total volume, per capita water availability is roughly one quarter of the world average (Jin and Young, 2001). Moreover, water resources are not distributed evenly across regions or time. Northern China possesses roughly 20% of the nation's water resources and 64% of land area (Zhen and Routray, 2002). The nation also receives most of its precipitation in only one season—late summer. Parts of Northeast China and almost all of Northwest China have suffered from chronic severe water shortages in the face of rapidly rising demand. The water table has fallen rapidly over the last decades, in some cases over 2 m per year, raising pumping costs, resulting in land subsidence, saltwater intrusion, and causing farmers to abandon thousands of wells (Kendy et al., 2003). Overexploitation in the upstream regions of the Hai River Basin completely eliminates river flow in

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the basin's lower reaches during most years (Wang et al., 2005).

Dwindling water supplies have important implications for northern China's agricultural sector. Northern China (which in our study includes North China, most of Northwest China and Northeast China) is an important agricultural region. The North China Plain alone produces roughly one quarter of China's grain (Zhen and Routray, 2002) and more than half of its vegetables and fruits (China National Statistical Bureau, 2004). Irrigation status has a positive impact on both yields and cropping revenue (Huang et al., 2002). Hence, the future of water resources will impact both food security and rural income.

The response of China's government to the impending crisis must be considered within the context of the history of the nation's water policy. Over the past 50 years (indeed for the past centuries), China has constructed a vast and complex bureaucracy to manage its water resources. Until recently, however, water conservation was not a major concern of policymakers. Instead, the system was designed to construct and manage water resources to prevent floods that have historically devastated the areas surrounding major rivers and to effectively divert and exploit surface water resources for agricultural and industrial development.

Over the last decade or more, concern over impending water scarcity has increased as it has become apparent that China's water resources are becoming alarmingly scarce in some areas. Zuo (1997, p. 121) notes that as of 1995, ''The Party Central Committee and the State Council are much concerned with the problems arising from serious water shortage[s]''. Policy makers have begun to develop strategies. Some policies (e.g., the requirement for receiving a permit before sinking a new well) have not been effective due to the vast number of villages in northern China and the problems involved with monitoring such a spatially dispersed economic activity. Others have not been implemented for political reasons. For example, water pricing policies have not been implemented as China's government has spent considerable policy effort in recent years to reduce taxes and fees.

China's government has begun in recent years to invest in research on water saving agricultural techniques. Zuo (1997) reports that since ''the beginning of the Seventh Five-Year Plan (1986–1990), water-saving and dry-land farming have been designated [as a] major scientific research [program] by the government, involving many specialists from different institutions, and more than 3000 practical achievements have been obtained in dry-land farming.'' International organizations and foreign governments have collaborated with China's government and research institutions on these projects. In addition to sponsoring research, government and non-governmental organization-sponsored programs have promoted the adoption of specific water saving technologies, sometimes providing financial support for infrastructure.

Despite substantial investment in the development of water saving technology and the potential impact of widespread adoption, there is little evidence that farmers have adopted the new techniques (Lohmar et al., 2003). The efficacy of current water saving technology extension programs is a matter of debate (Deng et al., 2004). There has been little research on the extent of adoption in northern China, the conditions under which water saving technology is adopted, or the impact of adoption on water use and rural welfare.

Our goal is to sketch a picture of the state of water saving technology in northern China to increase awareness of past trends and current status. We wish to establish a set of first order facts about the role water saving technology has been playing in China's agricultural sector. We pursue three specific objectives: (1) to illustrate the progress in adoption over the past two decades, (2) to identify the characteristics of the most successful and unsuccessful technologies, and (3) to explain factors that might be promoting water saving technology and factors that might be holding back its adoption.

Our analysis is limited in several ways. We limit our geographic scope to northern China, where water shortages are most severe, and we examine data from a survey of village leaders. Although typically knowledgeable about agricultural production and water management issues (and, thus, able to provide high quality information on many topics), we believe the quality of some variables is influenced by each village leader's knowledge of hydrology and water engineering. By turning to key informants in rural communities throughout northern China, however, we are able to amass a large volume of information as seen from the farm and village points of view and can ask questions that are both quantitative and qualitative.

1. Data

Our analysis is based on data collected as part of two recent surveys designed to address irrigation practices and agricultural water management. The first survey, the China Water Institutions and Management survey (CWIM), was conducted in September 2004. Enumerators interviewed village leaders, groundwater managers, surface water irrigation managers and households in 48 villages in Hebei and Henan provinces. The villages were chosen according to location (which in the Hai River Basin often is correlated with water scarcity levels) in order to guarantee an adequate sample of villages in each of several water usage situations. In Hebei, villages were chosen near the coast, near the mountains and in the central region. In Henan, villages were chosen near the Yellow River and then increasingly further away. The CWIM survey is the second round of a panel survey, the first phase of which was conducted in 2001.

