RURAL WATER SAVING TECHNOLOGY ADOPTION IN NORTHERN CHINA: AN ANALYSIS OF SURVEY RESULTS

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The Role of Water Saving Technology in Confronting China's Water Crisis

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 late summer. Parts of Northeast China and almost all of Northwest China have suffered from chronic severe water shortages. The water table has fallen rapidly over the last decades, in some cases over two meters 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 Yellow and Hai River basin has completely eliminated river flow in the lower regions in several years (Wang, Huang, and Rozelle, 2003), and the Yellow River has run dry before reaching the ocean for parts of most years since the mid-1970s (Lohmar et al., 2003).

Dwindling water supplies have important implications for northern China's agricultural sector. Northern China is an important agricultural region, but many of its agricultural producers depend on irrigation and are facing growing competition from non-agricultural users for water resources. The North China plain alone produces roughly one quarter of China's grain (Zhen and Routray, 2002). The future of water resources will impact both rural welfare and food security. Irrigation status has a positive impact on both yields and cropping revenue (Huang, Rozelle, Huang, and Wang, 2002).

China's government's response 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. Indeed, China's success in using the nation's surface water resources may be one of the reasons that the nation faces water-shortage problems today.

Over the last decade or more, however, 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) 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]" (page 121). In facing China's water shortages, policy makers have begun to develop a number of 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 (e.g. water pricing policies which have not been implemented as China's government has spent considerable policy effort in recent years to cut a large array of taxes and fees).

In response to the water crisis, 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 the major scientific research project by the government, involving many specialists from different institutions, and more than 3000 practical achievements have been obtained in dry-land farming" (page 121). International organizations and foreign governments have collaborated with the Chinese government and research institutions on these projects. In addition to sponsoring research, government and nongovernmental 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 water saving technologies (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. During a recent conference in Beijing, however, a statement by one of the main policy officials who controls the expenditure of funds for rural economic development at the National Development and Reform Commission shows that the government still places high hopes on water saving technology as a way to solve China's water crisis; unfortunately, although central authorities are willing to invest heavily in the development and extension of water saving technology, they do not believe they know enough about past successes and future prospects to allocate large sums of funding.

The overall goal of our analysis is to sketch a picture of the state of water saving technology in northern China in order to increase awareness of past trends and current status. In simplest terms, we would like to establish a set of first order facts about the role that water saving technology has been playing in China's agricultural sector. To do so, we have three specific objectives. First, we seek to illustrate the progress in adoption that has been made over the past two decades. Second, we want to identify the characteristics of the technologies that have been most successful and those that have not. Finally, we hope to begin to understand the factors that may be promoting water saving technology and the factors that are holding back its spread.

Our analysis is limited in several ways. First, we limit the geographic scope of our analysis to northern China, where water shortages are most severe. Second, the results presented in this paper are based on a survey of village leaders. Although typically knowledgeable about agricultural production and water management issues (and, thus, able to provide high quality information on most topics), we believe the quality of some variables is affected by the 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 micro point of view and can ask questions that are both quantitative and qualitative.

To meet our objectives, the remainder of the paper proceeds as follows. First, to understand how water saving technology promotion efforts have succeeded and to understand what is really going on in northern China's villages, we describe the data that we collected explicitly for this purpose. In the next section, using our data as a guide to the most commonly used technologies, we describe the major types of water saving practices, categorizing them into three types: traditional technologies, household-based technologies and community-based technologies. The following sections then use our data to track the adoption paths of the different types of technologies and search for the characteristics of communities and farmers that have adopted them (as well as for characteristics of communities and farmers that have not). The final section concludes.

Data

The core of our analysis is based on data collected as part of two recent surveys specifically designed to address irrigation practices and agricultural water management. The first survey, the China Water Institutions and Management survey (CWIM), was collected 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 geographic location (which in the Hai River Basin is often correlated with water scarcity levels). 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 increasing 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 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. In the rest of the paper when we use the term *northern China* we mean all provinces in North and Northeast China and all provinces in Northwest China with the exception of Xinjiang.

Because of the way we choose our sample and collected the data, we are able to make statements that are reasonably representative for northern China. We used a stratified random sampling strategy to generate a sample expressly for this purpose. To choose the sample, we first sorted counties in each of our regionally representative sample provinces into one of four 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 socioeconomic 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 efficiency; and the source of technology extension. Information on almost all variables were asked for two years, 2004 and 1995.

