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Economic Analysis of Adoption of Water-saving Land Improvements in Northern China

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ECONOMIC ANALYSIS OF ADOPTION OF WATER SAVING LAND IMPROVMENTS IN NORTHERN CHINA

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by
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Accepted by
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ABSTRACT

Although water shortages are becoming a severe problem in Northern China, the agricultural sector, China's biggest consumer of water in the nation, uses water inefficiently. Adopting water-saving land improvement technologies may help to alleviate water shortages in Northern China. Determinants for farmers' choice of water-saving land improvements in Northern China are analyzed with a sample survey of 401 villages. The analysis focuses on two aspects of adoption, whether to adopt and if a technology is adopted, how much land the technology is applied to.

In the first stage, "whether to adopt", multinomial logit models are applied to analyze the discrete choice of alternative land improvement strategies. In the second stage of adoption, "how much to adopt", both sample selection models and OLS models are utilized to measure the adoption extent of field leveling, use of borders, and use of furrows. The econometric results of this study indicate that farmers are willing to adopt water-saving land improvements and change water use behavior when water is less abundant. Water availability has a positive impact on both the probability and the intensity of adoption of water-saving land improvements. Government interventions such as extension service, demonstration fields, or provision of subsidies or loans boost the adoption of water-saving land improvements. In addition, farmers with more arable land are less likely to adopt traditional water-saving land improvements and more likely to switch to modern water-saving

land improvements. Another interesting finding in this study is that while the amount of arable land per household is negative and significant in the discrete choice model on the choice of traditional water-saving land improvements, it is positive and significant in the continuous choice model, which implies a threshold value for arable land per household.

Nonetheless, this study provides some policy implications for the Chinese policy makers. Although the adoption rate of water-saving land improvements in Northern China is relative low, with the right incentive farmers are willing to switch to more efficient water-saving land improvements. Government can subsidize or issue loans to induce the adoption of modern water-saving land improvements which require a sizable upfront investment that Chinese farmers usually cannot afford to. Demonstration fields also provide an effective way to encourage farmers’ adoption of water-saving land improvements. The land rental market which emerged in rural China starting in the 1990s can induce land circulation and the achievement economies of scale in farming and in turn increase the adoption of more efficient water-saving land improvements. Finally, the nine-year compulsory education program in China will benefit farmers and likely increase technology adoption. Continued government support of each of these programs will encourage increased adoption of water-saving land improvements.

Although whether or not adopting modern water-saving land improvements such as sprinkler or drip irrigation conserves water is still debated, Caswell and Zilberman

(1986) found that switching to sprinkler or drip irrigation from border or furrow irrigation saves water at the field level under certain circumstances. Therefore, under some hydrologic conditions, adopting water-saving land improvements, either traditional or modern may, lead to water saving in the field.

DEDICATION

I dedicate this work to my parents. They taught me how to write my name when I was three.

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CHAPTER ONE: INTRODUCTION

With the world's largest population at 1.3 billion people, China is among the countries with the scarcest water resources in the world (Crook and Diao, 2000). Although China's total quantity of water, including both surface water and ground water, ranks sixth in the world, water availability per capita is 1,945 cubic meters, just one quarter of the world average (Statistic Bulletin of Water Resources, 2006).

Uneven spatial distribution of water between the southern and the northern parts of the country makes the situation even more critical. Northern China, with 64% of total cultivated land (95 million hectare), has only 19% of the nation's water (Ministry of Water Resources, 2004). Water availability per capita is 300 cubic meters, less than one twentieth of the world average (Statistic Bulletin of Water Resources, 2006). Most of Northern China is either arid or semi-arid area. The annual rainfall averages less than 300 mm in Northwest China and 400-600 mm in other parts of Northern China (Feng et al, 1999, Deng et al 2004). Even though the two staple foods in Northern China, wheat and maize, are relatively less water-consuming than rice, the annual precipitation is barely sufficient for these crops. Furthermore, the rainfall concentrates in late summer, leaving the crops relatively dry in winter and spring (Feng et al, 1999, Deng et al, 2004). In short, irrigation is critical to agricultural success in Northern China.

During the last several decades, Northern China has experienced both increasing water demand and decreasing water supply (Wang et al 2005, Huang et al 2006). Gross domestic product in Northern China has increased more than ten times since the 1950s and the gross domestic product in the agricultural sector has increased more than five times (China National Bureau of Statistics 2002). The growing industrial sector and the increase in living standards have both increase water demand (Wang et al 2005). At the same time, the ground water table has fallen dramatically due to overexploitation during the last several decades in Northern China where ground water is the major source of irrigation water (Ministry of Water Resources, World Bank, and AusAID, 2001). From 1958 to 1998, the ground water table dropped by 50 meters in shallow aquifers and by 90 meters in the deep aquifers of the Hai River Basin, which provides water for 92 million people who live in two metropolitan areas, Beijing and Tianjin, and Hebei Province (Ministry of Water Resources, World Bank, and AusAID, 2001, Crook and Diao, 2000).

Despite the scarcity, China’s water resources are poorly managed. The largest water consumer, the agricultural sector, consumes 65% of nation’s water, yet uses irrigation water inefficiently (Wang et al 2005). Irrigation efficiency, an index calculated by dividing the effective amount of water used by a crop by the actual amount of water applied to the crop, is about 0.46 for China, far below the average value of 0.8 among developed countries (Statistic Bulletin of Water Resources, 2006). One reason for the low irrigation efficiency is that water had not been treated as a commodity and had not been priced for agriculture users until the 1970s (Lohmar et al

2003). Even though water began to be priced after the agricultural reform launched in 1978, the price for agriculture users was and is still very low compared to domestic and industrial users (Lohmar et al 2003, Huang et al 2006). More importantly, in most areas agriculture users are charged based on field size rather than on a volumetric basis for water. In short, the water pricing system in the agricultural sector provides little incentive for farmers to conserve water.

In response to the water scarcity problem, the Chinese government has put more effort in increasing the water supply during the past several decades (Lohmar et al 2003, Wang et al 2005). The Chinese government has invested more than USD 100 billion to develop new water resources since the 1950s (Wang, 2000). Most recently, the government recently launched China's South-North Water Transfer Project (*Nan Shui Bei Diao*) to transfer water from the Yangtze River to the Northern China Plain at a cost of more than USD 50 billion (Wang et al, 2005).

Some economists suggest that the government should increase the water price to address the demand side of the water scarcity problem and that increasing water prices is the only effective way for farmers to conserve water (Lomar et al 2003). Huang et al (2006) recently studied the water scarcity problem in Hebei Province, China and found that a price increase would reduce water consumption by farmers and alleviate the scarcity problem. Others, however, argue that water for agriculture is a price inelastic good (Ogg and Gollehon, 1989; Kendy et al 2003b) and increasing water price would only increase revenue for the government with little impact on the consumption of water (Lohmar et al, 2003).

Even if increasing water price alleviated the water scarcity problem, it will not likely be favored in the near future politically. Huang et al (2006) found that, although increasing the price of water decreases water consumption, production of major crops decreases and farmers' net income declines. Net crop income decreases by almost 3.5% when irrigation cost increases by 10%. Worrying about the increasing income gap between urban and rural areas, the Chinese government launched a series of policies to alleviate farmers' burden in recent years. The government cut taxes and fees for agricultural production in 2004 and cancelled all taxes and fees for agricultural production starting Jan 1st 2006. Increasing water prices or taxing water use would create a conflicting image with government efforts to alleviate farmers' burden. In addition, due to the small average plot size in China, installing and maintaining water measurement gates on each field would be very costly. Therefore, government officials believe that promoting water-saving technologies might be a more promising way to address the water scarcity problem in the foreseeable future.

Indeed, the government has already spent 3.5 billion Yuan to promote water saving technologies since 1985 (Zhang et al 2005), but the promotion has not worked well (Lomar et al 2003). The adoption rate for water-saving technologies in Northern China is still low. Blanke et al (2007) and Lomar et al (2003) found that many farmers in Northern China have yet to adopt the most rudimentary water-saving technologies such as border or furrow irrigation, to say nothing of more technically efficient irrigation technologies such as sprinkler and drip irrigation. Although there is a lot of research focusing on water resource problems in China, little is focused on quantitative analysis of the adoption of water-saving land improvement technologies.

The overall goal of this research is to determine what factors influence farmers' decision to use alternative water-saving land improvements. This research will help policy makers have a better understanding of which factors influence the adoption decision and what incentives are needed for farmers to voluntarily adopt water-saving land improvement technologies.

The remainder of the dissertation is organized as follows: in the next section, the definitions of water-saving land improvements analyzed here are provided. Previous empirical studies on adoption of water-saving land improvement technologies most relevant to this analysis are summarized in Chapter Three. This is followed by development of the theoretical model and description of the data sources and variables used in this study. Estimation results of the analysis of the discrete choice of adopting water-saving land improvements are presented in Chapter Six, while Chapter Seven explains the sample selection model and the empirical results explaining farmers' continuous choice of traditional water-saving land improvements. This is followed by conclusions and policy implications.

CHAPTER TWO: WATER-SAVING LAND IMPROVEMENTS

In this study, five water-saving land improvements are addressed: field leveling, use of borders, use of furrows, sprinkler irrigation, and drip irrigation. While focus of this analysis is investments in land where farmers have access to irrigation water, fifteen percent of the sample villages did not have irrigation water. Nonetheless, these land improvements can save water whether a farmer irrigates or relies on rainwater. The benchmark irrigation technology is flood irrigation, the most primitive irrigation technology, in which farmers let water flood the field with no constraints or controls. Five technologies analyzed are more technically efficient than flood irrigation (Deng et al 2004, Yang et al 2003). The five technologies studied here help crops utilize irrigation water or rainwater more efficiently. Field leveling, use of borders, and use of furrows are considered traditional water-saving land improvements while sprinkler irrigation and drip irrigation are defined as modern water-saving land improvements.

Traditional water-saving land improvements are more labor intensive and less capital intensive than modern water-saving land improvements (Yang et al 2003, Berson et al 1981, Negri and Brooks 1990, Lichtenberg, 1985). Farmers who use sprinkler or drip irrigation do not need to develop small ditches to deliver the water from the branch canal to the field, thus these technologies require less labor both initially and for maintenance than traditional irrigation. On the other hand, the capital cost for sprinkler or drip irrigation is higher. Lohmar et al (2003), for example, found that it took 3,000 Yuan per hectare to install sprinklers in China in 2000, while for border or furrow irrigation, capital costs are low.

2.1 Definitions of Water-saving Land Improvements

1. Traditional Water-saving Land Improvements

Field leveling involves farmers using any artificial way to smooth an entire field. Field leveling allows water to be delivered more smoothly and evenly without designing bunds or channels to direct water flow (Blanke et al 2005, 2007). Field leveling in this study does not include laser field leveling, which has a higher water use efficiency than traditional field leveling (Blanke et al 2005, 2007). Deng et al (2004) found that flood irrigation with field leveling can increase water infiltration and reduce soil erosion compared with flood irrigation without field leveling. Li (2002) states that field leveling can improve irrigation uniformity and increase water use efficiency compared to flood irrigation without field leveling.

When using border irrigation, farmers develop different zones in the field separated by raised dirt borders, and irrigate each zone sequentially, rather than flooding the entire field at once (Blanke et al 2005). The objective of border irrigation is to improve irrigation uniformity, decrease irrigation time, and reduce percolation by shortening field length, decreasing field width, and splitting the land into small basins (Hao, 2006). An example of field borders is shown in Figure 2.1.1.

Source: Chinese Academy of Agricultural Science, 2006

Figure 2.1.1: Border Irrigation

When using furrow irrigation, farmers develop furrows, or ditches, close to the crops and use the ditches to deliver water to the crop rather than flooding the whole field (Blanke et al 2005). Furrows are usually 0.5-0.8 meter wide and have shorter lengths in areas with sandy soil in comparison to areas with clay soil due to the difference in water holding capacity (Li, 2002). An example of use of furrows is shown in Figure 2.1.2.

Note that field leveling, use of borders, and use of furrows can be used in fields to improve the utilization of rainwater on non-irrigated land. For example, in plots that are rain-fed, borders or furrows are used to trap rainwater and increase the amount of water available to crops. In addition, use of borders or furrows reduces rainwater losses to infiltration and percolation and improves the land productivity even when no irrigation water is available (Deng et al 2004, Hao, 2006).

Source: Center for Chinese Agricultural Policy, Chinese Academy of Science

Figure 2.1.2: Furrow Irrigation

2 Modern Water-saving Land Improvement

Sprinkler irrigation requires higher pressure to distribute water to the fields. Villages typically need to build a water tower to achieve sufficient pressure for distributing water and install piping networks and sprinkler heads (Blanke et al 2005, 2007). An example of a water tower is shown on the left-hand picture in Figure 2.1.3, and an example of a sprinkler head is shown on the right-hand picture in Figure 2.1.3. Besides these relatively high capital costs, the use of sprinkler irrigation requires field coordination of many farmers because of the small average field size in rural China (Blanke et al 2005, 2007). Therefore, sprinkler irrigation in China is usually adopted by the whole community rather than by individual households (Blanke et al 2005). While common in the United States and other advanced agricultural economies, central-pivot sprinkler irrigation and micro sprinkler irrigation are not common in Northern China and were not utilized by any of the villages of this study.

Source: Center for Chinese Agricultural Policy

Figure 2.1.3: Sprinkler Irrigation

Unlike sprinkler irrigation, drip irrigation does not need high pressure to distribute water. Drip irrigation applies water slowly to the roots of plants through a network of pipes, tubes, and emitters (Hao, 2006). Drip irrigation can precisely and uniformly deliver water to the crop root zone to increase water use efficiency and increase yield (Hao, 2006).

Drip irrigation is more technically efficient than sprinkler irrigation and sprinkler irrigation is more technically efficient than border or furrow irrigation (Deng et al 2004). Researchers have found that sprinkler and drip irrigation not only can increase water use efficiency but also save labor (Zuo, 1997). Because of the higher fixed costs of sprinkler irrigation and drip irrigation, these two technologies are most commonly applied to vegetables and fruits and in greenhouses, as shown in Figure 2.1.4 (Deng et al 2004, Hao, 2006).

Source: Chinese Academy of Agricultural Science, 2006

Figure 2.1.4: Drip Irrigation

2.2 Irrigation Efficiency and Water Use Efficiency

One measure of the technical efficiency of irrigation technologies is called irrigation efficiency. Irrigation efficiency is the effective volume of water used by a crop divided by the actual volume of water applied to the crop (Dickey 1981). The irrigation efficiency for each irrigation technology depends on a variety of factors such as crop choices, soil quality, field slope, and climate. Overall, the irrigation efficiency for border irrigation and furrow irrigation in the western United States is about 0.6. The irrigation efficiency for sprinkler irrigation is about 0.85, and 0.95 for drip irrigation (Dickey, 1981). Evans (2006) provided a range of irrigation efficiency for some irrigation technologies in USA. For example, the irrigation efficiency for furrow irrigation, central pivot sprinkler irrigation, and drip irrigation, ranges from 0.35-0.65, 0.6-0.85, and 0.8-0.98, respectively.

In China, researchers usually use crop water use efficiency (WUE), biological production per cubic meter of applied water (kg/m^3), to measure the efficiency of an irrigation technology. Li (2002) found that after applying border irrigation, the overall crop WUE can be increased to 1.7 kg/m^3 from 1.13 kg/m^3 under flood irrigation, a 50.4% yield increase for the same amount of applied water. Moreover, to achieve a given wheat yield of Y kg/hm^2, the water usage under border irrigation would be 34% less than if flood irrigation was used. The 34% of water saving is calculated as $0.34 = \frac{Y/1.13 - Y/1.7}{Y/1.13} = 1 - \frac{1.13}{1.7}$.

Wang et al (2004) find that changing from flood irrigation to furrow irrigation for winter wheat in Shandong Province can improve crop WUE from 1.51-1.67 kg/m3 to 1.96-1.99 kg/m3, which corresponds to about 30% water saving. Liu et al (2003) found that the WUE of winter wheat under sprinkler irrigation can be increased by

48% compared to border irrigation, which corresponds to water saving of 32% ($32\% = 1 - \frac{1}{1.48}$). Wang et al (2003) found that the WUE under drip irrigation for potato cultivation is 7.72 kg/m^3 compared to only 1.47 kg/m^3 under furrow irrigation, which corresponds to water saving of 81%. Thus, the field research on WUE in China indicates border or furrow irrigation is more technically efficient than flood irrigation, and sprinkler or drip irrigation is more technically efficient than border or furrow irrigation. Although the units of analysis are different, the estimation of water use from water use efficiency used by Chinese researchers is conceptually and empirically consistent with U.S. irrigation efficiency estimates.

2.3 Debate over Water Saving

Some researchers argue that more efficient irrigation technologies do not always save water (Peterson and Ding 2005, Caswell and Zilberman1986). Whether improvements in water use efficiency lead to increases or decreases overall water use depends in part on the size of expanded irrigated land, *ceteris paribus* (Peterson and Ding 2005). If water efficient irrigation encourages a significant increase in irrigation acreage due to the lower cost of effective water, total water use may actually increase. Even holding the irrigation acreages constant, Caswell and Zilberman (1986) find that when switching from traditional irrigation to sprinkler irrigation or drip irrigation, both water use at the field level and the crop yield will increase if the elasticity of marginal product of effective amount of water (EMP) is less than 1 and the well is very deep. However, if the crop yield is kept constant, no matter what value EMP takes or how deep the well is, water saving happens when switching from traditional irrigation to sprinkler irrigation or drip irrigation, all other factors equal.

Other researchers believe that water lost from low efficiency technologies will flow back to shallow aquifers, and suggest that real water saving from implementation of more efficient technology only comes from reducing evapotranspiration loss, which “may not be much” (Kendy et al 2003a). However, for two sample provinces in this study, Inner Mongolia and Henan, the backflow is nearly impossible because most of the irrigated land is well above the water table (Wang et al 2005). In addition, if water is pumped from a deep aquifer, then the water recharge rate is very slow. Since a long time is required for the water to flow back to the deep aquifer, the reduction in evapotranspiration loss is most significant for the dry, hot, and windy areas of China’s Yellow River Basin (Wang et al 2005).

In China, quantitative studies of the irrigation water saving on a whole river-basin are limited (Yang et al 2003). Using data from several experimental sites in the Northern China, Pereira et al (2000) found that the use of more technically efficient irrigation technology will conserve up to 30% of current water use in a river-basin level, if irrigated hectares and yield remain constant.