We conducted a second survey, the North China Water Resource Survey (NCWRS), in December 2004 and January 2005. This survey of village leaders from 400 villages in Inner Mongolia, Hebei, Henan, Liaoning, Shaanxi and Shanxi provinces used an extended version of the village portion of the September (CWIM) survey. We use information from these provinces to estimate water saving technology adoption and other water-related issues in all provinces north of the Huai River. Throughout the paper we use the term *northern China* to refer to the following provinces: Gansu, Hebei, Henan, Heilongjiang, Inner Mongolia, Jilin,

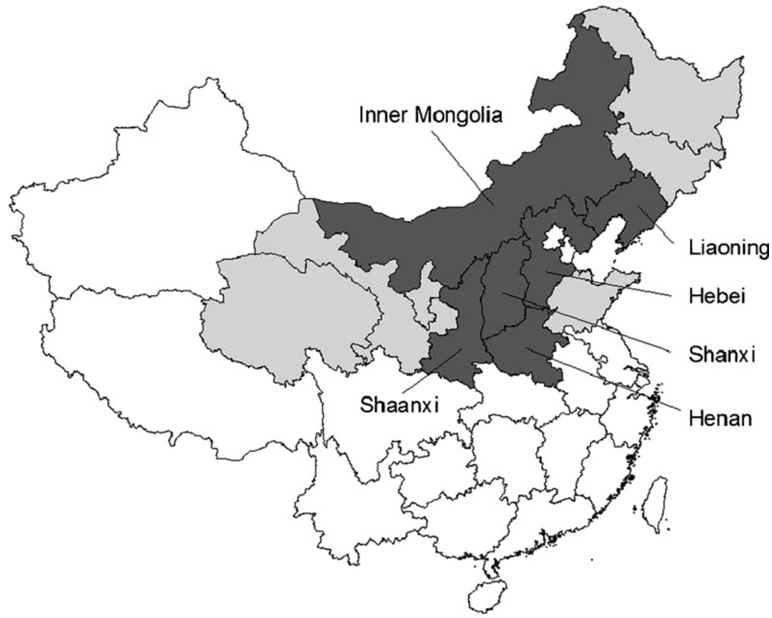

Fig. 1 – Map of CWIM and NCWRS Survey Sites. *Note*: The China Water Institutions and Management (CWIM) covers two provinces: Hebei and Henan Provinces; the North China Water Resource Survey (NCWRS) covers six provinces: Inner Mongolia, Hebei, Henan, Liaoning, Shaanxi and Shanxi provinces. Survey provinces are shaded in dark grey. The remaining provinces in northern China are shaded in light grey.

Liaoning, Ningxia, Qinghai, Shaanxi, Shandong, and Shanxi (Fig. 1).

Because of the way we chose our sample and collected the data, we can make statements that are reasonably representative for northern China. We used a stratified random sampling strategy to generate a sample for this purpose. We first sorted counties in each of our regionally representative sample provinces into one of four irrigation or water scarcity categories: very scarce, somewhat scarce, normal, and mountain/desert.[1] We randomly selected two townships within each county (one with income above the median, and one below) and four villages within each township (two with income above the median, and two below) for a total of 50 counties, 100 townships and 401 villages. To generate regionally representative statistics, we have calculated a set of population weights that apply to both surveys.

The survey instrument was composed of more than 40 blocks and sections, including blocks focused on socio-economic characteristics of the village, agricultural production, the water resources of the village, water infrastructure investments and government regulation. Three of the survey's 41 pages were devoted exclusively to water saving technology. Using information from this part of the survey, our dataset includes variables describing the extent of adoption of each technology; stated reasons for adoption, non-adoption, or technology retirement; crops with which the technology is used; technology funding sources; estimated impacts on water use; and the source of technology extension. Information on almost all variables was obtained for 2 years, 2004 and 1995.

2. Water saving technology

During our survey of leaders and water managers in more than 400 villages, we discovered that there are many types of water savings technologies being used in northern China. For analytical convenience, we have divided water saving technologies into three groups: traditional, household-based, and community-based. We exclude discussion of a series of novel water saving technologies (such as drip, intermittent irrigation, and chemical-based sprays) because across our sample, they had very low levels of adoption (that is, nearly zero).

Our use of the term water saving is limited to perceived, field level applied irrigation savings. Our definition of water

[1] In Hebei province, where county level groundwater overdraft statistics are available, the scarcity categories were defined according to a Ministry of Water Resource publication that categorized counties by scarcity (which almost certainly is related to the degree of annual overdraft). In the remaining provinces, all four scarcity indices were defined according to the percentage of irrigated area as follows: very scarce (between 21 and 40%), somewhat scarce (between 41 and 60%), normal (more than 61%), and mountain and desert (less than 20%). Within each of the scarcity strata, we sampled two or three counties; of all of the counties in the mountainous and desert counties, we chose one county. Although these categories are not necessarily completely synonymous with scarcity, they help stratify the observations to produce a final sample that gives us sets of villages and households that have access to a range of different water management institutions and different levels of ease of access to water.

use efficiency is likewise limited to field level measures of crop production per unit of water input. We understand that in some cases technology adoption may not save water when net water use is measured on an irrigation system- or basin-scale. The real water saving properties of each technology depend not only on the technical features of the technology, but also on the hydrology of the system and the economic adjustments to production that are associated with adoption of the technology.[2]

2.1. Traditional technologies

Traditional technologies include border and furrow irrigation and field leveling. We have grouped these technologies because they are widely adopted and village leaders in a majority of villages report adopting these techniques well before the beginning of agricultural reform in the early 1980s. These irrigation methods have relatively low fixed costs and are divisible in the sense that one farm household can adopt the practice independent of the action of its neighbors. We assume that readers are familiar with border/furrow irrigation and the water saving properties of these technologies, relative to flood irrigation.[3]

A third traditional technology is targeted at the entire field plot. Field leveling includes any artificially flattening of the plot. Leveling a plot allows water to spread across the plot more evenly without designing bunds or channels to direct the water flow. It is reported to enhance water infiltration and reduce soil erosion, in addition to raising yields (Deng et al., 2004).