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 the purposes of this paper, the term water saving technology encompasses a wide variety of irrigation techniques and agricultural production practices. For analytical convenience, we have divided the list of technologies into three groups: traditional, household-based and community-based. In the rest of the paper, we are excluding any discussion of a series of novel water saving technologies (such as drip, intermittent irrigation, and chemicals and drugs) 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. We understand that in the case of many technologies that we are considering, their adoption may not save water when net water use is measured on a basin scale. The real, or basin-wide, 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]

Traditional Technologies

Traditional technologies include border and furrow irrigation and field leveling. We have grouped these technologies because they are widely adopted and because 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 separable in the sense that one farm household can adopt the practice independent of the action of its neighbors.

One of the most rudimentary of the traditional technologies is done by developing channels or bunds in the field in order to direct the flow of the water to the crops without letting the water flow freely across the plots. Border irrigation is an irrigation technique in which a single plot is separated into zones. Each zone is on a slightly different level so that water flows from one to the other, rather than flooding the field all at once. This technology increases the control a farmer has over irrigation application on each section of his plot, which may result in reduced applied irrigation.

Closely related, furrow irrigation is an irrigation system in which crops are planted on raised ridges between furrows. Once applied, irrigation water flows through these furrows. One study performed at the Shandong Academy of Agricultural Science comparing winter wheat grown in raised beds with furrow irrigation to the same crop grown with traditional flood irrigation found that using furrow irrigation improved water use efficiency (Wang Fanong et al., 2004).

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).

Household-based Technologies

Household-based technologies include plastic sheeting, drought resistant varieties, retain 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 adoption of the traditional technologies.

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

Drought resistant varieties include any seed variety that is relatively able to withstand low water 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 over 10 percent over those varieties that are not drought resistant in years of below average rainfall.

Retain 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 of mulching using crop residue in northern China show that it can improve water use efficiency by reducing soil evaporation and increase yields in comparison to traditional techniques including furrow (Deng et al., 2004, Pereira et al., 2003, and Zuo, 1997). While in some sense this technology resembles no till practices that are being promoted 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 producers 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 farmers' fields. Often white, surface level hose technology is made of soft, flexible plastic pipe. In China, due to their color and shape, farmers often call these "white dragons." Zuo (1997) notes that surface water piping techniques, including low pressure pipes, can save up to 30 percent of water in addition to small amounts of land.

Community-based Technologies

Community-based technologies include underground pipe systems, lined canals and sprinkler systems. We have grouped 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 often require collective action or ongoing coordination of multiple 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 means 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 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. He cites high costs as the reason for the concentration of sprinkler technology in vegetable and fruit production.

Underground pipe systems include any system of underground pipe (cement, metal, or plastic) 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 to 100 meters. Zuo (1997) notes that these techniques save water (up to 30 percent) in addition to a small fraction of land area, compared to unlined canal systems.

Lined canals are irrigation canals lined with cement or any other relatively impermeable material. Lining an irrigation canal reduces the percent of water that seeps through the canal into the surrounding soil during conveyance from the water source (surface system or well) to the field, which can increase the percent of water in the canal available for irrigation (Cai and Rosegrant, 2004). In many villages, the lined canals were installed or subsidized by the surface water irrigation district in conjunction with the local water resource bureau. Lined canals, like underground pipe systems, may increase water use efficiency in some circumstances (Zuo, 1997).

Farmer Perceptions of Technology Traits

Ultimately, the most important proximate determinant of adoption is the farmers' perception of the benefits and costs of adoption. In this section, we document the way that farmers view the new water saving technologies. The first part of this discussion examines perceptions of the water saving properties of each adopted technology. In the second part, we examine perceptions of additional beneficial traits.

Perceived Water Savings

Although, as discussed above, field level water savings and real, basin-wide water savings may differ due to a number of agronomic and hydrological factors, water saving technology adoption will increase in response to water shortage only to the degree that users (farmers and village leaders) perceive that adoption will lead to water savings. Our data, in fact, show that while the most commonly observed water saving technologies are perceived to save water, there are differences among them (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 retain stubble / low till (8%). While a bit higher (perhaps due to the way we asked the question; perhaps due to the status of our informant; and/or perhaps due to the nature of the sample), our results in fact, are fairly consistent with those of Yang et al. (2003) which reports 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" (page 147).