CHAPTER THREE: LITERATURE REVIEW

In this section, the literature on water-saving land improvements most relevant to this study is summarized, focusing specifically on adoption of the irrigation technologies analyzed in this research. Therefore, most of literature review deals with the adoption of irrigation technology. In most prior studies, irrigation technologies are usually divided into two categories, traditional irrigation such as flood, border, and furrow irrigation, and modern irrigation such as sprinkler and drip irrigation. The major factors affecting farmer choice of water-saving land improvements can be categorized as environmental, institutional, and socio-economic variables.

3.1 Adoption and Environmental Variables

Environmental variables affecting water-saving land improvement technology choice include such things as physical water scarcity, soil characteristics, and climate. Theoretically, there is a positive relationship between physical water scarcity and the adoption of more efficient irrigation technology (Caswell and Zilberman 1986). Previous studies usually use the irrigation water source (ground water or surface water) or the depth of the well to serve as a proxy for the physical scarcity of water resources, and find that the more scarce water is, the more likely farmers will adopt modern irrigation technologies. For example, Caswell and Zilberman (1985) estimated a multinomial logit model to analyze the choice among furrow, sprinkler, and drip irrigation by fruit growers in the Central Valley of California, and found that farmers who apply groundwater are more likely to adopt sprinkler and drip irrigation than farmers who use surface water. Caswell and Zilberman (1986) developed a theoretical model to measure the determinants of the diffusion of drip irrigation and found that there is a greater tendency for farmers in areas with deep wells to use drip irrigation. Schuck et al (2005) found that a drought condition in Colorado is positively related with the adoption of more efficient sprinkler systems relative to gravity systems. Shrestha and Gopalakrishnan (1993) developed a probit model to estimate the choice of drip irrigation in Hawaii's sugar industry and found that farmers who use more groundwater than surface water are more likely to adopt drip irrigation than farmers using more surface water.

Zhou et al (2008) used a logit model to explain the conditions that motivate Chinese farmers to adopt Ground Cover Rice Production System (GCPRS), which can save water in rice production. They found that farmers in villages where irrigation water is abundant and reliable are less likely to adopt GCPRS, but farmers in downstream villages with less abundant water are more likely to adopt GCPRS.

Previous researchers have found a negative relationship between land quality and the adoption of modern irrigation technology. Caswell and Zilberman (1986) report that locations with low land quality are more likely to adopt drip irrigation, whereas locations with high land quality are more likely to use traditional surface irrigation since sprinkler or drip irrigation are land quality-augmenting technologies. In addition, Caswell and Zilberman (1985) note that the light soil with lower water-holding capacity in Kern County, CA explains the high adoption rate of modern irrigation technology. Dinar and Yaron (1990) examine the adoption rate of modern irrigation technology by Israeli citrus growers. Their results show that modern irrigation technologies are more likely to be adopted on light soils, which have low water-holding capacity, than on heavy soils, which have high water-holding capacity. Green et al (1996, 1997) reported that soil permeability is a very important determinant in the adoption of irrigation technology by California farmers. In addition, Lichtenberg (1989) and Negri and Brooks (1990) found a negative relationship between soil quality and the adoption rate of relatively efficient water irrigation technology by U.S. farmers.

Abudulai et al (2005) found that soil characteristics are an important influence on Chinese farmers' adoption of water saving rice production technology. For example, farmers with fields of yellow soil (high water holding capacity) have a lower probability of adopting this technology.

Climate is also an important determinant in the water irrigation technology adoption decision. Negri and Brooks (1990) used census data from thirty U.S. states to estimate farmers adoption of sprinkler irrigation and found that the probability of adopting sprinkler irrigation is positively correlated with total rainfall and negatively correlated with the length of growing season. Dinar and Yaron (1990) found a positive relationship between the adoption of modern irrigation technology and the temperature by Israeli citrus growers. The adoption rate of modern irrigation technology such as drip irrigation is higher in high temperature areas than in low temperature areas.

3.2 Adoption and Institutional Variables

Institutional variables include extension service efforts, government subsidies or loans to adopt new technology, and demonstration projects. Abdulai et al (2005) use a sample of 240 Chinese farm households to measure the determinants of the adoption of water saving technology for rice production. They found that involvement with extension service personal has a positive and significant impact on adoption. The results show that extension service membership raised the probability of adoption about 18-24 percent. In addition, farmers who adopted other production technologies in the last ten years were more likely to also adopt a water saving technology. In another study, Adeoti et al (2007) use a sample of 108 farmers in Ghana to estimate the adoption of treadle pump irrigation and find that the number of extension visits per year has a positive impact on the probability of adoption.

Karami (2006) applied cluster analysis to analyze the choice of irrigation methods with a sample of 460 farmers in Iran. He found that farmers’ capacity to obtain a loan is the major determinant of adopting sprinkler irrigation. In addition, farmers who have access to agricultural information sources that provide information about irrigation methods are more likely to adopt sprinkler irrigation. Brennan (2007) found that the low adoption rate of sprinkler irrigation in Gnangara Mound, Western Australia is due to the insufficient extension regarding water productivity and technology.

Foltz (2003) estimated the adoption of drip irrigation by farmers in Tunisia. He found that farmers who had observed the drip irrigation before are more likely to become the early adopters of drip irrigation, suggesting that demonstration projects can positively influence adoption.

3.3 Adoption and Socio-economic Variables

Socio-economic variables analyzed in previous studies include farm scale, output price, crop choice, water price, cost of other inputs, household income, non-agricultural income, and the level of educational attainment. Shrestha and Gopalakrishnan (1993) developed a model to estimate the choice of drip irrigation in Hawaii’s sugar industry and found that larger field size is positively correlated with drip irrigation adoption. Green et al (1996) used a multinomial logit model to estimate California farmers choices among traditional irrigation technologies (furrow, flood, and border), high pressure sprinkler, and low pressure systems like drip, micro-sprinklers, and fan jets. Their results indicated that farmers who have larger fields are more likely to adopt drip irrigation and less likely to adopt furrow and sprinkler irrigation. Feder and Onchan (1987) studied Thailand farmers adoption of bunding, or borders to allow better water control and moisture retention. They found that farmers are more likely to develop bunds, or borders, on a larger plot than a smaller one.

Previous studies show that output price expectation is positively related to the adoption of modern irrigation technology, with farmers more likely to switch from traditional irrigation to modern irrigation when output price is high. Schaible et al (1991) use modified multinomial logit models to analyze the impacts of commodities price on water irrigation technology transition in the United State's Pacific Northwest. Results show that the ratio of the price of alfalfa to the price of energy, a measure of relative output price, is positively correlated with switching from gravity irrigation to sprinkler irrigation, whereas the ratio of the price of corn to the price of energy has a negative effect on the switching from gravity irrigation to sprinkler irrigation. The authors claim these results are possibly due to alfalfa being a critical feedstock for the regional livestock sector and therefore the price of alfalfa is higher than the price of corn.

Water cost is also positively correlated with the adoption of modern irrigation technology (eg. Caswell and Zilberman 1985). Green et al (1996) found that water prices are positively correlated with the adoption of drip irrigation. That is, farmers in California switch from both furrow and sprinkler irrigation to drip irrigation when the price of water increases. Negri and Brooks (1990) use census data from thirty U.S. states to estimate farmers adoption of sprinkler irrigation and find that the probability of adopting sprinkler irrigation increases as the water price goes up. Dinar and Yaron

(1990) also suggest that increasing water price has a positive impact on the adoption rate of modern irrigation technology by farmers in Israel. However, Green et al (1997) use field level data from California's Central Valley and find that water price has different effects on different crops. Growers of high value citrus crops are more likely to switch to drip irrigation as water price increases while vineyard growers are less sensitive to the water price change.

Costs of other inputs such as labor and capital are also positively related with the adoption of modern irrigation technology. Negri and Brooks (1990) find that farmers in the United States shift from flood irrigation or furrow irrigation to sprinkler irrigation when labor cost is high, likely because gravity irrigation is more labor intensive than sprinkler irrigation (Berson et al 1981). Lichtenberg (1985) finds there is a negative relationship between capital cost and adoption of center pivot technology in Nebraska.

Household income is positively correlated with the adoption of irrigation technologies. Abdulai et al (2005) and Zhou et al (2008) find that household income is positively correlated with the probability of Chinese farmers adoption of water saving rice production technology.

The impact of off-farm income on farmers adoption of land improvements is ambiguous (Templeton and Scherr 1999). When the off-farm income increases, the opportunity cost of agricultural production is higher and farmers are less likely to allocate their labor in agricultural production and conduct land improvements.

Therefore, off-farm income may have a negative impact on farmers' investment in land improvements. For example, Connelly (1994) found that Rusigna farmers abandoned terraces, a labor intensive land improvement, due to the higher labor cost when the opportunity of off-farm income rose. Connelly (1994) stated that terraces help slow the runoff of rainfall during the heavy rains and prevent the soil erosion and hold soil moisture. Zimmerer (1993) also found that Bolivia farmers stop practicing ditches and terraces which help conserve soil because farmers shift their labor from conservation practice to off-farm employment. On the other hand, off-farm income may help farmers who face credit constraints to finance their investment in land improvements. Hence, off-farm income may alternatively also have a positive impact on farmers' investment in land improvements. For example, Clay et al (1998) found that Rwandan farmers are more likely to invest in land improvements such as developing ditches and terraces if off-farm income is higher.

Finally, Schuck et al (2005) found a positive relationship between the level of educational attainment and the adoption of sprinkler irrigation technology by Colorado farmers. Zhou et al (2008) also found that the education attainment has an impact on Chinese farmers adoption of water saving technology. Karami (2006) found that there is a positive relationship between the education and the adoption of sprinkler irrigation by farmers in Iran.

CHAPTER FOUR: THEORETICAL MODEL

The model originates with the model of Caswell and Zilberman (1986). It is developed to analyze representative farmer adoption of alternative strategies to augment the capacity of land to utilize water. The model depicts a profit maximizing choice of how much, if any, land to improve with a particular water-saving method and how much, if any, water to apply on the land. In particular, the model is used to analyze these choices as two simultaneous parts. The discrete choice part of the model is used to analyze a representative farmer's choice of which combination of specific land improvements to make. The continuous choice part of the model is used to analyze the amount land that is improved in accordance under a specific land improvement technology. This is an extension to the model of Caswell and Zilberman (1986), who assume farmers use one major input, irrigation water, to produce. Besides the additional input, land, this analysis also introduces the amount of rainwater and the influence of government extension as exogenous variables, two resource constraints, and a credit constraint. The inclusion of a credit constraint is motivated by Sunding and Zilberman (2001).

4.1 Model Set-up

A. Production Function

A representative farmer uses two major inputs, irrigation water and land, to produce output. The amount of rainwater also contributes to the crop production and it is a perfect substitute for irrigation water. Rainwater, however, is exogenous because the farmer can't control it. The production function is concave, which implies the marginal product of two major inputs is non-increasing, $Q''_{ee} \le 0, Q''_{MM} \le 0$, and also $Q''_{ee}Q''_{MM} - (Q''_{eM})^2 \ge 0$. The production function for the representative crop under technology *j* is given by:

(1)
$$\begin{aligned} f_j &= AQ\{h_j[a_j(\delta) + RF], M_j\} \\ &= AQ(e_j(\delta), M_j) \end{aligned}$$
$$j = (1,2,3,4)$$

Index j represents types of land improvements. $j = 1$ represents no land improvement, $j = 2$ represents field leveling, $j = 3$ represents use of borders or furrows, and $j = 4$ represents sprinkler or drip irrigation. As *j* increases in value, the technology enables farmers and crops to better utilize either irrigation water, rainwater, or both. h_j denotes the water-utilization effectiveness under land improvement *j*, and a_j denotes the actual amount of irrigation water used per hectare for land improvement *j*. Parameter RF denotes the rainwater and e_j denotes the effective amount of water used per hectare for technology *j* given land quality δ. Land quality affects the effective amount of water, either irrigation water or rainwater, via soil characteristics such as soil permeability and water-holding capacity (Caswell and Zilberman 1986, 1990). The second input, land, is represented by variable M_j, the hectare of land for technology *j*. Parameter *A* reflects other exogenous factors, with specific focus on agricultural extension service. Increase in *A*, agricultural extension service, can increase output with a given amount of two major inputs.

In equation (2a), the water-utilization effectiveness, denoted as h_j, is the effective amount of water contributing to crop production, e_j, divided by the actual amount of both irrigation water and rainwater being applied to crop, a_j and RF. Water-utilization effectiveness of technology *j* depends only on land quality (Caswell and Zilberman, 1986). Higher land quality δ leads to higher water-utilization effectiveness, but at a decreasing rate as indicated in inequality (2b). A more advanced technology has a higher water-utilization effectiveness. Mathematically, $h_4(\delta) > h_3(\delta) > h_2(\delta) > h_1(\delta)$, and also assume $h_1(\delta) \equiv \delta$, the quality of land without any land improvements, since the other three types of technologies are water-saving land improvements.

(2a) $$h_j(\delta) = \frac{e_j(\delta)}{a_j(\delta) + RF} \Leftrightarrow e_j(\delta) = h_j(\delta) * [a_j(\delta) + RF]$$

(2b) $$0 < h_j(\delta) < 1, h_{\delta}^{'} > 0, h_{\delta\delta}^{''} < 0.$$

B. Profit Function

The representative farmer's profit is depicted in the equation (3):

(3) $$\pi = \sum_j [pAQ\{h_j[a_j(\delta) + RF], M_j\} - r(\delta)M_j - (k_j + c_j M_j) - w_e * \beta(d) * a_j(\delta)]$$

where *p* represents the output price, assuming the farmer only grows a single crop. It is also assumed that the representative farmer is a price taker in both output and input market given the small scale of Chinese farms. Variable *r* represents the per hectare rental rate of the land, which reflects the opportunity cost of the land. Farmers do not own the land and cannot sell the land but can rent their land to others. The rental rate is a function of the land quality and increases with the land quality. Variable k_j represents the fixed cost while c_j represents the per hectare cost for each land improvement. The fixed cost and the per hectare cost for each technology are assumed to increase with the level of land improvement *j*, therefore $k_1 = 0 < k_2 < k_3 < k_4$, and $c_1 = 0 < c_2 < c_3 < c_4$. For example, the farmer needs the sizable fixed cost to build a water tower to use sprinkler irrigation. The fixed cost for creating borders or furrows is also required but less than the fixed cost for sprinkler or drip irrigation and greater than the fixed cost for field leveling. Also assume that both the fixed cost and the per hectare cost of no land improvement (*j*=1) are zero. Variable $\beta(d)$ represents the amount of electricity required per unit of actual water use. Coefficient w_e denotes the unit price of electricity. By multiplying w_e and $\beta(d)$ and $a_j(\delta)$, the electricity cost of irrigation under technology *j* is obtained. Variable $\beta(d)$ is assumed to increase as the depth to the groundwater table increases, $\beta_d^{'} > 0$. Notice that while only the effective amount of water $e_j(\delta)$ contributes to the production, farmers pay the expense for the actual amount of water $a_j(\delta)$ applied. Water that crops do not use evaporates or flows back to the aquifer. The effective amount of water is the actual amount of water weighted by the irrigation efficiency.

C. Resource Constraints

(4) $$0 \le \sum_j a_j \le \bar{a},$$

(5) $$0 \le \sum_j M_j \le \bar{M},$$

A representative farmer faces two resources constraints, available irrigation water and land. In inequality (4) and (5), $\bar{a}$ and $\overline{M}$ denote the total irrigation water and land endowment of a representative farmer, respectively. a_j and M_j represent the amount of irrigation water and the hectare of land allocated for land improvements, respectively. Note that for farmers in villages without irrigation water, $\bar{a} = 0$. In these villages, farmers are totally dependent on rainwater.

D. Credit Constraint

$$(6) \qquad \sum_j k_j + c_j M_j \leq NAG + \sum_j T_j,$$

A representative farmer may also face a credit constraint. The left hand side of inequality (6) represents the use of funds for the adoption of land improvements, while the right hand side is the sources of funds, namely government subsidies or loans for the water-saving technology T_j, and farmer's non-agricultural income NAG. A representative farmer has, by assumption, no access to credit. Although this assumption seems strong, it is close to the reality in rural China (Cheng, 2006, Tsai, 2004). Farmers seldom get loans from banks since they cannot provide anything as collateral. The biggest asset managed by the farmers, the land, is legally owned by the whole village, not by individual farmers, hence farmers cannot use the land as collateral in China (Cheng, 2006, Tsai, 2004). Hence, a representative farmer faces a credit constraint. For example, when the source of fund is very limited, farmers are unlikely to adopt land improvements which require a sizeable upfront investment.

E. Constrained Profit Maximization

Farmers maximize profit subject to constraints on irrigation water, land, and credit. The constrained profit maximization problem for a representative farmer is this:

$$(7)\,\underset{a_j, M_j}{Max}\{\pi = \sum_j [\,pAQ\{h_j[a_j(\delta) + RF], M_j\} - r(\delta)M_j - (k_j + c_j M_j) - w_e * \beta(d) * a_j(\delta)]\}$$

Subject to $\quad (4)\;\; 0 \le \sum_j a_j \le \bar{a},$

$$(5)\;\; 0 \le \sum_j M_j \le \overline{M},$$

$$(6)\;\; \sum_j k_j + c_j M_j \le NAG + \sum_j T_j,$$

$$\forall j = (1,2,3,4)$$

Hence, equation (7) and its constraint set can be rewritten as:

$$(8) L = \sum_j [pAQ\{h_j[a_j(\delta) + RF], M_j\} - r(\delta)M_j - k_j - c_j M_j - w_e * \beta(d) * a_j(\delta)]$$

$$+ \lambda_w(\bar{a} - \sum_j a_j) + \lambda_m(\overline{M} - \sum_j M_j) + \lambda_c(NAG + \sum_j T_j - \sum_j (k_j + c_j M_j))$$

$$\forall j = (1,2,3,4)$$

The optimal solutions of equation (8) must satisfy the following Kuhn-Tucker conditions (Chiang, 1984).

$$(9)\qquad \frac{\partial L}{\partial a_j} = pAQ'_{e_j} h_j(\delta) - w_e * \beta(d) - \lambda_w \le 0,\ \forall a_j \ge 0, and, \frac{\partial L}{\partial a_j} * a_j = 0$$

$$(10)\qquad \frac{\partial L}{\partial M_j} = pAQ'_{M_j} - r(\delta) - (1 + \lambda_c)c_j - \lambda_m \le 0, \forall M_j \ge 0, and, \frac{\partial L}{\partial M_j} * M_j = 0$$

$$\forall j = (1,2,3,4)$$

4.2 Discrete Choice of Adoption

The representative farmer might adopt only a single technology or a combination of technologies. In light of available data, six mutually exclusive options are relevant to this study: $s=1$ represents no land improvement; $s=2$ represents field leveling only; $s=3$ represents a combination of field leveling and use of borders or furrows; $s=4$ represents use of borders or furrows only; $s=5$ represents a combination of sprinkler or drip irrigation with or without field leveling; and $s=6$ represents a combination of use of borders or furrows, sprinkler or drip irrigation, with or without field leveling. Note that from strategy 2 to 6, farmers may or may not have some land unimproved. Farmers choose the strategy that maximizes profit. Within their constraint set, strategy *s* is chosen when the profit under this strategy π_s^* is the highest among all alternative strategies, that is, if

$$
\begin{aligned}
(11)\qquad & \pi_s^*(a_{s1}^*, M_{s1}^*; a_{s2}^*, M_{s2}^*; a_{s3}^*, M_{s3}^*; a_{s4}^*, M_{s4}^*) \\
& > \pi_{-s}{}^*(a_{-s1}^*, M_{-s1}^*; a_{-s2}^*, M_{-s2}^*; a_{-s3}^*, M_{-s3}^*; a_{-s4}^*, M_{-s4}^*), \\
& s \in (1,2,3,4,5,6)\,; -s \in \text{ not } s
\end{aligned}
$$

4.3 Continuous Choice of Adoption

When the representative farmer chooses the optimal strategy, the actual amount of water used under technology *j* and the optimal amount of land under technology *j* are determined simultaneously. Hence, the factors influencing the optimal choice of land improvement are also the determinants of the optimal amount of land and water under each technology *j*.