2.2. Household-based technologies

Household-based technologies include plastic sheeting, drought resistant varieties, retaining stubble/low till and surface level plastic irrigation pipe. We have grouped these technologies because they are adopted by households (rather than villages or groups of households), have relatively low fixed costs and are highly divisible. Typically, adoption of these technologies is more recent than the adoption of the traditional technologies.

Plastic sheeting is a production technology rather than an irrigation technique. This term describes several more specific techniques that involve the use of plastic film to trap moisture between the ground and the sheeting. Plastic film is used to cover soil during or before the crop growing season. For example, one use of plastic sheeting is as a component of an agronomic system called Ground Cover Rice Production System (GCRPS—Abdulai et al., 2005). In experiments, GCRPS is reported to save 50–90% of applied irrigation water under experimental field conditions while requiring little training (Abdulai et al., 2005). In addition, farmers using GCRPS say that it increases soil temperature allowing earlier planting and harvesting. Plastic sheeting also increases soil temperatures under experimental field conditions (Li et al., 2003). A field experiment for wheat grown in Dingxi county in Gansu province found that using plastic sheeting in combination with pre-sowing irrigation increased both yields and water use efficiency in addition to increasing soil temperature, but that plastic sheeting by itself did not increase yields (Li et al., 2004).

Drought resistant varieties include any seed variety that is able to withstand relatively low water moisture conditions. China's wheat and maize breeding system has always prided itself on incorporating drought resistance into some of the highest yielding germplasm (Hu, 2000). Zuo (1997) also reports that drought resistant varieties of crops – including millet, sorghum, beans, tubers, buckwheat and flax – have been developed and extended in China. In some cases, these varieties show yield increases of more than 10% over those varieties that are not drought resistant in years of below average rainfall.

Retaining stubble/low till is a technique in which the stubble from one crop is left on the field after this crop is harvested. Field studies in northern China show that low till methods can improve water use efficiency by reducing soil evaporation and increasing yields in comparison to traditional agronomic techniques including furrows (Deng et al., 2004; Pereira et al., 2003; Zuo, 1997). While in some sense this technology resembles no till practices that are used in many developed and developing countries, in most cases, the stubble is retained only after the wheat crop is harvested in the spring and before the maize crop is planted. Most farmers in northern China plow their fields after the maize crop is harvested during the fall (hence the name *low* till instead of *no* till).

Surface level plastic irrigation pipe refers to a coil of hose used to transport irrigation water to a farmer's field. Often white, surface level hose technology is made of soft, flexible plastic pipe. In China, due to its color and shape, farmers often call this technology a ''white dragon''. Field experiments have shown that surface water piping techniques, including low pressure pipes, can save up to 30% of water and small amounts of land (Zuo, 1997).

2.3. Community-based technologies

Community-based technologies include underground pipe systems, lined canals and sprinkler systems. We have grouped

[2] Does water saving technology, save water? The answer to this question depends not only on the technical properties of each technology, but also on the hydrology of the system in which water saving technology is used. In systems where irrigation water is being pumped from a shallow aquifer, water that is applied to a field but not evaporated from the soil surface or transpired by the growing crop recharges the aquifer and is not lost to the system. In cases like this (e.g. the Luancheng county, Hebei study reported in Kendy et al., 2004), real water savings come only from reduced evapotranspiration (ET) and adopting water saving technology that reduces seepage (e.g. underground pipe systems or lined canals) or applied water applications (furrow irrigation, level fields, or sprinklers for example) will not result in significant real water savings. Also, recharge in one area may impact the groundwater available for irrigation in another. In this case, reducing recharge by using water saving technology could have a negative impact on groundwater availability elsewhere.

[3] Both border and furrow irrigation have been practiced in China for many years. The definitions of these irrigation methods used during the survey were general and so we are not able to distinguish between traditional border/furrow irrigation practices and relatively new techniques that may even further increase field level water savings.

these technologies because they tend to be adopted by communities or groups of households rather than by individual households. In most applications, they have large fixed costs and require collective action or ongoing coordination of many households. Sprinkler systems, for example, require substantial water pressure to operate. To attain sufficient pressure, some villages need to construct water towers and elaborate piping networks. In addition, the small size of plots and fragmented nature of most farm holdings in northern China mean that operating a sprinkler system requires coordination for use. It is difficult to use a sprinkler that irrigates in a large circular pattern on one plot without irrigating the plots of other households around it.

Despite the coordination problems, sprinkler systems can increase water use efficiency, given fixed plot areas and crop choice (e.g., Peterson and Ding, 2005). Zuo (1997) also notes that sprinkler and drip systems save labor in addition to water, but have relatively high costs, which might limit the use of sprinkler technology to vegetable and fruit production.

Underground pipe systems include cement, metal, or plastic pipes used to transport water for irrigation. In China, almost all underground piping systems utilize PVC material. In many parts of northern China, installation requires digging trenches during the short period of time that elapses between the harvest of maize (or another summer crop) and the planting of winter wheat. Typically, underground piping systems have above-ground access fittings every 50–100 m. These techniques can save water (up to 30%) in addition to a small amount of land area, compared to unlined canal systems (Zuo, 1997).