Other Beneficial Traits

One of the most surprising findings that we encountered during our research in the field was that in many cases respondents would tell 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, we found that, in many cases, technologies that are associated with water savings often have other traits that are demanded by farmers. For example, according to our data, in the case of plastic sheeting and retain stubble/low till, water saving was not the primary motivation for adoption for more than half of adopting villages (Table 2). In the case of plastic sheeting, although 46 percent of respondent's report that water saving was the primary objective, in 84 percent of the remaining cases, 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 retain stubble/low till, saving water was cited as the primary motivation for adoption by only 19 percent of respondents; in 76 percent of the remaining adopting villages, saving fertilizer was the most frequently cited reason. In fact, these results are consistent with experimental findings about the effects of both plastic sheeting and retain 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 water saving, even in the case of the many technologies for which water saving was the primary objective.

Water Saving Technology Adoption

The adoption paths of different water saving technologies trace three distinct sets of contours. Moreover, the general path of each technology within each major category—traditional, household-based and community-based—tends to follow the trajectory of the other similar technologies within its category. In this section, we track adoption with two sets of measures; 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; and the second, the percentage of sown area using the technology, is a measure of the extent of adoption.

Village Adoption

As the name implies, traditional water saving technologies have been used for many years (Figure 1). 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 percent 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 (Figure 1). Between the early 1980s and 2004, village level adoption rose from 68 to 77 percent for field leveling and from 60 to 68 percent for border 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 technological adoption path during the past 55 years (Figure 1, middle set of lines). Although it is difficult to distinguish exact levels of adoption from Figure 1 (the paths are too tightly bunched), household-based water saving technology adoption rates were all low in 1949, ranging from 1 percent (surface pipe) to 10 percent (retain 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 to 40 years. It is not until the early 1990s that their adoption rates soar. For example, between 1995 and 2004 village-level adoption of surface pipe more than doubled, from 23 to 48 percent. The use by farmers of retained stubble/no till, plastic sheeting and drought resistant varieties all grew by at least 17 percentage points. By 2004, farmers in at least 45 percent 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 set off a surge of adoption activity.

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 (Figure 1, 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 percent. 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 only be found in 25 percent of northern China's villages. The average rate of increase of the three community-based technologies between 1995 and 2004 was only 9 percentage points.

While, based on these descriptive contours, it is unclear what is driving the adoption path of community-based technologies, it is likely that there are two sets of forces that are at once encouraging and holding back adoption. On the one hand, rising scarcity of water resources is almost certainly pushing up demand for community-based technologies. On the other hand, 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) has 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.

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). As before when using village-level measures of adoption, 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 percent of sown area in 2004. Hence, while rising, the extent of adoption of traditional technologies, as measured in terms of sown area, still shows that 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 percent of sown area.

Likewise, in the case of household and community-based technologies, the extent of adoption, as measured by percentage of sown area, is generally growing, but is still quite low (Table 3, rows 3 to 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 percent). Despite rapid growth rates after 1995, the overall extent of adoption of household-based technologies was low, ranging from only 11 percent for plastic sheeting to 20 percent for retain 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 percent of sown area (the average of column 2, rows 3 to 6). The pattern of the extent of adoption of community-level technologies using sown area measures is similar, except that both the growth rates (in percentage terms between 1995 and 2004—only 5 percentage points, averaging across the technologies) and the final levels of adoption (in 2004—only 8 percent, on average) are lower.

Water Saving Technology Trends: Summary and Check of Data Quality

In 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 really only marginally more widely adopted than in the past. The typical community-based technology also has grown quite slowly and in 2004 covered less than 10 percent 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. The rate of adoption growth nearly doubles using village measures and is (on average) more than 100 percent using sown area measures.

Despite the growing usage 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 40 percent of sown area; no non-traditional technology covers more than 20 percent of sown area. In part, this may be due to the fact that not all areas of China are facing water shortages; in these areas, at least currently, there is no need for farmers to adopt water saving technology (see Wang et al., 2005, for a discussion of the variability of water scarcity in China). However, it is almost certain that the low levels of adoption in northern China mean that there are barriers that are holding back adoption. In fact, in one sense, the low levels of adoption are good news. Low levels of current adoption mean that 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 own data, comparisons with the few statistics that are available in the literature show that our data (and the conclusions drawn from them) may be fairly indicative of what is happening in northern China. Specifically, when we compare adoption rates from our data with those from provincial level adoption rates (measured in percentage of sown area) the two sets of statistics are relatively consistent. The 2001 yearbook-based estimates for the adoption of sprinklers and drip irrigation is 3 percent. This is precisely between our estimates of sprinkler and drip irrigation in 1995 (almost 0 percent) and 2004 (4 percent). Likewise the 2001 national estimate of lined canals (3) is close to our 1995 estimate (5 percent).[3]

Our findings and interpretations also are fairly consistent with those made in the rest of the 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.[4] With the exception of border irrigation, our results are in agreement.[5] Abdulai et al.'s study of Shi Yan district in Hubei province indicates that 34.9 percent of households adopt GCRPS, a method of using plastic sheeting in rice production.