From the first order condition of profit maximization:

(12a) $$a_j^* > 0 \Rightarrow pAQ'_{e_j} h_j(\delta) = w_e * \beta(d) + \lambda_w$$

(12b) $$pAQ'_{e_j} h_j(\delta) < w_e * \beta(d) + \lambda_w \Rightarrow a_j^* = 0$$

(13a) $$M_j^* > 0 \Rightarrow pAQ'_{M\ j} = r(\delta) + (1 + \lambda_c)c_j + \lambda_m$$

(13b) $$pAQ'_{M\ j} < r(\delta) + (1 + \lambda_c)c_j + \lambda_m \Rightarrow M_j^* = 0$$

$$\forall j = (1,2,3,4)$$

The left hand side of equations (12a) and (12b) is the value of the marginal product of actual use of water under technology *j* and the right hand side of equations (12a) and (12b) is the marginal cost of actual water under technology *j*, which includes the actual cost that the farmer pays for water, and the shadow value of water, λ_w. According to (12a), if the optimal use of water under technology *j* for the farmer is positive, the value of the marginal product of actual use of water under technology *j* is equal to the marginal cost of actual water under technology *j*. Equation (12b) implies that the optimal use of water under technology *j* for the representative farmer is zero if the value of marginal product of actual water is less than the marginal cost of actual water under technology *j*. Similarly, equation (13a) implies that the optimal amount of land used under technology *j* is positive if the marginal product of land is equal to the marginal cost of land. Equation (13b) implies that if the marginal product of land is less than the marginal cost of land the optimal amount of land used under technology *j* should be zero.

The six strategy options are associated with six different combinations of technology adoption. Maximization of equation (8) across these strategies implies an optimal combination of technology as well as an optimal amount of actual water and land used. When the farmer chooses the profit maximizing strategy, the actual water used under technology *j* and the optimal amount of land under technology *j* are also determined. Hence, the factors influencing the optimal choice of land improvements are the determinants of the optimal amount of land and water under each technology *j*.

For example, if the representative farmer chooses strategy 1 as optimal, he does not apply any land improvement and leave all the land unimproved ($M^*_{1,1} > 0; M^*_{1,2} = M^*_{1,3} = M^*_{1,4} = 0; a^*_{1,1} > 0; a^*_{1,2} = a^*_{1,3} = a^*_{1,4} = 0$). If the farmer chooses strategy 2 as optimal, he also levels a positive amount of land ($M^*_{2,2} > 0$) and applies a positive amount of any available irrigation water to the leveled land ($a^*_{2,2} > 0$). He does not improve land with borders, furrows, sprinkles, or drip tubes ($M^*_{2,3} = M^*_{2,4} = 0; a^*_{2,3} = a^*_{2,4} = 0$). He might cultivate unimproved land ($M^*_{2,1} \geq 0$), and if so, use flooding to irrigate it ($a^*_{2,1} \geq 0$).

If the farmer chooses strategy 3 as optimal, he levels some land ($M^*_{3,2} > 0$), creates borders or furrows on other land ($M^*_{3,3} > 0$), and applies positive amounts of any available irrigation water to these fields ($a^*_{3,2} > 0, a^*_{3,3} > 0$). He does not use sprinkles or drip irrigation at all ($M^*_{3,4} = 0; a^*_{3,4} = 0$). He might cultivate unimproved land ($M^*_{3,1} \geq 0$), and if so, use flooding to irrigate it ($a^*_{3,1} \geq 0$).

If the farmer chooses strategy 4 as optimal, he creates borders or furrows on some land ($M_{4,3}^{*} > 0$) and applies a positive amount of any available irrigation water to the field ($a_{4,3}^{*} > 0$). He does not improve land with field leveling, sprinkle, or drip tubes ($M_{4,2}^{*} = M_{4,4}^{*} = 0; a_{4,2}^{*} = a_{4,4}^{*} = 0$). He might cultivate unimproved land ($M_{4,1}^{*} \geq 0$), and if so, use flooding to irrigate it ($a_{4,1}^{*} \geq 0$).

If the farmer chooses strategy 5 as optimal, he uses sprinkles or drip irrigation on some land ($M_{5,4}^{*} > 0$) and applies a positive amount of any available irrigation water to the field ($a_{5,4}^{*} > 0$). He might or might not level some land ($M_{5,2}^{*} \geq 0$), and applies non-negative amounts of any available irrigation water to these fields ($a_{5,2}^{*} \geq 0$). He does not improve land with borders or furrows ($M_{5,3}^{*} = 0; a_{5,3}^{*} = 0$). He might cultivate unimproved land ($M_{5,1}^{*} \geq 0$), and if so, use flooding to irrigate it ($a_{5,1}^{*} \geq 0$).

If the farmer chooses strategy 6 as optimal, he creates borders or furrows on some land ($M_{6,3}^{*} > 0$), uses sprinkles or drip tubes on other land ($M_{6,4}^{*} > 0$), and applies positive amounts of any available irrigation water to these fields ($a_{6,3}^{*} > 0, a_{6,4}^{*} > 0$). He might or might not level some land ($M_{6,2}^{*} \geq 0$), and applies non-negative amounts of any available irrigation water to these fields ($a_{6,2}^{*} \geq 0$). He might cultivate unimproved land ($M_{6,1}^{*} \geq 0$), and if so, use flooding to irrigate it ($a_{6,1}^{*} \geq 0$). A more straightforward view is presented in Table 4.3.1.

Table 4.3.1: Summary of Strategy Choices and Corresponding Technology Choices

		Discrete Choice	**Continuous Choice**	
Optimal Strategy	Technology Choices (j)	Adoption Criterion	Optimal use of water under strategy s and technology j	Optimal use of land under strategy s and technology j
$s^* = 1$	j=1	$\pi_1^* = \max(\pi_s^*)$ $\forall s = (1,2,3,4,5,6)$	$a_{1,1}^* > 0$, $a_{1,2}^* = a_{1,3}^* = a_{1,4}^* = 0$	$M_{1,1}^* > 0$, $M_{1,2}^* = M_{1,3}^* = M_{1,4}^* = 0$
$s^* = 2$	j=2 and possibly 1	$\pi_2^* = \max(\pi_s^*)$ $\forall s = (1,2,3,4,5,6)$	$a_{2,1}^* \geq 0$, $a_{2,2}^* > 0$, $a_{2,3}^* = a_{2,4}^* = 0$	$M_{2,1}^* \geq 0$, $M_{2,2}^* > 0$, $M_{2,3}^* = M_{2,4}^* = 0$
$s^* = 3$	j=2and 3 and possibly 1	$\pi_3^* = \max(\pi_s^*)$ $\forall s = (1,2,3,4,5,6)$	$a_{3,1}^* \geq 0$, $a_{3,2}^* > 0$, $a_{3,3}^* > 0$, $a_{3,4}^* = 0$	$M_{3,1}^* \geq 0$, $M_{3,2}^* > 0$, $M_{3,3}^* > 0$, $M_{3,4}^* = 0$
$s^* = 4$	j=3 and possibly 1	$\pi_4^* = \max(\pi_s^*)$ $\forall s = (1,2,3,4,5,6)$	$a_{4,1}^* \geq 0$, $a_{4,2}^* = 0$, $a_{4,3}^* > 0$, $a_{4,4}^* = 0$	$M_{4,1}^* \geq 0$, $M_{4,2}^* = 0$, $M_{4,3}^* > 0$ $M_{4,4}^* = 0$
$s^* = 5$	j=4 and possibly 2 or 1 or both	$\pi_5^* = \max(\pi_s^*)$ $\forall s = (1,2,3,4,5,6)$	$a_{5,1}^* \geq 0$, $a_{5,2}^* \geq 0$, $a_{5,3}^* = 0$, $a_{5,4}^* > 0$	$M_{5,1}^* \geq 0$, $M_{5,2}^* \geq 0$, $M_{5,3}^* = 0$, $M_{5,4}^* > 0$
$s^* = 6$	j=3 and 4 and possibly 2 or 1 or both	$\pi_6^* = \max(\pi_s^*)$ $\forall s = (1,2,3,4,5,6)$	$a_{6,1}^* \geq 0$, $a_{6,2}^* \geq 0$, $a_{6,3}^* > 0$, $a_{6,4}^* > 0$	$M_{6,1}^* \geq 0$, $M_{6,2}^* \geq 0$, $M_{6,3}^* > 0$, $M_{6,4}^* > 0$

CHAPTER FIVE: DATA

5.1 Data Sources and Study Area

Most of the data for this study comes from the North China Water Resource Survey (NCWRS), which was conducted in December 2004 and January 2005 by Center for Chinese Agricultural Policy, Chinese Academy of Science. Four hundred and one village leaders in Hebei, Henan, Shaanxi, Shanxi, Inner Mongolia, and Liaoning provinces were interviewed. All sample provinces are located north of the Huai River in Northern China. In addition, climate variables, the average total annual rainfall and the growing season length, were obtained from each county government website.

Sample counties, townships, and villages were selected by a stratified sample selection. All counties in each province were sorted into four water scarcity stratum: mountain or desert, very scarce, somewhat scarce, and normal. These stratums are defined by the percentage of arable land that is irrigated according to the Ministry of Water Resources. ‘Mountain or Desert’, ‘Very Scarce’, ‘Somewhat Scarce’, and ‘Normal’ describe counties where the percentage of irrigated arable land less than 20%, between 21% and 40%, between 41% and 60%, greater than 60% respectively. One to three counties were randomly chosen from each stratum. Then all the townships within each county were sorted according to income level and one township from the counties with income above the median and one township from the counties with income below the median were randomly chosen. Subsequently two villages were randomly chosen from the townships with higher income level and two villages from the townships with lower income level. The total sample size is 6 provinces, 50 counties, 100 townships and 401 villages. Table 5.1.1 reports the detailed sample distribution of this study. Figure 1 shows the map of sample Provinces. The light grey area shows the provinces in Northern China that are not included in the sample and the dark grey area highlights the sampled provinces in Northern China.

Table 5.1.1: Sample Distribution of Data

Code	**Province**	**County**	**Township**	**Village**
1	Hebei	7	14	56
2	Henan	7	14	56
3	Shaanxi	9	18	72
4	Shanxi	9	18	73*
5	Inner-Mongolia	9	18	72
6	Liaoning	9	18	72
	Total	50	100	401

Source: Survey Conducted by Center for Chinese Agricultural Policy

*One additional village was interviewed in Shanxi Province.

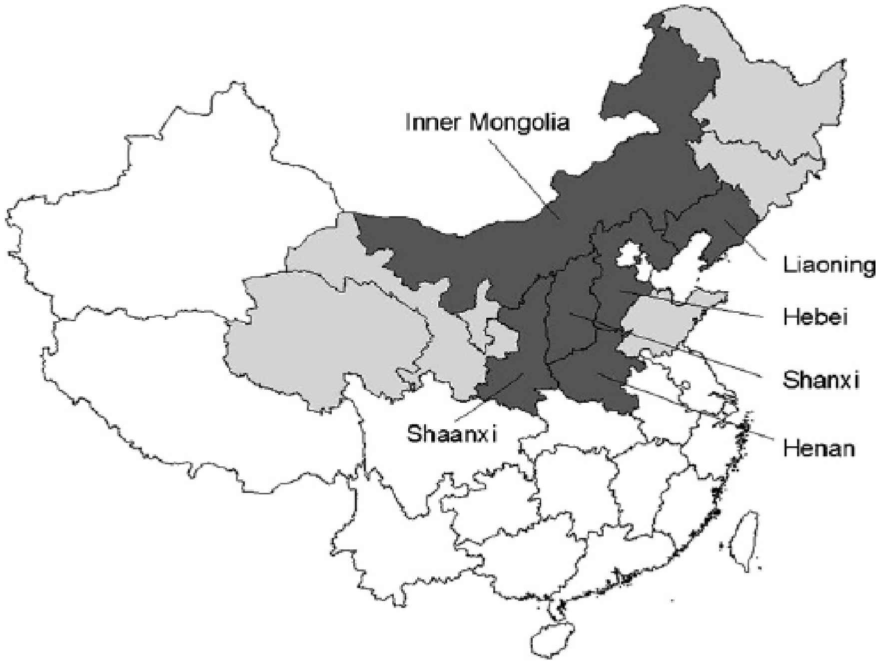

Figure 5.1.1: Spatial Distribution of Sample Provinces

5.2 Definition of Variables

A sixty page survey was designed for interviews with village leaders. The information collected includes social and economic characteristics for each village. These characteristics are broadly categorized here as environmental, institutional, and socio-economic. Three pages of the survey focus on village adoption of water saving technology, including adoption technology and the adoption area of each technology. This information is summarized in section 5.4. Although most of data was collected for both 1995 and 2004 to reflect a time trend, this analysis focuses on the 2004 data because 2004 data is more comprehensive.

Environmental Variables

Key environmental characteristics are water availability, land quality, and climate variables. Water availability is measured by water source, whether or not the village is in an irrigation district, and location of the village relative to a stream.

The dummy variable, GROUNDONLY, is used to measure the physical scarcity of water. This variable takes a value of one if a village has access only to groundwater, and zero if the village has access to surface water or no irrigation water. The dummy variable NOIRRI is used to measure whether a village has access to irrigation water or not. NOIRRI takes a value of one if a village does not have access to irrigation water, and zero if the village has irrigation water. If villages did not irrigate in 2004 or in 1995, they are assumed to not have access to irrigation water. Fifty-four of the 57 villages that didn't have irrigation water in 2004 did not irrigate in 1995 either.

The variable NOTDISTRICT has a value of one if a village is not located in an irrigation district, and zero if not. The variable DOWNSTREAM takes a value of one if a village is located in the downstream of an irrigation district. All water availability variables are used to measure water endowment in villages, hence affect the variable "$\bar{a}$" in the theoretical model.

Soil variables are used to indicate the major soil type in each village. The variable CLAYSOIL takes a value of one if the major soil type is clay soil, and zero if not. The variable LOAMSOIL takes a value of one if the major soil type is loamy soil, and zero if not. The other major soil type in this sample is sandy soil, which has a lower water holding capacity than either clay soil or loamy soil. Loamy soil falls somewhere between sandy soil and clay soil (Natural Resource Conservation Service). These soil characteristics affect the land quality variable "δ" in the theoretical model.

Climate variables consist of the total annual rainfall and growing season length. Total annual rainfall, RAINFALL, is total average rainfall in millimeters per year, representing the variable "RF" in the theoretical model. The length of growing season, GROWSEASON, is the length of time between the last frost free day and the first frost day per year, and affects the variable "A" in the theoretical model. Since this information is not available at the village level, these two variables are constructed using county level data. Data for these two variables was obtained from each county government website.

Institutional Variables

Institutional variables include government extension, government subsidies or loans for water-saving technology, and government demonstration efforts to promote water-saving technologies in a village.

The government extension variable, GOVEXTEN, is a dummy variable that takes a value of one, if agricultural extension service or upper level government officials ever came to a village to promote water-saving technologies in the last three years (from 2001 to 2004). Otherwise GOVEXTEN is zero. The government provision of subsidies or loans, LOANSUB, is a dummy variable and takes a value of one if a village got either a subsidy or a loan from upper level government to adopt any water-saving technologies in the last three years (from 2001 to 2004). If not, LOANSUB takes a value of zero. If a village had a demonstration field to show farmers how to use a water-saving technology in the last three years (from 2001 to 2004), then DEMONSTRATION is one; otherwise it is zero. These three institutional variables are chosen based on previous research and the theoretical model. Farmers who receive help from government extension service or who observe a demonstration of water-saving technology may be able to produce more with a given amount of input. Thus both the government extension and demonstration variables might shift the production function, changing " A " in the theoretical model. Government subsidies or loans, on the other hand, ease the credit constraint on investing new land improvements, thus affect the variable "T" in the credit constraint (inequality (6)) of theoretical model.

Socio-Economic Variables

Socio-economic variables generated from the NCWRS survey include arable land per household, non-agricultural income per household, the depth to the ground water table, electricity price, and the level of education attainment.

Average arable land per household, ARLANDHH, is total arable land in a village divided by total number of farm households[1] in the village. Forest land, orchard land, and pasture land are treated as non-arable land and not included in total amount of arable land in a village. This variable is used to measure the farmer land endowment variable $"\overline{M}"$ in the theoretical model.

Village per capita income was reported by the village leader and includes agricultural net income (total revenue of agricultural production minus total cost of agricultural production) and non-agricultural income. Non-agricultural income per household, NONAGINC, is used to measure farmers' financial ability to invest in new technologies. Credit market does not function very well in rural China and farmers face credit constraints which limit investment in new technology (Cheng, 2006, Tsai, 2004). Non-agricultural income per household is defined as non-agricultural income per capita times total population divided by the total number of farm households in a village. Farmers with higher non-agricultural income are more capable of financing their adoption of new technology, as reflected in the credit constraint of the theoretical model by $"NAG"$.

The depth to the groundwater table, GROUNDTABLE, is the average distance from the surface to the groundwater table in 2004. The greater the depth to groundwater, the higher groundwater pumping cost. The depth to the groundwater table is missing value for villages that don't have irrigation water. Therefore, the interactive term, GROUNDTABLE*IRRI, the depth to the groundwater table times

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[1] Almost all households live in a village are farm households. Few non-farm households live in villages and do not have land.

irrigation dummy is used to proxy water cost for villages that have access to irrigation water. The depth to the groundwater table is used to measure the pumping cost of water and is reflected as the variable "d" in the theoretical model. This cost is not relevant for villages that do not irrigate, thus this variable is zero for those villages.