Lining an irrigation canal with cement or other materials reduces seepage during conveyance. However reducing seepage might not lead to water savings, particularly in situations where groundwater pumping relies on an aquifer recharged by canal seepage. In many villages lined canals have been installed or subsidized by a surface water irrigation district in conjunction with a local water resource bureau. Lined canals, like underground pipe systems, might increase water use efficiency in some circumstances (Zuo, 1997).

2.4. *Farmer perceptions of technology traits*

Ultimately, the most important proximate determinant of technology adoption is the farmer's perception of the incremental benefits and costs to his own farm budget. Hence we examine farm-level perceptions of the water saving properties and other characteristics of each technology.

2.4.1. *Perceived water savings*

Field level water savings and real, basin-wide water savings may differ due to several agronomic and hydrologic factors. Water saving technology adoption will increase in response to water shortage only if users (farmers and village leaders) perceive that adoption will lead to water savings or generate other benefits. Our survey captures these perceived water savings by asking respondents in villages where a particular technology was in use to estimate the water savings of that technology, relative to the status quo without use of the technology. Our data show that while the most commonly observed water saving technologies are perceived to save water, there are differences among the technologies (Table 1). For example, the highest perceived savings rate is for underground pipes (42%). The lowest perceived savings rates are for drought resistant varieties (20%), plastic sheeting (28%) and retaining stubble/low till (8%). The estimated savings we report are higher than those of Yang et al. (2003) who report that "officials and technicians interviewed in Henan, Ningxia and Hebei estimated that around 10–20% saving in water is attainable in their irrigation districts through application of conventional water-saving methods and better management" (p. 147). Our estimated savings rates may be a bit higher due to the way we asked the question, the status of our informant, and/or the nature of the sample.

Table 1 – Village leader estimates of water savings, by technology

Technology	Estimated water savings (%)
Traditional technologies	
Border irrigation	38
Furrow irrigation	39
Level fields	33
Household-based technologies	
Plastic sheeting	23
Drought resistant varieties	20
Retaining stubble/low till	8
Surface pipe	35
Community-based technologies	
Underground pipe	42
Lined canal	30
Sprinkler	39

Note: These data from the authors' survey of village leaders and they include only observations from villages where the technology was adopted. Respondents were asked to estimate the average percent of water saved by the technology. *Data Source*: Authors' survey.

2.4.2. *Other beneficial traits*

One of the most striking findings of our research is the number of respondents who told us that, although farmers in their villages were adopting water saving technologies, they often were doing so for reasons other than water saving. In other words, technologies associated with water savings have other traits demanded by farmers. For example, in the case of plastic sheeting and retaining stubble/low till, water saving was not the primary motivation for adoption in more than half of the adopting villages (Table 2). In the case of plastic sheeting, although 46% of respondents report that water saving was the primary objective, in 84% of the remaining cases (that is, of the remaining 54%), the technology's main purpose was thought to be increasing the soil temperature around the crop in the early part of the growing season. In the case of retaining stubble/low till, saving water was cited as the primary motivation for adoption by only 19% of respondents. In 76% of the remaining adopting villages, saving fertilizer was the most frequently cited reason. These results are consistent with experimental findings about the effects of both plastic sheeting and retaining stubble/low till (Deng et al., 2004; Pereira et al., 2003; Li et al., 2004; Zuo, 1997; Abdulai et al., 2005). There were often secondary reasons for adoption, beyond

Table 2 – Was this technology adopted to save water? If not, why was it adopted?

Technology	Was this technology primarily adopted to save water? (percent of villages responding ''Yes'')	Other reasons for adoption[a]
Traditional technologies		
Border irrigation	93	
Furrow irrigation	90	
Level fields	94	
Household technologies		
Plastic sheeting	46	Moderate temperature (84%), increase yield (35%)
Drought resistant varieties	74	
Retaining stubble/low till	19	Save fertilizer (76%), increase yield (23%), save labor (17%)
Surface pipe	83	
Community technologies		
Underground pipe	93	
Lined canal	99	
Sprinkler	88	

Note: These data are from the authors' survey of village leaders and they include only observations from villages where the technology was adopted. If households in a village were using a technology, the respondent was asked whether or not the technology was primarily adopted to save water. If the technology was not primarily adopted to save water, the respondent was asked to list other reasons for adoption. *Data source*: Authors' survey.

[a] Only listed for technologies which less than 2/3 of villages adopt to save water. Percent of villages that did not adopt to save water in parenthesis.

water saving, even for technologies for which water saving was the primary objective.

3. Water saving technology adoption

We track adoption with two sets of measures derived from our survey data. The first is a village measure in which a village is considered to have adopted a technology if at least one plot or farmer in the village uses the technology. While this does not mean that all, or even most, farmers in a village use the given technology, information on how many villages have at least one farmer using the technology provides an understanding of how spatially pervasive the practice has become. It also provides a convenient measure to track the diffusion of each technology over time. The second measure, the percentage of sown area using the technology, is a measure of the actual extent of adoption at the farm level.

3.1. *Village adoption*

As the name implies, traditional water saving technologies have been used for many years (Fig. 2). The strongest distinguishing characteristic of traditional water saving technologies is that, even as of the early 1950s, they were being used in a relatively large share of China's villages. For example, in 1949 farmers in 55% of northern China villages were already leveling their land. Likewise, in the early years of the Peoples Republic, farm households in slightly less than half of northern China's villages were using border/furrow irrigation. Clearly, before the shortage of water across China began to elicit national and international attention, farmers in more than half of China were already using these traditional agronomic techniques. To the extent that they were doing so to save water, farmers have long been actively managing their water resources.