The Determinants of Water Saving Technology Adoption

The objective of this section is to begin to identify why it is that farmers in some villages adopt (and sometimes adopt on a large share of the village's sown area) and farmers in other villages do not. We have seen that some types of technologies were popular before the 1980s; some have become increasingly common after 1990; and other have yet to take off. We hope to identify some of the correlates that can explain these patterns. To do so, we first examine the role of incentives as one of the key determinants of why an individual would adopt or not. We also examine the role of the state in providing information, investment and coordination.

Adoption and Water Scarcity

Theory predicts that as a resource becomes more scarce, resource conserving technologies are more likely to be adopted. Irrigation costs that increase with water use give some farmers an incentive to reduce water usage. For 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 that they apply to crops or by changing the mix of crops that they choose to produce. Foster et al. (2004) report that farmers in the North China Plain reduce the number of irrigation applications from three to two, in addition to seeking other water saving measures, when pumping from 50 meters.

Alternatively, farmers may respond by adopting new technologies or production techniques, consistent with a large literature that shows the correlation between water scarcity and adoption of water saving technologies. In China, Yang et al. (2003)

demonstrate that farmers in groundwater irrigated areas of their sample of five irrigation districts in Henan, Hebei, and Ningxia are motivated to adopt water saving technologies because they have control over the volume. Their paper concludes that when farmers bear the cost of the water that they use, the adoption rates for white dragons and other water saving techniques are higher.

However, if farmers do not pay for water on a volumetric basis 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 fact, in northern China there are a number of situations in which farmers have little incentive to save water. For example, in almost all irrigation districts, farmers that use surface water rarely buy water on a volumetric basis. Surface water irrigation fees paid by farmers are almost always based on sown area (Wang and Huang, 2001, Lohmar et al., 2003, Yang et al., 2003). As a result, farmers are often unaware of the specific amount they pay for surface water irrigation services and have little incentive to reduce water usage.

In fact, when examining the relationship between surface water, groundwater and water saving technology, we find that there is a negative relationship between the level of adoption of most water saving technologies and the use of surface water (Table 4). In fact, with the exception of lined canals and drought resistant varieties (which we do not include in the table—see note to table), adoption rates are higher in groundwater using villages for all technologies. Among all of the technologies, the differences are greatest for border/furrow irrigation and surface pipe.[6]

Inside groundwater villages, the incentives to adopt technology are much clearer; we would expect that groundwater using villages with the lowest water levels would be most likely to adopt. In fact, our data show us precisely this result when using either village-level or sown area-based measures (Table 5). With the exception of field leveling, retain stubble/no till and sprinkler technologies, farmers in villages that pump water from depths of 30 to 150 meter more frequently are observed to be using water saving technologies than farmers in villages that pump from less than 10 meters (columns 1 and 2). Likewise, with the exception of field leveling, the fraction of sown area on which farmers use water saving technologies is greater in villages that pump from deeper wells than in those that pump water from shallow wells (columns 3 and 4). Tellingly, the differences are greatest for those 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).[7]

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 that there must be other, non-pecuniary determinants of why some farmers adopt and others do not. In this section, we examine the role of the government and policy in promoting technology.

Adoption And Investment

Technologies with high fixed costs may be beyond the reach of farmers without outside assistance, posing a higher hurdle to adoption. Weakening of the collective's financial resources (Lin, 1993) indicates that the collective may have a declining ability to make such investments. Traditional and household-based technology investment comes from farmers (Table 6). For community-based technologies, investment comes from three groups, farmers, villages, and upper levels of government. For sprinkler systems, the percent of villages receiving upper level government investment is particularly large (51%).

Adoption and Extension Efforts

Extension may be an important factor in adoption. Abdulai et al. (2005) find that membership in an extension service is the "most important driving factor" in adoption of GCRPS and posit that this is because extension provides subsidized inputs and access to information. 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. Household-based technology information comes from county governments, other governments, other farmers, and, in the case of drought resistant varieties, from seed companies. Traditional technology information comes primarily from other farmers and tradition. Community-based technology information comes from the village, the county government, and higher levels of government.