Electricity price, ELECPRICE, was reported by the village leader and is the cost for pumping water from ground or lifting water from a river or a canal. Electricity cost impacts agricultural productivity and is specified as the variable "w_e" in the theoretical model. The interactive term ELEC*IRRI is used to measure the cost of irrigation since only villages that have access to irrigation water will incur electricity cost for applying irrigation water. While water price would be expected to significantly influence irrigation decisions, within each individual village water price is very heterogeneous. Farmers who use surface water usually pay a water fee based on field size (Yuan/hectare) or irrigation hours (Yuan/hour), while farmers who apply ground water are charged based on irrigation hours (Yuan/hour), volume of electricity, or field size (Yuan/hectare). Thus it is nearly impossible to determine a single water price at the village level, and the water price is not included in the empirical model. Instead electricity price and depth to the groundwater table are used to proxy water cost for villages that have access to irrigation water.

In rural China, few farmers go to college due to financial constraints. Therefore, the percentage of farmers with some middle school education (more than 6 years) in a village, MIDDLEPERC, is used to measure the education level of a village. Farmers with a higher education level may be more productive, all else constant, and educational attainment can be used to control for the parameter "A" in the theoretical model.

Five Provinces dummy variables are used to capture fixed effects between the six Provinces, with Liaoning Province as the base. The definitions of all independent variables are provided in Table 5.2.1.

Table 5.2.1: Definitions of Independent Variables

Independent Variables	Definitions
Environmental Variables	
GROUNDONLY	1=Villages have access only to groundwater; 0=otherwise
NOIRRI	1=Villages don't have irrigation water; 0=otherwise
IRRI	1=Villages have irrigation water; 0=otherwise
DOWNSTREAM	1=In the downstream of an irrigation district; 0=otherwise
NOTDISTRICT	1=Not in an irrigation district; 0=in an irrigation district
LOAMSOIL	1=loamy soil ; 0=others
CLAYSOIL	1=clay soil ; 0=others
RAINFALL	The total average annual rainfall for each county
GROWSEASON	The average length between the last frost day and the first frost day annually for each county
Institutional Variables	
GOVEXTEN	Whether agricultural extension service or the upper level government officials ever came to a village to promote water-saving technologies in the last three year (from 2001 to 2004)
LOANSUB	Whether a village got either a subsidy or a loan from upper level government to adopt water-saving technologies in the last three year (from 2001 to 2004)
DEMONSTRATION	Whether this village has a demonstration field to promote water-saving technologies in the last three year (from 2001 to 2004)
Socio-economic Variables	
ARLANDHH	Total arable land area in a village divide by total number of farm household in a village in 2004
NONAGINC	Non-agricultural Income per household in 2004
GROUNDTABLE	The depth to the ground water table in 2004
GROUNDTABLE*IRRI	The depth to the ground water table times irrigation dummy
ELECPRICE	The price of the electricity in 2004
ELEC*IRRI	The electricity price times irrigation dummy
MIDDLEPERC	Percentage of farmers in the village went to middle school in 2004

5.3 Descriptive Analysis of Variables

Means and variances of all independent variables are reported in Table 5.3.1. Means and variances for all independent variables for the six technology strategies are reported in Table 5.3.2. To test whether there is a difference between the means of independent variables across strategies compared with the base category, the results of paired t-test[2] is also presented in Table 5.3.3. In addition, the expected signs of all independent variables are reported in Table 5.3.3. These expected signs are the simple correlation between the independent variables and dependent variables, whether or not farmers choose a given land improvement strategy. The hypothesis is that there is no difference between the mean of the base strategy and the means of all other strategies.

The descriptive analysis shows that farmers would be less likely to adopt any land improvement strategies when they have no access to irrigation water (NOIRRI=1), but more likely to adopt any land improvements when have access only to groundwater (GROUNONLY=1). Village location variable, DOWNSTREAM, is predicted to have a positive sign except for strategies 5 and 6, while variable RAINFALL is predicted to have a negative sign except strategy 4.

Two institutional variables, GOVEXTEN and DEMONSTRATION, are predicted to have a positive impact on the switching from the base strategy to all other

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[2] $t = \dfrac{\bar{X}_s - \bar{X}_1}{S_{s1} * \sqrt{\dfrac{1}{N_1} + \dfrac{1}{N_s}}}$, $S_{s1} = \sqrt{\dfrac{(N_1 - 1)S_1^2 + (N_s - 1)S_s^2}{N_1 + N_s - 1}}$, $s = 2,3,4,5,6$. Assume the variance is equal across strategies.

land improvement strategies. Farmers are expected to switch from the non-adoption of land improvements to any land improvement strategies when government interventions are involved. Variable LOANSUB is expected to have a positive impact on adoption of strategies 2, 5, and 6.

The means of variable ARALANDHH for strategies 5 and 6 positively and significantly differ from the mean of the base strategy while the means of variable ARALANDHH for strategies 3 and 4 negatively and significantly differ from the mean of the base strategy. Variable ELEC*IRRI is expected to have a positive impact on the adoption of all land improvement strategies, with farmers expected to switch from no-adoption of land improvements to any other strategies when the electricity price is higher. Another variable used to measure water cost, GROUNDTABLE*IRRI, or the depth to groundwater table, is only predicted to have a positive impact on the adoption of strategies 3 and 4.

Table 5.3.1: Descriptions of Independent Variables

Independent Variables	**OBS**	**Mean**	**Std. Dev.**	**Min**	**Max**
Environmental Variables					
GROUNDONLY	401	0.41	0.49	0.00	1.00
NOIRRI	401	0.15	0.36	0.00	1.00
IRRI	401	0.85	0.36	0.00	1.00
DOWNSTREAM	401	0.20	0.40	0.00	1.00
NOTDISTRICT	401	0.63	0.48	0.00	1.00
LOAMSOIL	401	0.16	0.36	0.00	1.00
CLAYSOIL	401	0.44	0.50	0.00	1.00
RAINFALL (mm)	401	596.00	180.69	170.00	959.00
GROWSEASON (days)	401	179.00	40.24	100.00	271.00
Institutional Variables					
GOVEXTEN	401	0.60	0.49	0.00	1.00
LOANSUB	401	0.20	0.40	0.00	1.00
DEMONSTRATION	401	0.24	0.43	0.00	1.00
Socio-economic Variables					
ARALANDHH (Hectare)	401	0.58	0.56	0.05	4.81
NONAGINC (Yuan=$1/7)	401	3493.28	3561.01	0.00	27130.09
GROUNDTABLE (m)	301	33.72	47.57	0.50	480.00
GROUNDTABLE*IRRI (m)	400	26.73	44.74	0	480
ELECPRICE (Yuan=$1/7)	385	0.51	0.17	0.00	1.37
ELEC*IRRI (Yuan=1/$7)	389	0.42	0.23	0.00	1.37
MIDDLEPERC (%)	401	52.59	23.59	0.00	100.00

1. “RAINFALL” and “GROWSEASON” are collected from the website of the county government.

2. “GROUNDONLY”, “NOIRRI”, “GROUNDTABLE”, and three institutional variables are best guesses from village leaders’ professional judgment.

3. All other variables are generated from the information that village leaders were required to report to the upper level government every year.

Table 5.3.2: Descriptions of Independent Variables by Adoption Strategies

	Strategy 6 (N=15)				**Strategy 5 (N=16)**				**Strategy 4 (N=42)**			
Independent Variables	**Mean**	**Std.Dev.**	**Min**	**Max**	**Mean**	**Std.Dev.**	**Min**	**Max**	**Mean**	**Std.Dev.**	**Min**	**Max**
Environmental Variables												
GROUNDONLY	0.40	0.51	0.00	1.00	0.81	0.40	0.00	1.00	0.53	0.50	0.00	1.00
NOIRRI	0.20	0.41	0.00	1.00	0.06	0.25	0.00	1.00	0.02	0.15	0.00	1.00
IRRI	0.80	0.41	0.00	1.00	0.94	0.25	0.00	1.00	0.98	0.15	0.00	1.00
DOWNSTREAM	0.00	0.00	0.00	0.00	0.06	0.25	0.00	1.00	0.21	0.42	0.00	1.00
NOTDISTRICT	0.87	0.35	0.00	1.00	0.88	0.34	0.00	1.00	0.62	0.49	0.00	1.00
LOAMSOIL	0.13	0.35	0.00	1.00	0.38	0.50	0.00	1.00	0.14	0.35	0.00	1.00
CLAYSOIL	0.27	0.46	0.00	1.00	0.13	0.34	0.00	1.00	0.38	0.49	0.00	1.00
RAINFALL	548.43	205.16	225.00	880.00	554.69	134.08	375.00	760.00	632.08	132.82	325.00	958.90
GROWSEASON	168.13	57.14	100.00	271.00	141.25	23.27	100.00	167.00	204.00	35.23	135.00	271.00
Institutional Variables												
GOVEXTEN	0.60	0.51	0.00	1.00	0.94	0.25	0.00	1.00	0.61	0.49	0.00	1.00
LOANSUB	0.40	0.51	0.00	1.00	0.75	0.45	0.00	1.00	0.16	0.37	0.00	1.00
DEMONSTRATION	0.40	0.51	0.00	1.00	0.44	0.51	0.00	1.00	0.26	0.44	0.00	1.00
Socio-economic Variables												
ARLANDHH (Hectare)	1.30	1.28	0.15	4.81	0.93	0.56	0.20	2.06	0.40	0.22	0.05	1.18
NONAGINC (Yuan=1/$7)	3092.19	3223.21	537.39	11684.09	4186.21	3099.01	760.71	11149.84	4045.14	4651.74	66.32	22167.94
GROUNDTABLE (m)	19.21	31.00	1.00	115.00	23.28	46.23	3.00	195.00	34.49	34.58	1.00	300.00
GROUNDTABLE*IRRI	15.43	28.57	0.00	115.00	23.28	46.23	0.00	195.00	39.34	51.23	0.00	300.00
ELECPRICE (Yuan=1/$7)	0.53	0.14	0.32	0.74	0.55	0.11	0.34	0.71	0.50	0.19	0.00	1.37
ELEC*IRRI (Yuan=1/$7)	0.42	0.26	0.32	0.74	0.53	0.17	0.34	0.71	0.48	0.20	0.00	1.37
MIDDLEPERC (%)	44.82	26.21	4.00	97.27	46.68	26.75	10.00	93.00	56.54	22.23	0.00	100.00

Table 5.3.3: Descriptions of Independent Variables by Adoption Strategies (Continued)

	Strategy 3 (N=182)				Strategy 2 (N=87)				Strategy 1 (N=59)			
Independent Variables	**Mean**	**Std.Dev.**	**Min**	**Max**	**Mean**	**Std.Dev.**	**Min**	**Max**	**Mean**	**Std.Dev.**	**Min**	**Max**
Environmental Variables												
GROUNDONLY	0.53	0.50	0.00	1.00	0.24	0.43	0.00	1.00	0.12	0.33	0.00	1.00
NOIRRI	0.04	0.19	0.00	1.00	0.22	0.42	0.00	1.00	0.53	0.50	0.00	1.00
IRRI	0.96	0.19	0.00	1.00	0.78	0.42	0.00	1.00	0.47	0.50	0.00	1.00
DOWNSTREAM	0.20	0.40	0.00	1.00	0.30	0.46	0.00	1.00	0.12	0.33	0.00	1.00
NOTDISTRICT	0.64	0.48	0.00	1.00	0.49	0.50	0.00	1.00	0.71	0.46	0.00	1.00
LOAMSOIL	0.16	0.37	0.00	1.00	0.13	0.33	0.00	1.00	0.10	0.30	0.00	1.00
CLAYSOIL	0.45	0.50	0.00	1.00	0.49	0.50	0.00	1.00	0.49	0.50	0.00	1.00
RAINFALL	588.94	162.88	170.00	958.90	562.72	224.87	170.00	958.90	664.54	177.55	225.00	958.90
GROWSEASON	181.96	34.66	100.00	271.00	168.45	41.64	120.00	257.00	181.02	44.37	120.00	271.00
Institutional Variables												
GOVEXTEN	0.61	0.49	0.00	1.00	0.68	0.47	0.00	1.00	0.32	0.47	0.00	1.00
LOANSUB	0.16	0.37	0.00	1.00	0.21	0.41	0.00	1.00	0.12	0.33	0.00	1.00
DEMONSTRATION	0.26	0.44	0.00	1.00	0.25	0.44	0.00	1.00	0.07	0.25	0.00	1.00
Socio-economic Variables												
ARLANDHH (Hectare)	0.48	0.39	0.05	3.14	0.68	0.58	0.09	2.98	0.59	0.66	0.08	4.44
NONAGINC (Yuan=1/$7)	3542.05	3241.97	0.00	15274.15	3392.07	3936.93	0.00	27130.09	3013.30	3276.03	0.00	16209.38
GROUNDTABLE (m)	34.49	34.58	1.00	300.00	36.57	76.61	0.50	480.00	35.22	53.25	1.00	230.00
GROUNDTABLE*IRRI (m)	29.11	31.30	0.00	153.00	26.34	65.55	0.00	480.00	14.98	38.47	0.00	230.00
ELECPRICE (Yuan=1/$7)	0.49	0.16	0.00	0.95	0.51	0.19	0.00	1.10	0.53	0.16	0.30	0.91
ELEC*IRRI	0.48	0.19	0.00	0.95	0.39	0.25	0.00	0.86	0.24	0.28	0.30	0.90
MIDDLEPERC (%)	56.54	22.23	0.00	100.00	46.14	24.28	0.00	100.00	49.68	24.42	3.20	92.00

Table 5.3.4: Statistics Test of the Means of the Independent Variables across the Strategies

Independent Variables	Predicted Sign	Hypothesis	p-value
Environmental Variables			
GROUNDONLY	+	$\mu_6 > \mu_1$	0.0051***
	+	$\mu_5 > \mu_1$	0.0000***
	+	$\mu_4 > \mu_1$	0.0001***
	+	$\mu_3 > \mu_1$	0.0000***
	+	$\mu_2 > \mu_1$	0.0326**
NOIRRI	-	$\mu_6 < \mu_1$	0.0119**
	-	$\mu_5 < \mu_1$	0.0000***
	-	$\mu_4 < \mu_1$	0.0000***
	-	$\mu_3 < \mu_1$	0.0000***
	-	$\mu_2 < \mu_1$	0.0000***
DOWNSTREAM	na	$\mu_6 > \mu_1$	0.9173
	na	$\mu_5 > \mu_1$	0.7374
	+	$\mu_4 > \mu_1$	0.0991*
	+	$\mu_3 > \mu_1$	0.0724*
	+	$\mu_2 > \mu_1$	0.0052**
NOTDISTRICT	na	$\mu_6 > \mu_1$	0.1130
	+	$\mu_5 > \mu_1$	0.0940*
	na	$\mu_4 > \mu_1$	0.8341
	na	$\mu_3 > \mu_1$	0.8514
	na	$\mu_2 > \mu_1$	0.9957
LOAMSOIL	na	$\mu_6 > \mu_1$	0.3654
	+	$\mu_5 > \mu_1$	0.0039***
	na	$\mu_4 > \mu_1$	0.2667
	na	$\mu_3 > \mu_1$	0.1383
	na	$\mu_2 > \mu_1$	0.3251

*,**,***, represents significant at 10%, 5%, and 1% levels, respectively

Expected signs of switching from the strategy 1 to more efficient land improvement strategies

“+”, “-”, “na” represents the predicted signs are positive, negative, and ambiguous, respectively.

Table 5.3.5: Statistics Test of the Means of the Independent Variables (Continued)

Independent Variables	**Predicted Sign**	**Hypothesis**	**p-value**
CLAYSOIL	-	$\mu_6 < \mu_1$	0.0605*
	-	$\mu_5 < \mu_1$	0.0039***
	na	$\mu_4 < \mu_1$	0.8625
	na	$\mu_3 < \mu_1$	0.2677
	na	$\mu_2 < \mu_1$	0.6692
RAINFALL	-	$\mu_6 < \mu_1$	0.0158**
	-	$\mu_5 < \mu_1$	0.0122**
	na	$\mu_4 < \mu_1$	0.1595
	-	$\mu_3 < \mu_1$	0.0014***
	-	$\mu_2 < \mu_1$	0.0021***
GROWSEASON	na	$\mu_6 > \mu_1$	0.8262
	-	$\mu_5 < \mu_1$	0.0005***
	+	$\mu_4 > \mu_1$	0.0032***
	na	$\mu_3 > \mu_1$	0.4329
	-	$\mu_2 < \mu_1$	0.0418**
Institutional Variables			
GOVEXTEN	+	$\mu_6 > \mu_1$	0.0241**
	+	$\mu_5 > \mu_1$	0.0000***
	+	$\mu_4 > \mu_1$	0.0000***
	+	$\mu_3 > \mu_1$	0.0000***
	+	$\mu_2 > \mu_1$	0.0000***
LOANSUB	+	$\mu_6 > \mu_1$	0.0051***
	+	$\mu_5 > \mu_1$	0.0000***
	na	$\mu_4 > \mu_1$	0.3617
	na	$\mu_3 > \mu_1$	0.1972
	+	$\mu_2 > \mu_1$	0.0835*

*,**,***, represents significant at 10%, 5%, and 1% levels, respectively

Expected signs of switching from the strategy 1 to more efficient land improvement strategies

"+", "-", "na" represents the predicted signs are positive, negative, and ambiguous, respectively.

Table 5.3.6: Statistics Test of the Means of the Independent Variables (Continued)

Independent Variables	**Predicted Sign**	**Hypothesis**	**p-value**
DEMONSTRATION	+	$\mu_6 > \mu_1$	0.0003***
	+	$\mu_5 > \mu_1$	0.0001***
	+	$\mu_4 > \mu_1$	0.0307**
	+	$\mu_3 > \mu_1$	0.0004***
	+	$\mu_2 > \mu_1$	0.0020***
Socio-economic Variables			
ARALANDHH (hectare)	+	$\mu_6 > \mu_1$	0.0017***
	+	$\mu_5 > \mu_1$	0.0311**
	-	$\mu_4 < \mu_1$	0.0449**
	-	$\mu_3 < \mu_1$	0.0703*
	na	$\mu_2 < \mu_1$	0.8074
NONAGINC (Yuan=1/$7)	na	$\mu_6 > \mu_1$	0.4668
	+	$\mu_5 > \mu_1$	0.1016*
	+	$\mu_4 > \mu_1$	0.0968*
	na	$\mu_3 > \mu_1$	0.1393
	na	$\mu_2 > \mu_1$	0.2716
GROUNDTABLE*IRRI	na	$\mu_6 > \mu_1$	0.4832
	na	$\mu_5 > \mu_1$	0.2331
	+	$\mu_4 > \mu_1$	0.0039***
	+	$\mu_3 < \mu_1$	0.0024***
	na	$\mu_2 > \mu_1$	0.1165
ELEC*IRRI	+	$\mu_6 > \mu_1$	0.0177**
	+	$\mu_5 > \mu_1$	0.0001***
	+	$\mu_4 > \mu_1$	0.0000***
	+	$\mu_3 > \mu_1$	0.0000***
	+	$\mu_2 > \mu_1$	0.0009***

*,**,***, represents significant at 10%, 5%, and 1% levels, respectively

Expected signs of switching from the strategy 1 to more efficient land improvement strategies

"+", "-", "na" represents the predicted signs are positive, negative, and ambiguous, respectively.