During the reform period the adoption of traditional technologies grew slowly, in part because traditional technology adoption rates were already high in the pre-reform and early reform era (Fig. 2). Between the early 1980s and 2004, village level adoption rose from 68% to 77% for field leveling and from 60% to 68% for border/furrow irrigation. As traced in a typical S shaped diffusion path, technology adoption growth rates are often relatively slow at the beginning of the adoption process, speeding up as public information and experience with the technology increases and then slowing down again as the pool of potential adopters dwindles (e.g. Cabe, 1991). The high rates of early adoption and the recent slow growth rates of traditional technologies are consistent with a technology adoption (or diffusion) process that is near its maximum.

In contrast, household-based technologies have taken a different adoption path during the past 55 years (Fig. 2, middle set of lines). Although it is difficult to distinguish exact levels of adoption in 1949 from Fig. 2 (the paths are too tightly bunched), household-based water saving technology adoption rates were all low initially, ranging from 1% (surface pipe) to 10% (retaining stubble/low till). Unsurprisingly, due to the relative abundance of water and the nature of farming at the time (collective-based with few incentives to maximize profits), household-based technology adoption rates at the village level remained low over the next 30–40 years. It was not until the early 1990s that their adoption rates accelerated. Between 1995 and 2004 village-level adoption of surface pipe more than doubled, from 23% to 48%. The emergence of villages in which farmers use retaining stubble/low till, plastic sheeting and drought resistant varieties, was clear; the number of villages with at least one adopter for each technology rose by at least 17% points. By 2004, farmers in

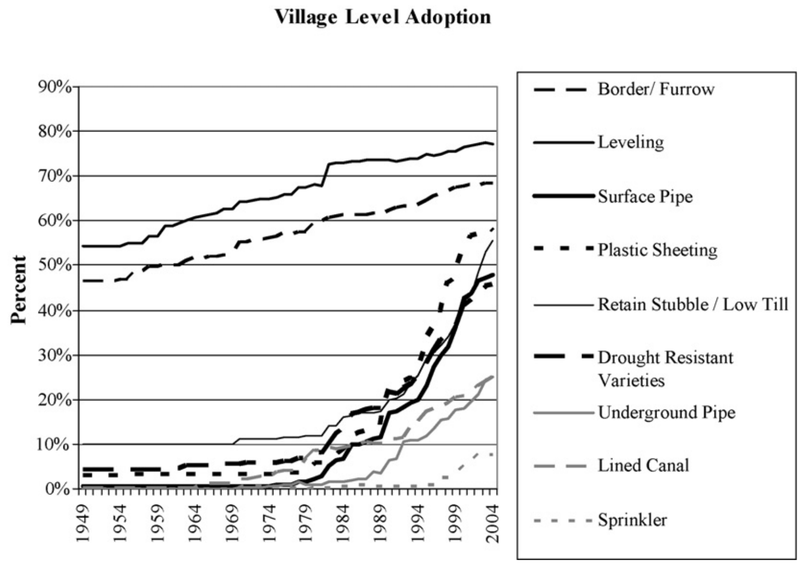

Fig. 2 – Percent of Villages Adopting Water Saving Technology in Northern China, 1949–2004. *Note*: Village level adoption means that at least one household (or plot) in the village is using the technology. The aggregated border and furrow irrigation adoption rates are estimated taking the covariance of adoption into account—only 34.6% of furrow adopters were not also adopters of border irrigation. *Source*: Authors' survey.

at least 45% of villages were using each type of household-based water saving technology. One explanation for the relatively rapid diffusion of household technologies is that at sometime in the 1980s or early 1990s, some barrier(s) to adoption of these technologies loosened, and this initiated a surge of adoption activity. Likely, the increasing autonomy that producers were granted in the 1980s is at least partially responsible for the rising interest of households in water saving technologies.

Finally, although the basic pattern of community-based technology adoption follows the same fundamental paths as household-level technologies, these paths start lower and rise at a slower rate (Fig. 2, lower set of lines). Between the 1950s and 1980s, like household-level technologies, adoption rates are low. By the beginning of the reforms in the mid-1980s, the highest village-level adoption rate of a community technology (lined canals) is only 10%. Although, as in the case of household-level technologies, adoption rates begin to rise after the early 1990s, in 2004 the most commonly adopted community-based technology, lined canals, could be found in only 25% of northern China's villages. The average rate of increase of the three community-based technologies between 1995 and 2004 was only 9% points.

Based on these adoption histories, it is unclear what is driving the adoption path of community-based technologies. Two sets of general economic forces might be at once encouraging and holding back adoption. Rising scarcity of water resources almost certainly is pushing up demand for community-based technologies, while the predominance of household farming in China (Rozelle and Swinnen, 2004) and the weakening of the collective's financial resources and management authority (Lin, 1991) have made it more difficult to gather the resources and coordinate the effort needed to adopt technologies that have high fixed costs and involve many households in the community. In contrast, household-based technologies may be more widely adopted due to relatively low fixed costs, divisibility, and minimal coordination requirements.

3.2. *Sown area extent of adoption measures*

The most striking finding of our examination of the extent of adoption of water saving technology is that, although it is growing rapidly, the extent of adoption is much lower than overall adoption rates (Table 3). The highest rates of adoption measured in terms of sown area are for traditional technologies (rows 1 and 2). Field leveling, for example, was adopted on 41% of sown area in 2004. Hence, farmers have yet to adopt even traditional technologies on most of northern China's sown area. Even the most basic, traditional water saving technologies are not used on at least 60% of sown area.