Conclusions

It is not surprising that levels of adoption of water saving technology in northern China have increased as water has become increasingly scarce. What is surprising is that the extent of adoption is quite low. However, both the rate and extent of adoption vary substantially across technologies. Of all the different types of water saving technologies, it is clear that household-based technologies have grown most rapidly and that several traditional technologies have the highest rates of adoption. Hence, according to our results, the most successful technologies have been those that are highly divisible, low cost, and do not require collective action or large fixed investments. Technologies that do not fit this description are adopted on a limited scale, which we believe in part is the failure of policy makers to overcome the constraints to adoption.

While it may be disappointing the more farmers have not adopted water saving technologies, the bright side of this is that 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 farmers operating in surface water systems. In other cases, information and financial ability may be constraining adoption. The good news of our analysis is that we show when given the right incentives and information and the ability to overcome the constraints of collective action, farmers adopt.

Since the main reason for non-adoption is that there are not strong incentives to save water and farmers, adequate information, or the ability to overcome collective action constraints, the policy implications are clear. Incentives need to be provided. In other work, Huang et al. (2005) has shown that pricing policy is an option in groundwater areas in rural China. We also have observed surface water irrigation districts that have set up systems to volumetric measure water to the field level. When these practices that be widely implemented, we should expect more interest in water saving technology by farmers. There also is a role for the state to encourage adoption by encouraging institutions that provide incentives to save and as a provider of information, extension, and in some cases the financial assistance and coordination. If the incentives and government-provided services can be delivered to those in water scarce areas, according to our paper there is a great deal of scope to conserve water and support China's agricultural sector despite tight water supplies.

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Table 1: Village Leader Estimates of Water Savings, by technology

Technology	Estimated Percent of Water Saved
Traditional Technologies	
Border Irrigation	38
Furrow Irrigation	39
Level Fields	33
Household-based Technologies	
Plastic Sheeting	23
Drought Resistant Varieties	20
Retain Stubble / Low Till	8
Surface Pipe	35
Community-based Technologies	
Underground Pipe	42
Lined Canal	30
Sprinkler	39

Note: Percentages 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 estimate the average percent of water saved by the technology.

Data source: Authors' survey

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 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
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	
Retain 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: Percentages 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 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

Table 3: Extent of Adoption: Percentage of Sown Area in which Farm Households Use Water Saving Technology in Northern China, 1995 and 2004.

Technology	1995 (percent)	2004 (percent)
Traditional Technologies		
Border/ Furrow Irrigation	31	38
Level Fields	39	41
Household-based Technologies		
Plastic Sheeting	5	11
Drought Resistant Varieties	11	18
Retain Stubble / Low Till	10	20
Surface Pipe	7	17
Community-based Technologies		
Underground Pipe	4	13
Lined Canal	5	9
Sprinkler	0	3

Note: Percentage of sown area calculated from the authors' survey of village leaders and includes 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

Table 4: Adoption rates in villages using Groundwater and Surface Water, 2004

Technology	Groundwater Using Villages, Percent Adopting	Surface Water Using Villages, Percent Adopting
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
Retain Stubble / Low Till	62	57
Surface Pipe	60	42
Community Technologies		
Underground Pipe	34	22
Sprinkler	10	6

Note: Percentages are calculated 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 percent of surface water villages and in only 25 percent of groundwater villages.

Data source: Authors' survey

Table 5: Adoption Rates and Extent in Groundwater Using Villages by Depth to Water, 2004

Technology	Water Level 0 to 10 m Percent of Villages Adopting	Water Level 30 to 150 m Percent of Villages Adopting	Water Level 0 to 10 m Extent of Adoption, Percent of Sown Area	Water Level 30 to 150 m Extent of Adoption, Percent of Sown Area
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
Retain 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: Percentages are calculated 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 percent of surface water villages and in only 25 percent of groundwater villages. The aggregated border and furrow irrigation adoption rates are estimated taking the covariance of adoption into account – only 34.6 percent 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

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
Retain 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: The percentage of adopting village in each category is 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.