Table 5.3.7: Statistics Test of the Means of the Independent Variables (Continued)

Independent Variables	**Predicted Sign**	**Hypothesis**	**p-value**
MIDDLEPERC (%)	na	$\mu_6 > \mu_1$	0.6291
	na	$\mu_5 > \mu_1$	0.6652
	+	$\mu_4 > \mu_1$	0.0296**
	+	$\mu_3 > \mu_1$	0.0298**
	na	$\mu_2 > \mu_1$	0.8001
Provincial Dummies			
HEBEI	na	$\mu_6 > \mu_1$	0.2859
	na	$\mu_5 < \mu_1$	0.2311
	+	$\mu_4 > \mu_1$	0.0104***
	+	$\mu_3 > \mu_1$	0.0002***
	na	$\mu_2 < \mu_1$	0.5075
HENAN	na	$\mu_6 > \mu_1$	0.1459
	-	$\mu_5 < \mu_1$	0.0249**
	na	$\mu_4 > \mu_1$	0.4478
	-	$\mu_3 < \mu_1$	0.0910*
	-	$\mu_2 < \mu_1$	0.0076***
SHAANXI	+	$\mu_6 > \mu_1$	0.1098*
	-	$\mu_5 < \mu_1$	0.0249**
	na	$\mu_4 < \mu_1$	0.8864
	na	$\mu_3 < \mu_1$	0.2180
	na	$\mu_2 < \mu_1$	0.4532
SHANXI	-	$\mu_6 < \mu_1$	0.0358**
	na	$\mu_5 < \mu_1$	0.2854
	-	$\mu_4 < \mu_1$	0.1039*
	na	$\mu_3 < \mu_1$	0.6758
	na	$\mu_2 < \mu_1$	0.5532

*,**,***, represents significant at 10%, 5%, and 1% levels, respectively

Expected signs of switching from the strategy 1 to more efficient land improvement strategies

“+”, “-”, “na” represents the predicted signs are positive, negative, and ambiguous, respectively.

Table 5.3.8: Statistics Test of the Means of the Independent Variables (Continued)

Independent Variables	**Predicted Sign**	**Hypothesis**	**p-value**
MONGOLIA	+	$\mu_6 > \mu_1$	0.0020***
	+	$\mu_5 > \mu_1$	0.0499**
	+	$\mu_4 > \mu_1$	0.0263**
	na	$\mu_3 > \mu_1$	0.6164
	+	$\mu_2 > \mu_1$	0.0034***

*,**,***, represents significant at 10%, 5%, and 1% levels, respectively

Expected signs of switching from the strategy 1 to more efficient land improvement strategies

"+", "-", "na" represents the predicted signs are positive, negative, and ambiguous, respectively.

Paired t-test: $$t = \frac{\bar{X}_s - \bar{X}_1}{S_{s1} * \sqrt{\frac{1}{N_1} + \frac{1}{N_s}}}, \quad S_{s1} = \sqrt{\frac{(N_1 - 1)S_1^2 + (N_s - 1)S_s^2}{N_1 + N_s - 1}}, \quad s = 2,3,4,5,6 .$$

Assume the variance is equal across strategies.

5.4 Descriptive Analysis of the Adoption of Water-saving Land Improvements

The adoption rate of five water-saving land improvements is derived from NCWR survey and is reported in Table 5.4.1. The first column reports the percentage of villages where at least one farmer had adopted the specified technology in 2004, and the third column shows the percentage of sown area for which the technology was used. The most popular water-saving land improvements remain the traditional ones. Seventy-three percent of the sample villages used field leveling in 2004, and 49.1% of the sown area employs field leveling. About 74% of the sample villages used either borders or furrows on 45.3% of total sown area.

The use of modern water-saving land improvements is relatively low. The percentage of sample villages adopting sprinkler irrigation and drip irrigation are 7.2% and 1.3%, respectively, and the area for which sprinkler irrigation and drip irrigation are used is only 2.1% and 0.4%, respectively. For comparison, similar village data for 1995 is also summarized in Table 5.4.1. Use of all five water-saving land improvements has increased over the last ten years in the study villages. Adoption rates of sprinkler irrigation and drip irrigation in 2004 are both about three times greater than in 1995.

Table 5.4.1: Distribution of Water-saving Land Improvements in Sample Villages, 2004 and 1995

Technologies	Percent of villages adopting this technology		Percent of sown area for which this technology is used	
	(2004)	**(1995)**	**(2004)**	**(1995)**
Traditional Water-saving Land Improvements				
Field Leveling	73.3	69.6	49.1	46.0
Use of Borders	53.6	50.1	37.6	33.1
Use of Furrows	20.7	17.5	7.7	7.8
Modern Water-saving Land Improvements				
Sprinkler Irrigation	7.2	2.0	2.1	0.6
Drip Irrigation	1.3	0.5	0.4	0.1

Source: Survey Conducted by Center for Chinese Agricultural Policy

Summary statistics for the total adoption area of the five water-saving land improvements in 2004 and in 1995 are reported in Table 5.4.2. The mean adoption area of field leveling is greater than the summation of the mean adoption area of all other four technologies in this sample. Use of borders ranks the second and is also significantly more common than the other technologies except field leveling. Sprinkle and drip irrigation technologies account for only a small portion of cultivated area, although an increasing trend is evident. For five villages that used drip irrigation in 2004, four of them grew greenhouse vegetable, flowers, or grapes. The remaining one grew maize.

So far, the findings have been largely descriptive. In the next chapter, empirical models of the discrete choice of the land improvement strategy will be presented.

Table 5.4.2: Statistical Description of Adoption Area of Water-saving Land Improvements in 2004 and 1995 (Unit: Hectare)

	Mean	**Std. Dev.**	**Min**	**Max**
Technologies (2004)				
Traditional Water-saving Land Improvements				
Field Leveling	99.52	160.68	0.00	1333.33
Use of Borders	59.01	97.87	0.00	580.00
Use of Furrows	15.09	52.05	0.00	466.67
Modern Water-saving Land Improvements				
Sprinkler Irrigation	6.68	50.31	0.00	864.00
Drip Irrigation	1.69	19.26	0.00	240.00
Technologies (1995)				
Traditional Water-saving Land Improvements				
Field Leveling	90.07	148.76	0.00	1443.33
Use of Borders	52.98	89.14	0.00	513.33
Use of Furrows	14.06	50.76	0.00	493.33
Modern Water-saving Land Improvements				
Sprinkler Irrigation	0.97	11.95	0.00	213.33
Drip Irrigation	0.25	3.72	0.00	66.67

Source: Survey Conducted by Center for Chinese Agricultural Policy

CHAPTER SIX: WHETHER FARMERS ADOPT OR NOT?

6.1 Empirical Model: Multinomial Logit Model

This chapter presents an empirical model which is used to estimate the determinants of farmers discrete choice of alternative land improvement strategies. Within an individual village, farmers may choose to adopt more than one land improvement, which means the five technologies analyzed here (field leveling, use of borders, use of furrows, sprinkler irrigation, and drip irrigation) are not mutually exclusive at the household level or even at the field level.

Several different combinations of mutually exclusive choices can be made based on the actual combinations of technologies implemented in the surveyed villages. The absence of any land improvement technologies is defined as strategy one. Adoption of field leveling only is defined as strategy two. Adoption of field leveling and use of borders or furrows is strategy three. Adoption of borders or furrows only is strategy four. Adoption of a combination of sprinkler or drip irrigation and some field leveling is labeled as strategy five, and adoption of a combination of use of borders or furrows, sprinkler or drip irrigation, and some field leveling is strategy six. Table 6.1.1 shows the distribution of these six strategies.

Out of 401 sample villages, 57[3] villages do not have access to irrigation water, either surface water or ground water. Thirty of these villages without irrigation supplies did not adopt any water-saving land improvements, but twenty-seven other

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[3] 54 of the 57 villages that didn’t have irrigation water in 2004 didn’t have irrigation water in 1995 either.

villages without irrigation water did adopt a water-saving land improvement technology to conserve water. These 27 villages used either borders or furrows to trap rainwater in the plot and increase crop yield.

Table 6.1.1: The Distribution of Six Adoption Strategies (N=401)

Strategy	**Field Leveling**	**Border/Furrow**	**Sprinkler/Drip**	**Villages**	**Percentage**
1	0	0	0	59	14.7%
2	1	0	0	87	21.7%
3	1	1	0	182	45.4%
4	0	1	0	42	10.5%
5a	1	0	1	11	2.7%
5b	0	0	1	5	1.2%
6a	1	1	1	14	3.5%
6b	0	1	1	1	0.2%
			Total	**401**	**100%**

*Strategy 1 is the base category, villages (59) that don't use any water-saving land improvements. 30 of them didn't have irrigation water and didn't use any water-saving land improvements. 29 of these had irrigation water but didn't use any water-saving land improvements (or only used flood irrigation). "1" represents villages that adopt a given technology; "0" denotes villages that did not use the technology. Sprinkler and drip irrigation are combined together for convenience. Use of border and use of furrows are also combined together since farmers usually don't apply these two technologies in the same field.

Fifteen villages (Strategy 6.a and 6.b) (3.7%) adopted both traditional water-saving land improvements (use of borders, use of furrows, and field leveling) and modern water-saving land improvements (sprinkler or drip irrigation). Sixteen villages (3.9%) adopted modern water-saving land improvements (sprinkler or drip irrigation) and some field leveling. Forty two villages (10.5%) use borders or furrows exclusively. One hundred and eighty-two villages (45.4%) utilize borders or furrows in combination with field leveling. Eighty seven villages (21.7%) exclusively use field leveling. The fifty-nine villages (14.7%) that do not use any water-saving land improvement represent the base category for this study. The other five strategies (specific technology combination) are all more efficient water application strategies. This research seeks to explain why a specific technology strategy was adopted in a given village.

Since the dependent variable is a discrete adoption strategy with six alternatives, multinomial logit models are used to estimate factors that influence adoption choice. For the ith farmer faced with six strategies, the profit of strategy s can be expressed as

$$\begin{aligned} \pi_{is} &= V(E_{is}, F_{is}, I_{is}) + \varepsilon_{is} \\ &= V(Z_{is}) + \varepsilon_{is} \\ &= \theta_{is} + \beta_{is} Z_{is} \end{aligned} \tag{14}$$

where E_{is} ,is a vector of environmental variables; F_{is} is a vector of socio-economic variables, and I_{is} is a vector of institutional variables for farmer i, and ε_{is} is the error term. To simplify the model, let Z_{is} be a vector that represents all the independent variables E_{is}, F_{is}, and I_{is}. The expected profit function is composed of two terms: the observed term V and the error term ε_{is}. A representative farmer knows his expected profit for each chosen strategy but the researcher does not know expected profit with certainty because the error term ε_{is} is unknown. If the farmer chooses strategy s, then the expected profit π_{is} from making this choice is the greatest one among the six strategies assuming profit maximizing behavior. For example, if the farmer adopts strategy one, then the expected profit from strategy one is greater than the expected profit of any remaining strategies. Mathematically this is expressed

$$\pi_{i1}^{*} > \pi_{it}^{*} \quad \text{for t=all other strategies.}$$

For the researcher, the farmer's choice of the best strategy is probabilistic in the mind. Therefore, the statistical model is driven by the probability that choice S is made is given by

(15) $$\Pr(V_{is} + \varepsilon_{is} > V_{ik} + \varepsilon_{ik}) \quad \text{for} \quad \forall, k \neq s$$

$$= \Pr(\varepsilon_{is} - \varepsilon_{ik} > V_{ik} - V_{is}) = \Pr(\varepsilon_{is} - \varepsilon_{ik} < -V_{ik} + V_{is})$$

It is assumed that error term ε_{is} follows the extreme value distribution, and is identical and independent.

(16) $$f(\varepsilon_{is}) = \exp\{-\varepsilon_{is} - e^{-\varepsilon_{is}}\},$$

Then the cumulative distribution function is

(17) $$F(\varepsilon_{is}) = \exp(-e^{-\varepsilon_{is}})$$

Let Y_i be a random variable that indicates the choice made. Then the probability of farmer *i* choosing strategy *s* is given by

(18) $$\Pr(Y_i = s) = \frac{e^{\theta_{is} + \beta_{is} Z_{is}}}{\sum_{k=1}^{6} e^{\theta_{ik} + \beta_{ik} Z_{ik}}} \qquad (s = 1,2,3,4,5,6)$$

The multinomial logit estimation is a maximum likelihood estimation. The likelihood and log-likelihood function are defined as

(19) $$L = \prod_{i=1}^{n} \prod_{s=1}^{6} (P_{is})^{Y_{is}}$$

(20) $$Ln(L) = \sum_{i=1}^{n} \sum_{s=1}^{6} [Y_{is} * Ln(P_{is})]$$

Y_{is} equals 1 if the farmer i chooses the strategy s and 0 otherwise. P_{is} represents the probability of farmer i choosing strategy s. The estimators of multinomial regression are obtained by taking the first derivative with respect to θ and β.

Marginal Effects

The marginal effects of a continuous variable (Z_{is}) for the six strategy probabilities are given by

(21) $$\frac{\partial P_{is}}{\partial Z_i} = P_{is}(\beta_{is} - \sum_{s=1}^{5} \beta_{is} P_{is}), (s = 1,2,3,4,5,6)$$

where P_{is} $(s = 1,2,3,4,5,6)$ represents the probability of farmer i choosing strategy s.

The marginal effects of change in the vector of a discrete variable (Z_{is}) for six strategy probabilities is given by

(22) $$P_{is}(Z_{is} = 1) - P_{is}(Z_{is} = 0), \quad (s = 1,2,3,4,5,6)$$

The marginal effects reported in this study are the mean of marginal effects rather than the marginal effects at the means.

Test of Independent Irrelevant Alternatives (IIA)

An important assumption for running a multinomial logit model is the concept of Independent Irrelevant Alternatives (IIA). This property requires that the ratio of probabilities of any two alternatives $({P_s}/{p_k})$ is independent of any remaining alternatives (Hausman and Mcfadden, 1984). If this is not true the estimation will be inconsistent (Greene 2003). A Hausman test is used to test this assumption. Hausman's specification test for assumption IIA is given by

(23) $$x^2 = (\beta_s - \beta_f)'[\Omega_s - \Omega_f]^{-1}(\beta_s - \beta_f)$$

where β_s represents the coefficients from the MNL models of the subset of strategies (drop one strategy) while β_f represents the coefficients from the MNL models of the full set of choices. Ω_s and Ω_f are the asymptotic covariance matrices for the subset of strategies and the full set of strategies, respectively.

6.2 Results and Discussions for Multinomial Logit Models

The cross-sectional data described in Chapter Five is used to explain the determinants of farmers' adoption of alternative land improvement strategies. The dependent variable is the discrete choice of one of the six technology strategies. The independent variables include the environmental variables, institutional variables, and socio-economic variables discussed in Chapter Five.

The multinomial logit models were estimated using maximum likelihood procedures. Multinomial logit estimation results with and without fix effects are reported in Table 6.2.2, and Table 6.2.3, respectively. The marginal effects for the model with fixed effects and without fixed effects are reported in Table 6.2.4 and Table 6.2.5, respectively. The estimation result from Table 6.2.2 (with fixed effects) is the preferred model for this analysis. In the model with fixed effects, some province dummies[4] are omitted in strategies 5 and 6 because there are no sample villages in these provinces that adopt these strategies. The DOWNSTREAM dummy is also not included in strategy 6 due to the same reason. The estimation results are robust. In addition, most of the results are consistent with prior expectations and previous studies. These results help to identify the factors influencing farmers' discrete choice of alternative land improvement strategies.

The Hausman test is used to test the assumption of Independent Irrelevant Alternatives (IIA). The Chi square results are reported in Table 6.2.1, suggesting that the null hypothesis[5] of IIA can not be rejected, thus a multinomial logit model is appropriate for this study and the categorization is reasonable. The log-likelihood functions and the pseudo R^2 are used to measure the reliability of the results. The log-likelihood function for strategy adoption under model with fixed effects is -376.78. The likelihood ratio (LR) test for model with fixed effects is 372.85, rejecting the null hypothesis that the independent variables are jointly equal to zero at the significant level less than 1%. The pseudo R^2, a measure of goodness-of-fit, is 0.3310.

The signs and significance of the estimated coefficients are relatively stable across both two models. A positive coefficient indicates that the independent variable induces a farmer to switch from the base category (no adoption of any water-saving land improvement) to one of the other five strategies. A negative coefficient implies that a farmer is less likely to implement one of the other technology strategies relative

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[4] Standard errors are huge if these province dummies are included in strategy 5 and strategy 6.

[5] The null hypothesis is that difference in coefficients between the full model and the partial model is not systematic.

the base category.

Environmental Variables

All environmental variables significantly influence strategy selection. Access only to the groundwater is used to measure the physical water scarcity in this study. Having access only to ground water, GROUNDONLY, has a positive and significant impact on strategies 2, 3, and 5. The positive sign implies that, farmers having access only to ground water are more likely to adopt field leveling only (strategy 2), field leveling and uses of borders or furrows (strategy 3), and a combination of some field leveling and sprinkler or drip irrigation (strategy 5). Farmers having access only to groundwater face a greater water constraint than Farmers having access to surface water. When water becomes less available, *ceteris paribus*, the marginal benefit of water increases, and so does the marginal cost of water. Hence, farmers are more likely to adopt more technically efficient technologies that can conserve water. This positive relationship is consistent with theory. For example, the Hick-Hayami-Ruttan-Binswanger hypothesis holds that an increase in the relative price of a factor induces innovation of technologies that conserve factor use. Previous research (Caswell and Zilberman, 1985, Green et al 1996, 1997) found that farmers who use groundwater are more likely to adopt more efficient irrigation technology. The impact of GROUNDONLY on the adoption of strategy 5 relative to the base strategy is greater than for strategy 2 or 3 relative to the base strategy. This may be because strategy 5 is more technically efficient than strategies 2 and 3. Therefore, farmers are more likely to switch to strategy 5 compared to strategies 2 and 3. However, the impact of GROUNDONLY on the adoption of strategy 3 has the biggest effect. According to the marginal effects reported in Table 6.2.4, the probability of adoption of a combination of use of borders or furrows and field leveling by farmers having access only to groundwater is 24.74% higher than for farmers having access to surface water. The probability of adoption of a combination of modern irrigation and use of borders or furrows and some field leveling by farmers having access only to groundwater is 6.64% higher than for farmers having access to surface water. The groundwater only dummy is not significant in explaining adoption of either strategy 4 or strategy 6.