In the case of household and community-based technologies, the extent of adoption, as measured by percent of sown area, is generally growing, but is still quite low (Table 3, rows 3–9). For example, in the case of household-based technology, as in the case of village-level adoption figures, adoption rose substantially in relative terms. The extent of adoption of nearly all household-based technologies doubled or more than doubled in percentage terms (except for drought resistant varieties, which rose from 10% to 18%). Despite rapid growth rates after 1995, the adoption of household-based technologies was low, ranging from only 11% for plastic sheeting to 20% for retaining stubble/low till. In other words, as of 2004, averaging across the four most commonly observed household-based technologies, a typical household technology covered only 16% of sown area (the average of column 2, rows 3–6). The pattern of the extent of adoption of community-level technologies using

Table 3 – Extent of adoption: proportion of sown area in which farm households use water saving technology in northern China, 1995 and 2004

Technology	1995 (%)	2004 (%)
Traditional technologies		
Border/furrow irrigation	31	38
Level fields	39	41
Household-based technologies		
Plastic sheeting	5	11
Drought resistant varieties	11	18
Retaining stubble/low till	10	20
Surface pipe	7	17
Community-based technologies		
Underground pipe	4	13
Lined canal	5	9
Sprinkler	0	3

Note: These data are from the authors' survey of village leaders and they include the sown area of all villages, those that adopt and those that do not adopt. If households in a village were using a technology, the respondent was asked to estimate the amount of sown area on which each of the technologies was used. For convenience, we have combined border and furrow irrigation because they are not used simultaneously and are both plowing-based, agronomic technologies. We have estimated percentages for the small number of observations for which the sown area in use is missing (0.04% in 2004 and 2.2% in 1995). Our estimates are predicted values based on regressions of sown area percent in the missing year on sown area percent in all non-missing years (this includes 2001 data for the CWIM data set), total cash crop sown area, total staple crop sown area, surface water usage status, groundwater usage status, and dummy variables for each of the province-scarcity strata. *Data source*: Authors' survey.

sown area measures is similar, except that both the growth rates (in percentage terms between 1995 and 2004—only 5% points, averaging across the technologies) and the final levels of adoption (in 2004—only 8%, on average) are lower.

3.3. *Water saving technology trends: summary*

Our data show a strong and consistent pattern of adoption of water saving technology. Perhaps the most important single result is that the gains in water saving technology adoption over the past decade or more have mostly come from household-based technologies. Traditional technologies are widely used, but in fact, are only slightly more widely adopted than in the past (thus deserving their name ''traditional''). The typical community-based technology also has grown relatively slowly and in 2004 covered less than 10% of northern China's sown area. In contrast, household-based technologies have expanded at a relatively rapid pace. Almost half of all villages have farmers that use each of the household-based technologies.

Despite the growing use of all water-saving technologies, the extent of water saving technology use is still low in China, especially when using sown area coverage as a measure of adoption. No one type of technology covers more than 50% of sown area; no non-traditional technology covers more than 20% of sown area. In part, this may be due to the fact that not all areas of China are facing water shortages. In many areas, at least currently, there is no need for farmers to adopt water saving technology (see Wang et al. (in press), for a discussion of the variability of water scarcity in China). However, the low levels of adoption in northern China might imply there are barriers to adoption. If policies can be created and incentives provided to farmers and groups of farmers to adopt new technologies, there is hope, at least at the field level, for large water savings in the coming years.

Although the analysis to this point has relied almost exclusively on our data, when we compare our adoption rates with provincial level adoption rates (measured in percentage of sown area) the two sets of statistics are relatively consistent. The 2001 yearbook-based estimate for the adoption of sprinklers and drip irrigation is 3% (calculation based on EBCAY, 2001). This is within the range of our estimates of sprinkler and drip irrigation in 1995 (almost 0%) and 2004 (3%). Likewise the 2001 yearbook estimate of lined canals (3%) is close to our 1995 estimate (5%).[4]

Our findings and interpretations also are fairly consistent with those appearing in other literature. For example, in a survey of five irrigation districts reported by Yang et al. (2003), the research team concludes that canal lining, border irrigation, hose water conveyance and plastic mulch are not widely used.[5] With the exception of border irrigation, our results are in agreement.[6]

4. The determinants of water saving technology adoption

We have seen that some types of technologies were popular before the 1980s; some have become increasingly common after 1990; and others have yet to be adopted. To begin explaining the pattern, we first examine the role of incentives as one of the key determinants of adoption. We also examine the role of the state in providing information, investment and coordination.

4.1. *Adoption and water scarcity*

Theory predicts that as a resource becomes more scarce, resource conserving technologies are more likely to be adopted (Ruttan and Hayami, 1984). Irrigation costs that increase with water use should motivate farmers to reduce water use. For

[4] For comparison with our statistics, province level yearbook data was aggregated using the same province level weights used in the authors' survey. The estimate for lined canals in 2001 is somewhat lower than our 2004 estimate (9%). The difference between our estimates and the figures generated by surveys run by the Ministry of Water Resources may be a difference in our samples and coverage, or it may also reflect differences in definitions. In our surveys, we included lined canals whether or not they were at the primary, secondary, tertiary or field levels. Frequently, in national statistical reporting systems, the lowest levels of lined canals are not counted (since they are counted more as ''ditches'' rather than ''canals'').