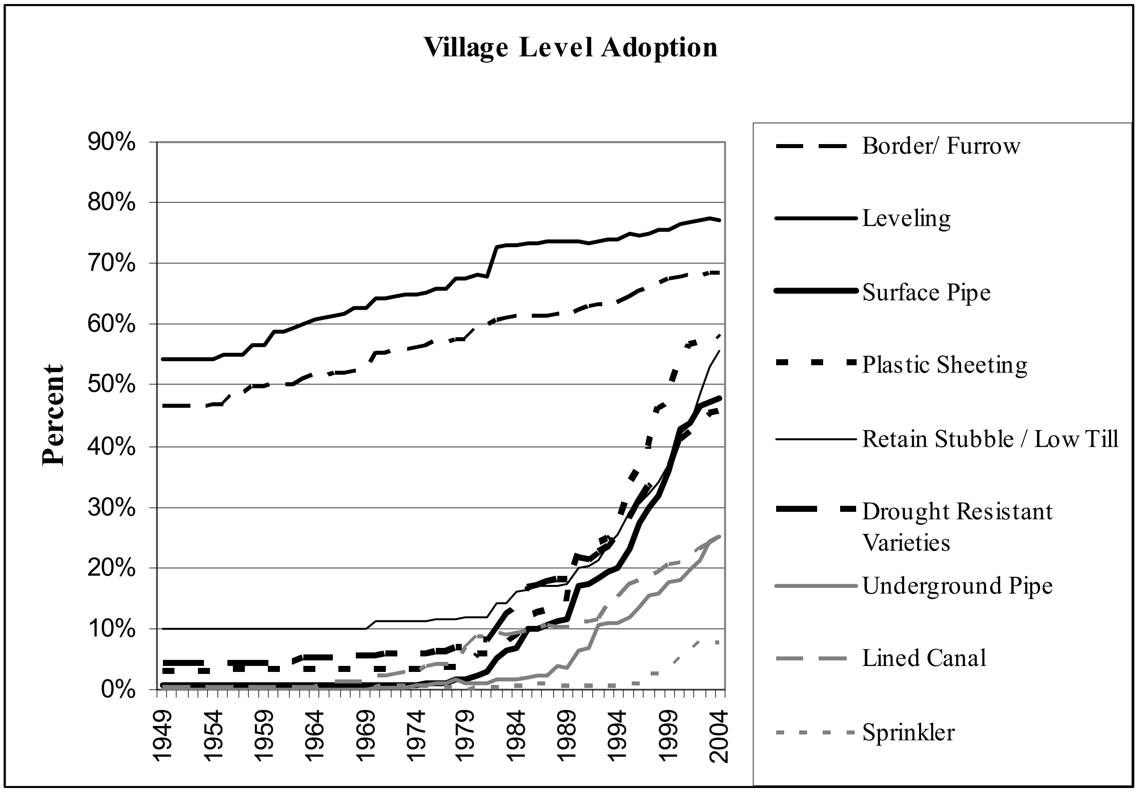
Data source: Authors' survey

Table 7: Sources of Technology Extension

Technology	Village	County	Other Govern-ment	Other Farmers	Tradit-ional	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%
Retain Stubble / Low Till	9%	23%	26%	23%	11%	0%	7%
Surface Pipe	8%	10%	20%	36%	1%	0%	22%
Community Technologies							
Underground 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: The percentage of adopting village in each category is 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 sources of extension or information about the technology.

Data source: Authors' survey



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 percent of furrow adopters were not also adopters of border irrigation.

Source: Author's data

Figure 1: Percent of Villages Adopting Water Saving Technology in Northern China, 1949-2004

[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 provinces 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 2 or 3 counties; of all of the counties in the mountainous and desert counties, we chose 1 county.

[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.

If, however, water that is not lost as ET is not available for irrigation elsewhere in the basin, adopting technologies that reduce seepage or applied water applications may result in real water savings. This is the case when water is being pumped from a confined aquifer, with no possibility of available recharge, or in surface irrigation systems where water lost through seepage is lost to the system.

The ultimate impact of water saving technology adoption on water availability is also dependent on the effect that it has on other agricultural production decisions including crop choice and the demand for irrigation. If irrigated area expands in response to water saving technology adoption (it becomes cheaper / more efficient to irrigate a larger area), the quantity of water applied as irrigation could actually increase. Some studies (e.g. You, 2001, and Kendy et al., 2004) have concluded that crop change or reducing ET is the only effective water conservation measure.

[3] The national, published estimates of lined canals in 2001 is somewhat lower than our 2004 estimate (9 percent). 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").

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

[5] 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.

[6] Interestingly the difference between plastic sheeting and retain 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.

[7] As in footnote 6, the result that retain 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).