The dummy variable NOIRRI is used to measure whether or not a village has irrigation water (either surface water or ground water) and is negative and significant for all strategies except strategy 5 and strategy 2. This negative sign suggests that farmers without irrigation water are less likely to adopt most water-saving land improvement strategies. Although field leveling and use of borders or furrows can be applied to fields utilizing rainfall, lack of irrigation water discourages farmers from adopting these technologies. Surprisingly, NOIRRI is positively correlated with the adoption of strategy 5 relative to the base strategy, implying that farmers are more likely to adopt field leveling and sprinkler or drip irrigation relative to the base strategy when there is no irrigation water in the village. This may be because field leveling, which does not require irrigation water to apply, is the dominant technology used in this strategy. According to the marginal effects reported in Table 6.2.4, the probability of adoption of strategy 2, field leveling only, by farmers without access to irrigation water is 10.66% higher than for farmers having access to irrigation water. In contrast, the probability of adoption of strategy 5 by farmers without access to irrigation water is 2.86% lower than for farmers having access to irrigation water

Another variable used to measure water availability, DOWNSTREAM, is positive and significant for strategies 2 and 3. The positive sign implies that famers in villages located downstream of an irrigation district are more likely to switch from non-adoption to field leveling or a combination of traditional water-saving land improvements, relative to farmers in villages located above an irrigation district. This positive relationship coincides with the findings of Zhou et al (2008) in their study of Chinese rice production. Farmers in villages located in the downstream portion of a river, where irrigation water is not abundant and less reliable, were more likely to adopt water-saving irrigation technologies for rice production than farmers in villages close to a river, where irrigation water is abundant and reliable (Zhou et al, 2008). According to the marginal effects reported in Table 6.2.4, the probability of adoption of strategies 2, 3, and 4, by farmers in villages located downstream of an irrigation district is 10.8%, 3.65%, and 2.1% higher than for farmers in villages located upper stream and middle stream of an irrigation district

The variable NOTDISTRICT is positively related to the adoption of strategy 6, a combination of traditional and modern water-saving land improvements. This positive sign implies that farmers in villages that are not located in an irrigation district are more likely to adopt a combination of traditional and modern water-saving land improvements, relative to farmers in villages that are located in the upper or middle stream of an irrigation district. These two findings are consistent with previous studies.

The soil type variable LOAMSOIL is positive and significant in strategy 5. The positive relationship suggests that farmers are more likely to switch from non-adoption to sprinkler or drip irrigation and some field leveling when the major soil type in a village is loamy soil. Another soil type variable CLAYSOIL is negatively correlated with farmers' adoption of strategy 6. This negative sign suggests that farmers are less likely to switch from non-adoption of land improvements to strategy 6 when the major soil type in a village is clay soil. As the water holding capacity increases, the marginal benefit of water decreases, and the marginal cost of water also goes down. Therefore, farmers have less incentive to switch to water-saving land improvements. Prior studies have also found that farmers are more likely to switch to more technically efficient irrigation technology such as drip irrigation if the soil type is sandy soil. This is consistent with the findings in this study. Soil dummies are not significant for strategies 2, 3, and 4. This might be because the soil definition used to classify soils in this study is the major soil type for the whole village rather than for a single plot, hence there may still be significant unmeasured soil variability within villages that strongly influence adoption.

The climate variable RAINFALL is negative and significant in strategy 4, which implies that farmers are less likely to use borders or furrows when rainfall is abundant. When the provincial dummies are excluded (Table 6.2.3), the variable RAINFALL is negatively related with strategies 2, 3, 4, and positively related with strategy 5. As precipitation increases, the amount of water pumped generally decreases because the marginal benefit of pumping additional water decreases. Hence, farmers are less likely to switch to more technically efficient technologies in high rainfall areas. The length of the growing season is positive in strategy 4 and negative in strategy 5. When provincial dummies are not included (Table 6.2.3), variable GROWSEASON is positively related with strategies 2, 3, 4, and negatively related with strategy 5. Negri and Brooks (1990) report that the probability of adopting sprinkler irrigation is positively correlated with total rainfall and negatively correlated with the length of growing season.

Institutional Variables

The influence of government extension is positive and significant for all strategies except strategy 6. Farmers are more likely to adopt water-saving land improvements relative to the base strategy when the government officials visit the village to promote the use of water-saving technologies. Both Abdulai et al (2005) and Zhou et al (2008) have noted that farmers participating in an extension service activity are more likely to adopt water-saving technology for rice production in China. Surprisingly, the government extension variable is not significant in strategy 6, a combination of borders or furrows, sprinkler or drip, and some field leveling.

Government provision of subsidies or loans for water-saving technologies is also positively related to farmers’ adoption of sprinkler or drip irrigation and field leveling (strategy 5). This positive sign implies that farmers are more likely to adopt a combination of modern irrigation and some field leveling when the government provides subsidies or loans to farmers for adoption water-saving technologies. However, government provision of subsidies or loans is negatively related to farmers’ adoption of strategies 3 and 4. This negative relationship may be because the Chinese government has focused more on the promotion of modern irrigation technology rather traditional water saving technologies in recent years. Among the 401 villages in Northern China studied by Blanke et al 2007, the government share of investment in traditional water-saving land improvements was 5% or less, but about 64% for sprinkler irrigation. In addition, the marginal effects reported in Table 6.2.4 also shows the negative relationship between the government provision of subsidies or loans and the probability of adoption of strategies 3 and 4.

The existence of demonstration fields in a village significantly influences all strategies except strategy 5. Farmers are more likely to adopt land improvement strategies if there is a demonstration field in the village from which farmers can learn how to use alternative land improvement technologies. Farmers who received help from government extension service or who observed a demonstration of water-saving technologies may be able to produce more with a given amount of water and land. This suggests that the marginal benefit of adoption of land improvements increases with knowledge and experience, hence increases the likelihood of adoption.

Socio-economic Variables

Arable land per household (ARLANDHH) has a negative impact on the adoption of traditional water-saving land improvement technologies (strategies 2, 3, and 4). These negative signs imply farmers are less likely to switch from non-adoption to traditional water-saving land improvements as arable land per household increases. This negative relationship might be because traditional water-saving land improvements such as use of borders or furrows and field leveling are more labor intensive compared to flood irrigation (Yang et al 2003), thus more expensive (requires more labor) to implement as the amount of arable land per household increases. On the other hand, arable land per household, ARLANDHH, has a positive influence on the adoption of sprinkler or drip irrigation and field leveling. This positive relationship suggests that farmers are more likely to switch from non-adoption to strategy 5 (modern water-saving land improvements and some field leveling) as arable land per household increases. The labor intensity for traditional water-saving land improvements may also explain the insignificance in strategy 6 for arable land per household because strategy 6 includes a combination of some field leveling, borders or furrows, and sprinkler or drip irrigation, which are less labor intensive.

Non-agricultural income per household, NONAGINC, is positively correlated with adoption of a combination of some field leveling, use of borders or furrows, and sprinkler or drip irrigation (strategy 6), which is consistent with previous studies. This result implies that farmers have a propensity to switch from non-adoption to strategy 6 as non-agricultural income rises. During a visit to a Chinese village in 2000, Lohmar et al (2003) found that installing sprinklers in the field costs about 3,000 Yuan per hectare. Although the government was willing to subsidize 1,350 Yuan per hectare to promote sprinkler irrigation, very few farmers adopted sprinkler irrigation because of the additional 1,650 Yuan per hectare cost. Therefore, low income is likely to constrain the use of modern irrigation technologies especially when there are limited or non-existent credit markets in rural China (Tsai, 2004, Cheng 2006, Li and Zhu, 2007). In contrast, non-agricultural income per household is not statistically significant in the adoption of borders or furrows only (strategy 4), borders or furrows and field leveling (strategy 3), and field leveling only (strategy 2). This might be because traditional technologies such as use of borders or furrows and field leveling are less capital intensive (Young et al 2003). In addition, as non-agricultural income increases, the opportunity cost for labor in agricultural labor rises, which increases the labor cost of developing borders and furrows in the fields.

Two economic variables, the depth to the groundwater table and electricity price, are used to measure the cost of pumping groundwater or lifting water from a canal or river. The depth to the groundwater table and the electricity price do not impact farmers in villages without irrigation water. Therefore, the interactive term, GROUNDTABLE*IRRI and ELEC*IRRI, are used to measure the pumping cost for farmers that have access to irrigation water. However, these two water cost variables are not significant in any adoption strategy.

Education level, as measured by the percentage of farmers with some middle school education, did not significantly influence the adoption of land improvements except adoption of borders or furrows (strategy 4) where it is found to have a positive influence. There is no positive relationship between education attainment and the adoption of modern water-saving land improvements, as expected. Foltz (2003) also didn’t find a positive relationship between education and the drip irrigation adoption by farmers in Tunisia. This may be because some middle school education is insufficient to make a difference. Previous studies that found a positive influence of education attainment on irrigation technology adoption are all conducted in developed countries (Schuck et al 2005), where farmers’ education level varies from primary school to college, while in China there are not many farmers with even a high school diploma. Limited variation in farmers’ education level may explain the lack of a significant relationship in this case.

Regional Variables

The base province in this study is Liaoning Province, located in the Northeastern part of China. The positive signs of the coefficients representing regional differences suggest that farmers in Hebei, Henan, Shannxi, and Shanxi Province are more likely to utilize a combination of field leveling, use of borders or furrows than farmers in Liaoning Province. This may be because these four provinces are warmer than Liaoning Province. The negative signs of the coefficients for a strategy show that farmers in Inner-Mongolia Province are less likely to switch from non-adoption to a combination of field leveling and sprinkler or drip irrigation than farmers in Liaoning Province. Province dummies are used to capture fixed effects that are not included in the models, such as temperature, topography, and demographic characteristics.

6.3 Conclusions

The main objective of this study is to find the determinants of farmers' discrete choice of water-saving land improvements in Northern China. Econometric results show that physical water scarcity as measured by villages location in an irrigation district or only having access to groundwater positively impacts on farmers' adoption of water-saving land improvement strategies relative to the base of no land improvement. In contrast, however, the complete lack of irrigation water discourages farmers from adopting water-saving land improvement strategies, even though field leveling, borders, and furrows can be applied in the fields utilizing rainfall. On the other hand, government extension activities to promote water-saving technologies and demonstration projects, positively influence farmers’ adoption of land improvement strategies. Thus government interventions may be needed to promote the adoption of water-saving land improvements. Subsidies or loans from the government also have a positive impact on adoption of sprinkler or drip irrigation. This suggests that government support can hasten the adoption of modern water-saving land improvements.

Farmers in villages that adopt water-saving land improvements may reduce water use in the field and increase water availability for other villages in the river basin. The benefit of increasing the use of water-saving land improvements is often greater than the benefit accruing to the individual farmer or village. When positive externalities exist, individual actions tend to produce less than the socially efficient outcome and government support can increase implementation of more efficient technology, increasing social benefits. As analyzed in this study, this support may be in the form of extension activities, demonstration projects, and subsidies or loans. In particular, modern water-saving land improvements require a sizable upfront investment which may be prohibitive for many farmers due to the absence of a functioning credit market in rural China (Tsai, 2004, Cheng 2006). Government can help address this problem by serving as a lender for rural areas. However, promotion of traditional water-saving land improvements, which are labor intensive, may be less effective for farmers with large arable land per household. Furthermore, labor intensive technologies are likely to become less and less applicable for the foreseeable future due to a widening labor shortage in rural China.

Table 6.2.1: Hausman Test for the Assumption of Independent Irrelevant Alternative

	all_2=partial_2	all_3=partial_3	all_4=partial_4	all_5=partial_5	all_6=partial_6
Drop Strategy 2	NA	chi2(21)=12.89, Prob>chi2=0.9124	chi2(21)=13.48, Prob>chi2=0.8909	chi2(18)=13.41, Prob>chi2=0.7667	chi2(19)=10.32, Prob>chi2=0.9447
Drop Strategy 3	chi2(21)=7.15, Prob>chi2=0.9978	NA	chi2(21)=12.5, Prob>chi2=0.9252	chi2(18)=12.62, Prob>chi2=0.8139	chi2(19)=11.34, Prob>chi2=0.912
Drop Strategy 4	chi2(21)=7.33, Prob>chi2=0.9974	chi2(21)=10.7, Prob>chi2=0.9683	NA	chi2(18)=7.97, Prob>chi2=0.9791	chi2(19)=8.73, Prob>chi2=0.9776
Drop Strategy 5	chi2(21)=6.41, Prob>chi2=0.999	chi2(21)=6.74, Prob>chi2=0.9986	chi2(21)=8.07, Prob>chi2=0.9948	NA	chi2(19)=3.97, Prob>chi2=0.9999
Drop Strategy 6	chi2(21)=8.04, Prob>chi2=0.9950	chi2(21)=9.84, Prob>chi2=0.9809	chi2(21)=8.93, Prob>chi2=0.9897	chi2(18)=23.42, Prob>chi2=0.1748	NA

* 1. The null hypothesis is that difference in coefficients between the full model and the partial model is not systematic. Failing to reject the null hypothesis implies that the assumption of IIA holds and the categorization is appropriate.

2. Hausman's specification test for IIA is $x^2 = (\beta_s - \beta_f)'[\Omega_s - \Omega_f]^{-1}(\beta_s - \beta_f)$. β_s represents the coefficients from the MNL models of the subset strategies(drop one choice) while β_f represents the coefficients from the MNL models of the full set of strategies. Ω_s and Ω_f are the asymptotic covariance matrices for the subset strategies and the full set of strategies, respectively.

Table 6.2.2: Multinomial Logit Model Estimation of Model with Fixed Effects

	Strategy 6	**Strategy 5**	**Strategy 4**	**Strategy 3**	**Strategy 2**
Environmental Variables					
GROUNDONLY	-1.4049	**4.0438*****	0.9110	**1.6110****	**1.0918***
	(1.2382)	(1.7629)	(0.7990)	(0.6537)	(0.6933)
NOIRRI	**-3.1531****	**6.3228***	**-5.5742*****	**-4.3463*****	-1.2648
	(2.1721)	(3.5595)	(1.6504)	(1.1404)	(1.1038)
DOWNSTREAM		1.9454	0.5665	**1.3229****	**1.5827****
		(2.2724)	(0.8525)	(0.6526)	(0.6719)
NOTDISTRICT	**1.8176***	1.7738	0.1209	0.0294	-0.0827
	(1.2136)	(2.0279)	(0.7686)	(0.5769)	(0.6010)
LOAMSOIL	-0.8892	**2.4859***	-0.9256	-0.2437	0.1804
	(1.2718)	(1.5523)	(0.8075)	(0.6395)	(0.6848)
CLAYSOIL	**-1.3933***	-0.5004	-0.7541	0.0464	0.6405
	(0.9434)	(1.3855)	(0.5997)	(0.4581)	(0.4599)
RAINFALL	0.0031	-0.0013	**-0.0054****	0.0001	0.0011
	(0.0048)	(0.0067)	(0.0029)	(0.0022)	(0.0022)
GROWSEASON	-0.0183	**-0.0767*****	**0.0318****	-0.0019	0.0009
	(0.0262)	(0.0288)	(0.0159)	(0.0124)	(0.0122)
Institutional Variables					
GOVEXTEN	0.0626	**4.8228*****	**1.0791****	**1.2111*****	**1.2646*****
	(0.8896)	(1.7324)	(0.5702)	(0.4471)	(0.4565)
LOANSUB	0.5631	**3.4333****	**-1.5807****	**-1.6111*****	-0.8957
	(1.0002)	(1.6774)	(0.7973)	(0.6339)	(0.6340)
DEMONSTRATE	**3.0006*****	0.6210	**1.4787***	**1.6298****	**1.3678***
	(1.1091)	(1.2209)	(0.8466)	(0.7287)	(0.7326)
Socio-economic Variables					
ARLANDHH	0.0328	**0.1295****	**-0.1544****	**-0.0815****	**-0.0810****
	(0.0401)	(0.0724)	(0.0738)	(0.0368)	(0.0370)
NONAGINC	**0.0002****	0.0001	0.0001	0.0001	0.0000
	(0.0001)	(0.0002)	(0.0001)	(0.0001)	(0.0001)
GROUNDTABLE*IRRI	0.0143	0.0093	0.0102	0.0006	0.0036
	(0.0120)	(0.0127)	(0.0064)	(0.0057)	(0.0049)
ELEC*IRRI	-1.1863	5.2310	-2.5075	-1.6868	-0.5206
	(3.1262)	(4.3666)	(1.9861)	(1.6712)	(1.7409)
MIDDLEPERC	0.0123	0.0099	**0.0181***	0.0073	-0.0139
	(0.0171)	(0.0187)	(0.0117)	(0.0089)	(0.0092)
Provincial Dummies					
HEBEI	**5.8853*****		1.5799	**4.4853*****	2.4534
	(2.3985)		(1.6583)	(1.4776)	(1.5846)
HENAN	**6.7732*****		-0.0340	**2.1618****	0.3119
	(2.2566)		(1.5406)	(1.1951)	(1.2157)
SHAANXI	2.2090		-0.3115	**2.1144****	1.4005
	(2.5936)		(1.4298)	(1.1568)	(1.1920)
SHANXI		-2.9179	-1.5104	**1.8390****	**1.5769***
		(2.2806)	(1.2603)	(0.8702)	(0.8730)
MONGOLIA	**3.7884***	**-7.4044***	-1.2161	1.3451	**2.6389****
	(2.5347)	(3.1391)	(1.6785)	(1.1107)	(1.1494)
Intercept	-5.5959	-2.2218	-1.3223	0.2232	-1.3321
	(5.8914)	(7.3328)	(3.0995)	(2.2839)	(2.3212)

Base Category: No-adoption of any land improvements

*,**,***, represents significant at 10%, 5%, and 1%, respectively. Standard errors are reported in parentheses

Log-Likelihood=-376.78; LR chi2(100) = 372.85, Prob > chi2 = 0.0000.