[5] Henan (Liuyuankou, and People's victory canal) Ningxia (Weining and Qingtongxia) and Hebei (Luancheng).

[6] The partial nature of Yang's sample and the large areas of China that still do not have border irrigation (according to our data) suggests that even for border irrigation our results do not conflict.

Table 4 – Adoption rates in villages using groundwater and surface water, 2004

Technology	Groundwater using villages (%)	Surface water using villages (%)
Traditional technologies		
Border irrigation	73	61
Furrow irrigation	20	30
Level fields	83	81
Household technologies		
Plastic sheeting	61	60
Drought resistant varieties	42	45
Retaining stubble/low till	62	57
Surface pipe	60	42
Community technologies		
Underground pipe	34	22
Sprinkler	10	6

Note: These data are from the authors' survey of village leaders. We did not include lined canals since most of these are funded by surface water irrigation districts. In fact, our data bear this out: lined canals are found in 43% of surface water villages and in only 25% of groundwater villages. *Data source*: Authors' survey.

example, as the groundwater table falls, the cost of pumping increases, raising the average cost of irrigation for farmers using pumped groundwater. Farmers may respond to the rising cost of water by altering the quantity of water they apply to crops or by changing the mix of crops they produce. Foster et al. (2004) report that farmers in the North China Plain reduced the number of irrigations as groundwater levels declined.

Alternatively, consistent with a large literature that shows the correlation between water scarcity and adoption of water saving technologies, farmers may respond by adopting new technologies. In China, Yang et al. (2003) demonstrate that farmers in groundwater irrigated areas adopt water saving technologies because they have control over the volume. When farmers bear the cost of the water they use, adoption rates for white dragons (surface piping) and other water saving techniques are higher.

If farmers do not pay for water by volume, or if they otherwise do not have an incentive to save water, we should not expect them to adopt water saving technologies on their own. In northern China there are many situations in which farmers have little incentive to save water. In almost all irrigation districts, farmers using surface water rarely buy water by volume. Surface water irrigation fees are almost always based on sown area (Wang and Huang, 2004; Lohmar et al., 2003; Yang et al., 2003).

We find a negative relationship between the level of adoption of most water saving technologies and the use of surface water (Table 4). With the exception of lined canals and drought resistant varieties (which we do not include in the table), adoption rates are higher in groundwater villages for all technologies. Among all of the technologies, the differences are greatest for border/furrow irrigation and surface pipe.[7]

Inside groundwater villages, the incentives to adopt technology are much clearer; we expect groundwater villages with the lowest water levels to be most likely to adopt. Our data depict precisely this result when using either village-level or sown area-based measures (Table 5). With the exceptions of field leveling, retaining stubble/low till, and sprinkler technologies, farmers in villages with water from depths of 30–150 m more frequently are observed to be using water saving technologies than farmers in villages with depths less than 10 m (columns 1 and 2). With the exception of field leveling, the portion of sown area on which farmers use water saving technologies is greater in villages using deeper wells than those with shallow wells (columns 3 and 4). The differences are greatest for technologies designed to work with groundwater pumps. In villages that pump from deeper wells, farmers use surface pipe and underground piping systems in nearly double the number of villages and on nearly double the sown area (although there is more of a difference for underground piping).[8]

4.2. *Role of the government*

While there is considerable evidence that adoption of water saving technology is associated with the cost of pumping and the need to pay for water volumetrically, perhaps a more surprising result is that it is not more correlated. Although there are explanations for certain technologies (footnotes 6 and 7), the fact is that for a number of cases, farmers in villages with surface water and those pumping from shallow wells were adopting technologies at higher rates than those pumping deeper wells. In addition, there were many villages and considerable amounts of sown area in villages pumping from deep wells that were not adopting technologies that clearly provided savings in water (as well as energy—in the form of electricity to drive the pumps). As a consequence, it would seem there must be other, non-pecuniary determinants of why some farmers adopt and others do not.

4.2.1. *Adoption and investment*

Technologies with high fixed costs may be beyond the reach of farmers without outside assistance, posing a hurdle to adoption. Weakening of the collective's financial resources (Lin, 1991) indicates that the collective may have a declining ability to make such investments. Traditional and household-based technology investments come from farmers (Table 6). For community-based technologies, investment comes from three groups, farmers, villages and upper

[7] Interestingly the difference between plastic sheeting and retaining stubble/low till were not very large; however, as shown in Table 2, these technologies, in fact, were not primarily adopted to save water. Hence, this result is not surprising.

[8] As in footnote 6, the result that retaining stubble/no till is not related to the cost of water, is almost certainly related to the fact that the technology, in fact, was not primarily adopted to save water. It also is understandable that there were no villages that pump from deep wells in our sample that used sprinkler technology since sprinklers are only adopted in communities that receive large subsidies; apparently, the officials that make the decisions are not overly concerned with the cost of pumping. The field leveling may be a result of the fact that field leveling is correlated with a village's natural geography. A large share of China's shallowest wells are in areas that are naturally flat (making the cost of field leveling low and raising adoption).