Pseudo R2 = 0.3310

Table 6.2.3: Multinomial Logit Model Estimation of Model without Fixed Effects

	Strategy 6	**Strategy 5**	**Strategy 4**	**Strategy 3**	**Strategy 2**
Environmental Variables					
GROUNDONLY	-0.0093	**5.0189*** **	**1.1670***	**1.7248*** **	0.6722
	(1.0276)	(1.6530)	(0.7483)	(0.6104)	(0.6462)
NOIRRI	-0.7190	2.3896	**-5.1010*** **	**-3.8524*** **	-1.1347
	(1.7427)	(2.6994)	(1.5233)	(1.0381)	(1.0184)
DOWNSTREAM		1.9857	0.8986	1.1125	**1.3973** **
		(1.8035)	(0.8187)	(0.6373)	(0.6543)
NOTDISTRICT	1.0108	0.5742	-0.0266	-0.0560	-0.0601
	(1.0783)	(1.4881)	(0.7430)	(0.5500)	(0.5643)
LOAMSOIL	-1.0296	**2.0166***	-0.9342	-0.4944	-0.1255
	(1.2387)	(1.1484)	(0.7866)	(0.6161)	(0.6600)
CLAYSOIL	-0.4131	-0.1723	-0.7583	-0.0465	0.3770
	(0.7709)	(1.1246)	(0.5686)	(0.4345)	(0.4419)
RAINFALL	-0.0031	**0.0114** **	**-0.0042*** **	**-0.0034** **	**-0.0026** **
	(0.0030)	(0.0049)	(0.0021)	(0.0015)	(0.0016)
GROWSEASON	0.0144	**-0.0354** **	**0.0391*** **	**0.0186*** **	0.0048
	(0.0121)	(0.0157)	(0.0088)	(0.0064)	(0.0064)
Institutional Variables					
GOVEXTEN	0.4472	**3.4790*** **	**1.2360** **	**1.2617*** **	**1.3881*** **
	(0.8048)	(1.3577)	(0.5474)	(0.4280)	(0.4373)
LOANSUB	0.3341	**2.1966** **	**-1.5041** **	**-1.4362** **	-0.7319
	(0.9050)	(1.1730)	(0.7565)	(0.5962)	(0.6140)
DEMONSTRATE	**1.9080*** **	0.9086	**1.2602***	**1.4164** **	**1.1845***
	(0.9566)	(1.0546)	(0.8271)	(0.7114)	(0.7209)
Socio-economic Variables					
ARLANDHH	0.0310	0.0789	**-0.1216** **	**-0.0974*** **	**-0.0634** **
	(0.0306)	(0.0554)	(0.0607)	(0.0317)	(0.0317)
NONAGINC	0.0001	0.0001	0.0001	0.0000	0.0000
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
GROUNDTABLE*IRRI	-0.0005	0.0125	0.0088	0.0022	0.0039
	(0.0109)	(0.0095)	(0.0060)	(0.0054)	(0.0049)
ELEC*IRRI	0.7078	1.4460	-1.9035	-1.4318	-0.2505
	(2.5720)	(3.5302)	(1.8849)	(1.5987)	(1.7015)
MIDDLEPERC	0.0022	0.0095	**0.0181***	0.0071	**-0.0143***
	(0.0150)	(0.0176)	(0.0115)	(0.0086)	(0.0089)
Intercept	**-4.1323***	**-13.3952** **	**-4.4718** **	0.4646	1.6578
	(2.5414)	(5.7782)	(2.0994)	(1.5247)	(1.5534)

Base Category: No-adoption of any land improvements

*,**,***, represents significant at 10%, 5%, and 1%, respectively. Standard errors are reported in parentheses

This scenario does not include the provincial dummies.

Log-likelihood= -410.79; LR chi2(79) = 304.84, Prob > chi2= 0.0000.

Pseudo R2 = 0.2706.

Table 6.2.4: Marginal Effects for Model with Fixed Effects

	$\frac{\partial P_6}{\partial Z_i}$	$\frac{\partial P_5}{\partial Z_i}$	$\frac{\partial P_4}{\partial Z_i}$	$\frac{\partial P_3}{\partial Z_i}$	$\frac{\partial P_2}{\partial Z_i}$	$\frac{\partial P_1}{\partial Z_i}$
GROUNDONLY (1,0)	-0.0093	0.0664	0.0127	0.2474	-0.1334	-0.1837
NOIRRI(1,0)	0.0146	-0.0299	-0.1035	-0.4178	0.1193	0.4172
DOWNSTREAM (1,0)	-0.0326	-0.0346	0.0210	0.0365	0.1080	-0.0983
NOTDISTRICT (1,0)	0.0335	0.0415	-0.0199	-0.0110	-0.0961	0.0521
LOAMSOIL (1,0)	-0.0222	0.0731	0.0004	0.0424	-0.0397	-0.0541
CLAYSOIL (1,0)	-0.0223	-0.0525	-0.0264	0.0119	0.0623	0.0271
RAINFAL (mm)	0.0005	0.0001	-0.0010	0.0003	0.0001	0.0000
GROWSEASON (Days)	0.0002	-0.0118	0.0120	-0.0008	0.0002	0.0002
GOVEXTEN (1,0)	0.0079	0.0592	-0.0065	0.0508	0.0616	-0.1730
LOANSUB (1,0)	0.0522	0.1430	-0.0314	-0.0927	0.0020	-0.0731
DEMONSTRATION(1,0)	0.0390	0.0466	-0.0198	0.0830	0.0034	-0.1522
ARLANDHH (Hectare)	0.0038	0.0288	-0.0329	0.0004	-0.0009	0.0009
NONAGINC (1000 Yuan)	0.0117	-0.0002	-0.0054	-0.0019	-0.0014	-0.0028
GROUNDTABLE	0.0005	-0.0002	0.0006	-0.0007	0.0543	-0.0002
ELEC*IRRI (1 Yuan)	0.0010	0.0011	-0.0775	-0.2194	0.1928	0.1019
MIDDLEPERC (%)	0.0001	-0.0005	0.0018	-0.0006	-0.0005	-0.0003
HEBEI	-0.0209	-0.0359	0.0282	0.3704	-0.1767	-0.1652
HENAN	0.0656	-0.0453	0.0523	-0.0441	-0.1104	0.0819
SHAANXI	-0.0269	-0.0480	0.0807	-0.0679	0.0407	0.0215
SHANXI	-0.0424	-0.0170	-0.0595	0.0866	0.0329	-0.0005
INNER-MONGOLIA	0.0675	0.0429	-0.1054	-0.1692	0.1959	-0.0317

Base Category: Non-adoption of any land improvements (P1)

Table 6.2.5: Marginal Effects for Model without Fixed Effects

	$\frac{\partial P_6}{\partial Z_i}$	$\frac{\partial P_5}{\partial Z_i}$	$\frac{\partial P_4}{\partial Z_i}$	$\frac{\partial P_3}{\partial Z_i}$	$\frac{\partial P_2}{\partial Z_i}$	$\frac{\partial P_1}{\partial Z_i}$
GROUNDONLY (1,0)	-0.0279	0.0116	-0.0064	0.2612	-0.1344	-0.1042
NOIRRI(1,0)	0.0397	0.0448	-0.0960	-0.5485	0.2282	0.3319
DOWNSTREAM (1,0)	-0.0193	0.0017	-0.0124	0.0170	0.0855	-0.0726
NOTDISTRICT (1,0)	0.0222	0.0008	0.0000	-0.0169	-0.0084	0.0023
LOAMSOIL (1,0)	-0.0127	0.0097	-0.0336	-0.0671	0.0658	0.0379
CLAYSOIL (1,0)	-0.0097	-0.0002	-0.0533	-0.0297	0.0936	-0.0006
RAINFAL (mm)	0.0000	0.0000	-0.0001	-0.0003	0.0001	0.0003
GROWSEASON (Days)	0.0000	-0.0001	0.0017	0.0021	-0.0025	-0.0013
GOVEXTEN (1,0)	-0.0176	0.0033	0.0067	0.0663	0.0590	-0.1176
LOANSUB (1,0)	0.0489	0.0169	-0.0316	-0.2197	0.0652	0.1204
DEMONSTRATION(1,0)	0.0183	-0.0005	-0.0004	0.0877	-0.0194	-0.0858
ARLANDHH (Hectare)	0.0026	0.0002	-0.0031	-0.0106	0.0038	0.0071
NONAGINC (1000 Yuan)	0.0029	0.0002	0.0050	0.0019	-0.0085	-0.0014
GROUNDTABLE	-0.0001	0.0000	0.0004	-0.0004	0.0003	-0.0003
ELEC*IRRI (1 Yuan)	0.0405	0.0035	-0.0658	-0.2502	0.1831	0.0890
MIDDLEPERC (%)	0.0000	0.0000	0.0012	0.0030	-0.0040	-0.0002

Base Category: Non-adoption of any land improvements (P1)

CHAPTER SEVEN: HOW MUCH DO FARMERS ADOPT?

7.1 Research Method: Sample Selection Model

In this section, the continuous choice of farmers' adoption of land improvements will be analyzed using the sample selection model proposed by Dubin and McFadden (1984). Six mutually exclusive technology strategies were delineated and explained in Chapter Six. They are a combination of use of borders or furrows, sprinkler or drip irrigation, and some field leveling (strategy 6), a combination of sprinkler or drip irrigation and some field leveling (strategy 5), use of borders or furrows only (strategy 4), a combination of field leveling and use of borders or furrows (strategy 3), field leveling only (strategy 2), and no land improvement (strategy 1).

Dubin and McFadden (1984) expanded Heckman's sample selection model and proposed a methodology to estimate a discrete-continuous choice model when the selection model is a multinomial logit model. The first stage of Dubin and McFadden (DM) model is a multinomial logit model of the discrete choice similar to the model estimated in Chapter 6. The second stage of the DM model is an OLS regression with sample selection correction terms which are generated from the estimated first stage multinomial logit model.

In this study, farmers in 87 sample villages choose strategy 2 (field leveling only). If farmers in villages choosing other strategies are hypothetically included to generalize the sample and the optimal amount of land leveled by farmers in all 401 villages is of concern to the researcher, the OLS regression may generate sample selection bias. Farmers land allocation decision for a land improvement technology is conditional on the choice of a strategy. The error term in OLS model may be correlated with the error term in the first stage, the choice model. OLS regressions ignore this correlation and may generate sample selection bias (Heckman 1979, Dubin and McFadden 1984), hence the sample selection model is used to produce unbiased estimates of the factors influencing the optimal amount of land on improvements. However, if the researcher is only concerned about the optimal amount of land leveled by farmers in these 87 villages, the OLS regression is appropriate.

In this study, the adoption extent of land improvements for the farmer i is estimated by OLS regression with selection correction terms suggested by Dubin and McFadden (1984).

$$Y_i = x_i^{'}\beta + \gamma_j \left(\sum_{j \neq i} \frac{P_j \ln P_j}{1 - P_j} + \ln P_i\right) + u_i \tag{24}$$

$$u_i \sim N(0,1),$$

where Y_i represents the true value of the adoption hectare per household of land improvements in the chosen technology strategy. $x_i^{'}$ is a vector of environmental, socio-economic, and institutional variables for the village i. u_i denotes the error term and follows the normal distribution $(0,1)$. P_i is the probability of the chosen strategy i while P_j is the probability of selecting an alternative strategy ($j \neq i$) as estimated in Chapter Six. $\sum_{j \neq i} \frac{P_j \ln P_j}{1 - P_j} + \ln P_i$ is the sample selection correction term. γ_j is the estimate of the sample selection correction term. If the null hypothesis that γ_j equals zero is not rejected, there is no significant sample selection bias in the continuous choice of land improvements. Hence OLS regression without sample selection terms would be unbiased (Dubin and McFadden, 1984).

Cross sectional data is used to estimate the determinants of the amount of land using each land improvement technology. There are too few observations in strategies 5 and 6 (16 and 15 observations respectively) for OLS regression to be estimated. Strategy 1 is the base of no adoption of any water-saving land improvements, the continuous choice of farmers choosing strategy 1 also is not presented. Therefore, the continuous choices of farmers who adopt only field leveling ($s=2$), use borders or furrows and level their field ($s=3$), and only use borders or furrows ($s=4$) are estimated here using OLS regression with sample selection terms.

Sample Selection Model for Strategy Two and Strategy Four:

The dependent variable in the continuous choice of DM model for farmers only adopting field leveling (strategy 2) is estimated on a per household basis. For strategy 4, OLS regression with sample selection terms are used to estimate the adoption extent of borders and furrows. The dependent variable for strategy 4 is the area per household of land on which farmers use borders or furrows.

Sample Selection Model for Strategy Three

Seemingly unrelated regression is used to estimate the adoption extent of strategy 3 since there might be a correlation between the extent of adopting two types of land improvements utilized in strategy 3. Sample selection terms are also included in the estimated models.

(25) $$Y_{1i} = x_{1i}'\beta_1 + \gamma_j\left(\sum_{j \neq i} \frac{P_j \ln P_j}{1-P_j} + \ln P_i\right) + u_{1i}$$

(26) $$Y_{2i} = x_{2i}'\beta_2 + \gamma_j\left(\sum_{j \neq i} \frac{P_j \ln P_j}{1-P_j} + \ln P_i\right) + u_{2i}$$

$$\begin{pmatrix} u_{1i} \\ u_{2i} \end{pmatrix} \sim N_2 \begin{pmatrix} \sigma_{11}, \sigma_{12} \\ \sigma_{21}, \sigma_{22} \end{pmatrix} \otimes \begin{pmatrix} 1,0 \\ 0,1 \end{pmatrix}$$

These two equations are estimated simultaneously, allowing for cross equation error correlation correction. Y_{1i} represents the adoption hectare per household of borders and furrows while Y_{2i} denotes the adoption hectare per household of field leveling.

Independent variables are again categorized as environmental variables, institutional variables, and socio-economic variables as before. Means of adoption hectare per household for each technology in each of the six strategies are summarized in Table 7.1.1. The definitions of independent variables are reported in Table 5.2.1, and the means and variances of independent variables are reported in Table 5.3.1.

Table 7.1.1: Descriptions of Adoption Area per Household by Six Strategies (Unit: Hectare)

Land Improvement Strategy	Sample Villages	Field Leveling	Border/Furrow	Sprinkler/Drip
1	59	0	0	0
2	87	0.44	0	0
3	182	0.32	0.35	0
4	42	0	0.31	0
5	16	0.35	0	0.39
6	15	0.59	0.42	0.17

7.2 Results and Discussions for Sample Selection Models and OLS Regressions

For comparison, both OLS regression with sample selection terms and without sample selection terms are estimated and the results of both models are reported. Table 7.2.1 lists the results for strategy 2, field leveling. Seemingly unrelated regressions of strategy 3 with selection terms and without selection terms are shown in Table 7.2.2, and Table 7.2.3, respectively. Table 7.2.4 reports the estimated results of OLS with and without sample selection terms for strategy 4. To check whether the estimation results are robust or not, sensitivity analysis is also applied and three models are presented in each Table. Most of results reported here are based on model one. An overall F-test is applied to test whether the coefficients of all independent variables are jointly different from zero and the results are reported in each table.

None of the coefficients of the sample selection terms in the OLS regression are significantly different from zero in strategy 4, which implies there is no selection bias (Dubin and McFadden, 1984). In both strategy 2 and strategy 3, the coefficients of the sample selection term for farmers adopting strategy 6 are significantly different from zero. However, the coefficients of OLS regressions with selection terms and without selection terms are similar in significance and in magnitude.

Results and Discussions for Environmental Variables

Among the eight environmental variables, only two, DOWNSTREAM and RAINFALL, are significantly related with adoption extent of strategy 2 in the OLS regression without selection terms. On the adoption extent of use of borders or furrows and field leveling in strategy 3 without selection terms, only the RAINFALL variable is significant. NOIRRI and RAINFALL are significant in strategy 3 without selection terms. On the adoption extent of borders or furrows in strategy 4 in OLS without sample selection terms, DOWNSTREAM and LOAMSOIL are significant.

The DOWNSTREAM dummy is positively related to the adoption extent of field leveling in strategy 2 and use of borders or furrows in strategy 4. The positive signs imply that farmers in villages located in the downstream portion of an irrigation district adopt field leveling on more land than farmers in villages located in the upper or middle-stream of an irrigation district. The adoption area for field leveling increases 0.2845 hectare (model 1) if farmers in villages located in the downstream of an irrigation district. The adoption area for use of borders or furrows increases 0.2557 hectare (model 1) if villages located in the downstream of an irrigation district. DOWNSTREAM is used to measure water availability of villages. The positive sign is expected and consistent with prior studies since farmers are more likely to adopt more efficient technologies on more land when water is less available (Zhou et al 2008). Surprisingly, DOWNSTREAM dummy is not significant in the adoption extent of strategy 3.

The dummy variable LOAMSOIL is positive and significant in strategy 4. This positive relationship implies that, for famers in 42 villages that only use borders or furrows, the adoption extent is higher if the major soil type in a village is loamy soil than sandy soil. Water holding capacity for loamy soil is between sandy soil and clay soil. Farmers in villages whose major soil type is loamy soil adopt 0.2612 hectare more in use of borders or furrows than farmers in villages whose major soil type is sandy soil holding other factors constant.

RAINFALL is negative and significant for the adoption extent of field leveling in strategy 2, and use of borders or furrows and field leveling in strategy 3. This negative relationship suggests that higher rainfall is correlated with lower adoption extent of traditional water-saving land improvements. The negative sign is also consistent with previous studies. Farmers reduce the area of water-saving land improvements as water becomes less scarce, and if they do adopt, they will do so to a lesser extent than farmers facing less rainfall. The adoption area for field leveling and use of borders or furrows decreases 0.05 hectare if the annual rainfall increases 100 mm.

The dummy variable GROUNDONLY is not significant in the adoption extent of any of these three strategies. GROUNDONLY, a measure of physical water scarcity, has a positive impact on the probability of adoption but no impact on the adoption extent of land improvements.

Results and Discussions for Institutional Variables

Among the three institutional variables, DEMONSTRATION is significant in strategy 2. On the adoption extent of strategies 3 and 4, LOANSUB is positive and significant.

The insignificance of government extension service and subsidies or loans in the adoption extent of field leveling is likely due to the recent focus of government extension service and subsidies or loans on modern water-saving land improvements, rather than the traditional water-saving land improvements. Government extension service has a negative impact on the adoption extent of borders or furrows in strategy 3, a traditional water-saving land improvement strategy.

The variable LOANSUB is positive and significant with the adoption extent of strategies 3 and 4. These positive signs imply that for farmers adopt strategies 3 and 4, the adoption extent of use of borders or furrows and field leveling is greater if they got subsidies or loans from government. The adoption area for use of borders or furrows and field leveling in strategy 3 increases 0.13 and 0.07 hectare, respectively, if farmers got subsidies or loans from the government. The adoption area for use of borders or furrows in strategy 4 increases 0.26 hectare if farmers got subsidies or loans from the government.