Table 5 – Adoption rates and extent in groundwater using villages by depth to water, 2004

Technology	Percent of villages adopting		Percent of sown area adopting	
	Water level: 0–10 m	Water level: 30–150 m	Water level: 0–10 m	Water level: 30–150 m
Traditional technologies				
Border/furrow irrigation	86	96	42	62
Level fields	93	80	49	45
Household technologies				
Plastic sheeting	52	62	9	15
Drought resistant varieties	34	57	11	22
Retaining stubble/low till	68	62	21	23
Surface pipe	58	65	18	31
Community technologies				
Underground pipe	17	63	13	33
Sprinkler	13	0	1	0

Note: These data from the authors' survey of village leaders. We did not included lined canals since most of these are funded by surface water irrigation districts. In fact, our data bear this out: lined canals are found in 43% of surface water villages and in only 25% of groundwater villages. The aggregated border and furrow irrigation adoption rates are estimated taking the covariance of adoption into account—only 34.6% of furrow adopters were not also adopters of border irrigation. The estimates of sown area for this category assume that the two technologies are exclusive. *Data source*: Authors' survey.

levels of government. For sprinkler systems, the proportion of villages receiving upper level government investment is particularly large (51%). It could be that investments are low because there is a wealth constraint limiting the ability of farmers and village leaders to make such investments.

4.2.2. *Adoption and extension efforts*

Extension may be an important factor in adoption. Abdulai et al. (2005) find that having access to advice from an extension agent is the ''most important driving factor'' in adoption of GCRPS in Hubei. They suggest this is because extension provides subsidized inputs and access to information (Table 7). However, agents in the extension system face poor incentives and low budgets (Deng et al., 2004; CCICED, 2004).

Access to extension, a potential source of information, is more varied than source of financial investment, especially for household-based technologies, for which information comes from county governments, other governments, other farmers, and seed companies. Traditional technology information comes primarily from other farmers. Community-based technology information comes from the village, the county government, and higher levels of government. Adoption of these technologies requires coordination and the source of information for adopters is concentrated in entities that can facilitate adoption (the village and upper levels of government). Hence, we expect adoption of community-based technologies to be responsive to government extension. Adopters of household-based technologies may also be responding to government extension, but to a more limited extent.

Table 6 – Primary source of investment in water saving technology

Technology	Government (%)	Village (%)	Farmer (%)	Water manager (%)	Other (%)
Traditional technologies					
Border irrigation	0	1	98	0	2
Furrow irrigation	2	0	95	0	3
Level fields	3	2	95	0	1
Household-based technologies					
Plastic sheeting	10	5	92	0	0
Drought resistant varieties	0	0	100	0	0
Retaining stubble/low till	2	0	96	0	3
Surface pipe	6	7	87	1	1
Community-based technologies					
Underground pipe	35	34	40	1	0
Lined canal	36	45	28	0	2
Sprinkler	51	13	48	0	1

Note: These data are calculated from the authors' survey of village leaders and includes only observations from villages where the technology was adopted. If households in a village were using a technology, the respondent was asked to name the primary source of investment. *Data source*: Authors' survey.

Table 7 – Sources of technology extension: percent of adopting villages by source of technology extension

Technology	Village (%)	County (%)	Other government (%)	Other farmers (%)	Traditional (%)	Seed Co. (%)	Outside village (%)
Traditional technologies							
Border irrigation	5	8	4	19	65	0	1
Furrow irrigation	3	5	6	44	41	0	7
Level fields	2	7	7	26	55	1	3
Household technologies							
Plastic sheeting	5	31	29	18	0	3	10
Drought resistant varieties	4	23	29	9	6	22	7
Retaining stubble/low till	9	23	26	23	11	0	7
Surface pipe	8	10	20	36	1	0	22
Community technologies							
Under-ground pipe	25	14	43	11	0	0	3
Lined canal	28	23	32	12	3	0	0
Sprinkler	0	33	52	0	0	0	16

Note: These data are from the authors' survey of village leaders and includes only observations from villages where the technology was adopted. If households in a village were using a technology, the respondent was asked to name sources of extension or information about the technology. *Data source*: Authors' survey.

5. Conclusions

The adoption of water saving technology in northern China has increased with increasing water scarcity, yet the extent of adoption is quite low. Both the rate and extent of adoption vary substantially across technologies. Of the different types of water saving technologies, household-based technologies have grown most rapidly and several traditional technologies have the highest rates of adoption. The most successful technologies have been highly divisible and low cost ones that are implementable without collective action or large fixed investments. Technologies that do not fit this description are adopted on a more limited scale, at least, in part due to the failure of policy makers to overcome the constraints to adoption.

While it may be disappointing that more farmers have not adopted water saving technologies, there is substantial scope for more adoption. Farmers in many parts of northern China have not adopted even fairly rudimentary water saving technology. In many cases this is due to poor incentives—especially in the case of surface water systems. In other cases, information and financial ability may be constraining adoption. Given the right incentives, information and the ability to overcome the constraints of collective action, farmers adopt.

The main reason for non-adoption, then, appears to be that farmers do not have strong incentives to save water. The state can encourage adoption by supporting institutions that provide incentives to save and as a provider of information, extension and in some cases financial assistance and coordination. If incentives and government-provided services can be delivered water scarce areas, there is a great deal of scope to conserve water and support China's agricultural sector despite tight water supplies.

Government policies created to encourage water saving technology adoption should focus on areas where field level water savings will result in increased water availability. Under some hydrologic conditions, adopting a water saving technology might lead to field level water savings, but have little or no impact on regional water availability. The state can have an important role in providing incentives for adoption in areas in which field level water savings will not increase local water availability but will lead to increased water availability elsewhere.

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