Presence of a demonstration field is positive and significantly related to the adoption extent of field leveling. The adoption extent of field leveling in strategy 2 will increase by 0.1462 hectare if a demonstration field is present according to the results reported in Table 7.2.1. For the government, demonstration fields are attractive because they have relatively low cost compared to subsidies spent to enhance the use of modern water-saving land improvements. Hence, if the promotion of modern water-saving land improvements is currently too costly, the government may still be able to promote water-saving technologies through use of demonstration fields.

Results and Discussions for Social Economic Variables

Among the five socio-economic variables, ARLANDHH and MIDDLEPERC have a significant impact on the adoption extent of strategies 2 and 4. On the adoption extent of borders or furrows and field leveling in strategy 3, ARLANDHH, GRROUNDTABLE*IRRI, and ELECPRICE are positive and significant.

The amount of arable land per household is positive and significant at the 1% level in strategy 2, and both borders or furrows and field leveling in strategies 3, and 4. For farmers that adopt strategy 2, the adoption area increase by 0.5979 hectare when the arable land per household increases 1 hectare as reported in Table 7.2.1. For farmers that adopt strategy 3, the adoption area for borders or furrows and field leveling will increase by 0.3646 hectare and 0.3430 hectare, respectively, when the arable land per household increases 1 hectare as reported in Table 7.2.3. For farmers that adopt strategy 4, the adoption area for borders or furrows will increase by 0.6987 hectare when the arable land per household increases 1 hectare as reported in Table 7.2.4.

An interesting finding here is the “discrepancy” of the variable arable land per household in the discrete choice model (multinomial logit model) versus the continuous choice model. In the discrete choice model, farmers with larger arable land are less likely to improve their land with any traditional water-saving land improvements because these methods require a higher labor input per hectare. However, for those farmers that do adopt one of these traditional water-saving land improvements, more arable land is associated with a more extensive use of traditional technology. A possible explanation is that there exists a threshold value for arable land per household. Above this threshold value, farmers are significantly less inclined to adopt any traditional water-saving land improvements due to the labor constraint, whereas below this threshold value, the labor requirement for the traditional water-saving land improvements can be met and the technologies can be implemented over a more significant proportion of that arable land capturing economies of scale and saving more water.

Non-agricultural income per household is insignificant in all three strategies. The insignificance of non-agricultural income per household is expected because traditional water-saving land improvements have relatively low capital costs. In contrast, modern water-saving land improvements have higher capital costs, which would be expected to be positively related to non-agricultural income per household.

Electricity price is positively and significantly related to the adoption extent of both borders or furrows and field leveling in strategy 3. As suggested by agronomists, use of borders or furrows or field leveling can increase the irrigation uniformity and reduce the irrigation hours (Li, 2002, Hao, 2006), which can save electricity cost if farmers use electricity to pump groundwater or lift surface water. For farmers that adopt strategy 3, the adoption area for borders or furrows and field leveling will increase by 0.3128 hectare and 0.3339 hectare, respectively, when electricity price increases by 1 Yuan per kw/hour as reported in Table 7.2.3. Another variable used to measure pumping cost, the depth to the groundwater table is also positively correlated with the adoption extent of borders or furrows in strategy 3, although the magnitude is trivial.

Education level, as measured by the percentage of farmers with some middle school education, significantly influences the adoption extent of field leveling in strategy 2, and is positively and significantly related with the adoption extent of borders or furrows in strategy 4. Educated farmers learn rapidly from each other and are more willing to learn from each other, which boosts the adoption extent of traditional water-saving land improvements. The adoption area of borders or furrows in strategy 4 increases by 0.034 hectare when the percentage of some middle school education increases by 10% according to the marginal effect reported in Table 7.2.4. The negative relationship between the adoption extent of field leveling in strategy 2 and the education level is likely due to the fact that field leveling is a very traditional technology.

7.3 Conclusions

The main purpose of this chapter is to estimate the influence of various factors on the continuous choice of water-saving land improvements. Due to the limited amount of observations for the modern water-saving land improvements, only farmers that adopt strategies 2, 3, and 4 are analyzed. Regression results from both OLS with sample selection terms and without sample selection terms indicate that the location of a village to an irrigation district, annual rainfall, demonstration fields, the amount of arable land per household, and the education level have an influence on the adoption extent of field leveling (strategy 2). Annual rainfall, government extension service and the provision of subsidies and loans, the amount of arable land per household, the depth to groundwater table, and electricity price have an impact on the intensity of adoption by farmers using borders or furrows (strategy 3). The location of a village to an irrigation district, major soil type, government provision of subsidies and loans, the amount of arable land per household, and education influence the level of farmers' creating borders or furrows in their field (strategy 4).

The positive relationship between subsidies or loans from the government and the adoption extent of use of borders or furrows and field leveling suggests that government subsidies or loans provide a strong incentive for farmers who want to adopt traditional water-saving land improvements. And with the right incentive, farmers are willing to switch to more efficient water-saving land improvements.

The positive relationship between the amount of arable land per household and the adoption intensity in the continuous model reflects an economy of scale to some extent. When developing borders or furrows at a one-acre field, using a tractor is not feasible, but when developing borders or furrows at a twenty-acre field, it is practical and the cost of developing borders or furrows per acre could be lowered. While the amount of arable land per household is not likely to increase, this positive relationship could be meaningful because it suggests that there is an alternative way to reach the economy of scale while holding the amount of arable land per household constant. Farmers in China are not allowed to sell their land but since the late 1980s, farmers have been allowed to rent out their land (Brandt et al 2004). Promoting the development of the land rental market would encourage land circulation and could lead to larger average farm size, which would encourage the adoption of water-saving land improvements.

The positive relationship between education attainment and adoption extent for some traditional water-saving land improvements confirms education matters in technology adoption. More specifically, higher education level increases the extent of adoption for some traditional water-saving land improvements, although the magnitude is small. If government continues to support the 9-year compulsory education program in China, farmers in China will benefit from this program, and the use of more efficient water-saving land improvements will likely increase. Demonstration fields promoting water saving technologies in villages also boost the adoption extent of the three traditional water-saving land improvements. Thus demonstration fields are an effective way to teach farmers to use water-saving technologies.

Table 7.2.1: OLS Regressions with and without Selection Terms for Farmers Adopting Field Leveling in Strategy 2 (Dependent variable: adoption area per household)

	OLS w Selection Terms			**OLS w/o Selection Terms**		
	(1)	**(2)**	**(3)**	**(1)**	**(2)**	**(3)**
Environmental						
GROUNDONLY	-0.1001	-0.0880		-0.0620	-0.0590	
	(0.1310)	(0.1300)		(0.1134)	(0.1054)	
NOIRRI	0.2219		0.2017	-0.0124		0.0193
	(0.2527)		(0.2504)	(0.1659)		(0.1545)
DOWNSTREAM	**0.2493*** **	**0.2708*** **	**0.2530*** **	**0.2845**** **	**0.2839*** **	**0.2782*** **
	(0.1208)	(0.1181)	(0.1203)	(0.1030)	(0.1019)	(0.1018)
NOTDISTRICT	0.1171	0.1514	0.0765	0.1371	0.1331	0.0991
	(0.1198)	(0.1130)	(0.1070)	(0.1187)	(0.1055)	(0.0957)
LOAMSOIL	0.1351	0.1127	0.1089	0.0277	0.0273	0.0107
	(0.1247)	(0.1219)	(0.1195)	(0.1135)	(0.1124)	(0.1085)
CLAYSOIL	-0.0127	-0.0191	-0.0242	-0.0589	-0.0593	-0.0650
	(0.0806)	(0.0801)	(0.0789)	(0.0711)	(0.0704)	(0.0698)
RAINFALL	**-0.0004***	**-0.0004***	**-0.0004***	**-0.0005****	**-0.0005****	**-0.0005****
	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)
GROWSEASON	-0.0012	-0.0007	-0.0009	0.0002	0.0002	0.0003
	(0.0015)	(0.0014)	(0.0015)	(0.0012)	(0.0012)	(0.0012)
Institutional						
GOVEXTEN	0.0414	0.0627	0.0707	0.0792	0.0795	0.0874
	(0.1153)	(0.1125)	(0.1083)	(0.0766)	(0.0759)	(0.0747)
LOANSUB	-0.0047	-0.0651	-0.0324	-0.0724	-0.0720	-0.0729
	(0.1257)	(0.1050)	(0.1199)	(0.0882)	(0.0873)	(0.0877)
DEMONSTRATE	0.0965	0.1107	0.0963	**0.1462***	**0.1469***	**0.1340***
	(0.1050)	(0.1035)	(0.1046)	(0.0951)	(0.0939)	(0.0919)
Socio-economic						
ARLANDHH	**0.6712*** **	**0.6399*** **	**0.6621*** **	**0.5979*** **	**0.5975*** **	**0.6038*** **
	(0.1104)	(0.1043)	(0.1093)	(0.0930)	(0.0921)	(0.0918)
NONAGINC	0.0045	0.0039	0.0057	0.0080	0.0082	0.0085
	(0.0132)	(0.0132)	(0.0131)	(0.0123)	(0.0121)	(0.0122)
GROUNDTABLE*IRRI	-0.0001	0.0000	-0.0001	0.0003	0.0003	0.0003
	(0.0006)	(0.0006)	(0.0006)	(0.0005)	(0.0005	(0.0005)
ELEC*IRRI	-0.1328	-0.2953	-0.1380	-0.2442	-0.2297	-0.2337
	(0.2643)	(0.1883)	(0.2633)	(0.2493)	(0.1556)	(0.2471)
MIDDLEPERC	**-0.0036***	**-0.0030***	**-0.0033***	**-0.0023***	**-0.0023***	**-0.0023***
	(0.0020)	(0.0018	(0.0019)	(0.0014)	(0.0014)	(0.0014)
Selection term for P1	0.3962	0.3266	0.3289			
Selection term for P3	0.0893	0.2323	0.1542			
Selection term for P4	-0.1911	-0.1167	-0.1883			
Selection term for P5	-0.7195	-0.8963	-0.7241			
Selection term for P6	**0.3518***	**0.3926***	**0.3648***			
Intercept	0.3976	0.4987	0.3739	0.2545	0.2477	0.2255

*,**,***, represents significant at 10%, 5%, and 1%, respectively. Standard errors are reported in parentheses

OLS Model 1: R2=0.7398, F(15,63)=11.19, Prob>F=0.0000
OLS Model 2: R2=0.7397, F(15,64)=12.13, Prob>F=0.0000
OLS Model 3: R2=0.7385, F(15,64)=12.05, Prob>F=0.0000

Table 7.2.2: Seemingly Unrelated Regressions for Borders or Furrows and Field Leveling in Strategy 3(with Selection Terms) (Dependent variable: adoption area per household)

	SUR w Selection Terms (1)		**SUR w Selection Terms (2)**		**SUR w Selection Terms (3)**	
	Border/Furrow	**Field Leveling**	**Border/Furrow**	**Field Leveling**	**Border/Furrow**	**Field Leveling**
Environmental						
GROUNDONLY	0.0522	-0.0807	0.0599	-0.0799		
	(0.0711)	(0.0615)	(0.0710)	(0.0612)		
NOIRRI	0.3983	0.2386	0.2595	0.2241	0.4294	0.1905
	(0.2237)	(0.1935)	(0.1804)	(0.1555)	(0.2200)	(0.1909)
DOWNSTREAM	-0.0308	0.0731	-0.0398	0.0721	-0.0348	0.0792
	(0.0839)	(0.0725)	(0.0837)	(0.0722)	(0.0838)	(0.0727)
NOTDISTRICT	-0.0652	-0.0030	-0.0731	-0.0038	-0.0474	-0.0305
	(0.0734)	(0.0634)	(0.0732)	(0.0631)	(0.0693)	(0.0602)
LOAMSOIL	0.0483	-0.0130	0.0168	-0.0163	0.0489	-0.0139
	(0.0739)	(0.0639)	(0.0676)	(0.0583)	(0.0740)	(0.0642)
CLAYSOIL	0.0388	-0.0130	0.0144	-0.0155	0.0404	-0.0154
	(0.0565)	0.0489)	(0.0516)	(0.0445)	(0.0566)	(0.0491)
RAINFALL	0.0000	**-0.0005****	-0.0002	**-0.0005****	-0.0001	**-0.0005****
	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)
GROWSEASON	-0.0015	-0.0002			-0.0016	0.0000
	(0.0014)	(0.0012)			(0.0014)	(0.0012)
Institutional						
GOVEXTEN	**-0.1257****	-0.0224	**-0.1174****	-0.0216	**-0.1290****	-0.0174
	(0.0578)	(0.0500)	(0.0574)	(0.0495)	(0.0577)	(0.0501)
LOANSUB	**0.1719****	0.0916	**0.1356****	0.0879	**0.1790****	0.0808
	(0.0776)	(0.0671)	(0.0696)	(0.0600)	(0.0771)	(0.0669)
DEMONSTRATE	-0.0258	-0.0236	-0.0114	-0.0221	-0.0296	-0.0178
	(0.0611)	(0.0528)	(0.0597)	(0.0515)	(0.0610)	(0.0529)
Socio-economic						
ARLANDHH	**0.3707*****	**0.3227*****	**0.3488*****	**0.3204*****	**0.3769*****	**0.3131*****
	(0.0811)	(0.0702)	(0.0786)	(0.0678)	(0.0808)	(0.0701)
NONAGINC	0.0002	0.0008	0.0004	0.0007	0.0003	0.0006
	(0.0007)	(0.0006)	(0.0007)	(0.0006)	(0.0007)	(0.0006)
GROUNDTABLE*IRRI	0.0007	0.0004	0.0009	0.0004	0.0007	0.0004
	(0.0008)	(0.0007)	(0.0008)	(0.0007)	(0.0008)	(0.0007)
ELEC*IRRI	**0.3128****	**0.3339****	**0.2680***	**0.3292****	**0.3393****	**0.2930****
	(0.1582)	(0.1368)	(0.1527)	(0.1317)	(0.1543)	(0.1339)
MIDDLEPERC	0.0011	0.0004	0.0016	0.0005	0.0009	0.0007
	(0.0013)	(0.0011)	(0.0012)	(0.0010)	(0.0013)	(0.0011)
Selection term for P1	0.4593	0.1296	0.3755	0.1209	0.4867	0.0872
Selection term for P2	-0.0749	0.1192	-0.1009	0.1165	-0.0431	0.0700
Selection term for P4	-0.2706	0.0187	-0.0764	0.0390	-0.2687	0.0158
Selection term for P5	0.2567	0.1372	0.1372	0.1247	0.2014	0.2227
Selection term for P6	**-0.4303***	**-0.3906***	**-0.4100***	**-0.3885***	**-0.4203***	**-0.4061***
Intercept	0.1780	0.3545	0.0146	0.3375	0.2439	0.2526

Table 7.2.3: Seemingly Unrelated Regressions for Borders or Furrows and Field Leveling in Strategy 3 (without Selection Terms) (Dependent variable: adoption area per household)

	SUR w/o Selection Terms (1)		**SUR w/o Selection Terms (2)**		**SUR w/o Selection Terms (3)**	
	Border/Furrow	**Field Leveling**	**Border/Furrow**	**Field Leveling**	**Border/Furrow**	**Field Leveling**
Environmental						
GROUNDONLY	0.0482	-0.0584	0.0484	-0.0578		
	(0.0598)	(0.0515)	(0.0598)	(0.0516)		
NOIRRI	**0.2643***	**0.1835***	**0.2688***	**0.1991***	**0.2525***	**0.1978***
	(0.1419)	(0.1223)	(0.1398)	(0.1206)	(0.1414)	(0.1220)
DOWNSTREAM	0.0043	0.0695	0.0058	0.0748	0.0026	0.0716
	(0.0743)	(0.0641)	(0.0739)	(0.0637)	(0.0744)	(0.0643)
NOTDISTRICT	-0.0293	0.0160	-0.0269	0.0243	-0.0060	-0.0121
	(0.0714)	(0.0615)	(0.0702)	(0.0606)	(0.0654)	(0.0564)
LOAMSOIL	-0.0028	-0.0423	-0.0020	-0.0397	-0.0037	-0.0412
	(0.0656)	(0.0565)	(0.0655)	(0.0565)	(0.0657)	(0.0567)
CLAYSOIL	0.0076	-0.0370	0.0085	-0.0341	0.0057	-0.0347
	(0.0496)	(0.0427)	(0.0493)	(0.0426)	(0.0496)	(0.0428)
RAINFALL	-0.0002	**-0.0006****	-0.0002	**-0.0005****	-0.0003	**-0.0005****
	(0.0002)	(0.0002)	(0.0002)	(0.0001)	(0.0002)	(0.0002)
GROWSEASON	0.0002	0.0005			0.0002	0.0005
	(0.0008)	(0.0007)			(0.0008)	(0.0007)
Institutional						
GOVEXTEN	**-0.0910***	-0.0293	**-0.0913***	-0.0305	**-0.0903***	-0.0302
	(0.0484)	(0.0417)	(0.0484)	(0.0418)	(0.0485)	(0.0419)
LOANSUB	**0.1252****	**0.0780***	**0.1256****	**0.0794***	**0.1296****	**0.0727***
	(0.0625)	(0.0539)	(0.0625)	(0.0539)	(0.0624)	(0.0539)
DEMONSTRATE	0.0381	0.0094	0.0379	0.0089	0.0373	0.0103
	(0.0529)	(0.0456)	(0.0529)	(0.0457)	(0.0530)	(0.0457)
Socio-economic						
ARLANDHH	**0.3646*****	**0.3430*****	**0.3631*****	**0.3380*****	**0.3604*****	**0.3482*****
	(0.0634)	(0.0546)	(0.0629)	(0.0543)	(0.0633)	(0.0546)
NONAGINC	0.0066	0.0083	0.0064	0.0076	0.0073	0.0075
	(0.0072)	(0.0062)	(0.0071)	(0.0061)	(0.0071)	(0.0061)
GROUTABLE*IRRI	**0.0014***	0.0006	**0.0014***	0.0007	**0.0014***	0.0006
	(0.0007)	(0.0006)	(0.0007)	(0.0006)	(0.0007)	(0.0006)
ELEC*IRRI	**0.3005****	**0.3480*****	**0.3023****	**0.3544*****	**0.3254*****	**0.3179*****
	(0.1500)	(0.1292)	(0.1497)	(0.1291)	(0.1470)	(0.1269)
MIDDLEPERC	0.0011	0.0007	0.0011	0.0007	0.0011	0.0007
	(0.0010)	(0.0009)	(0.0010)	(0.0009)	(0.0010)	(0.0009)
Intercept	0.0025	0.1598	0.0176	0.2121	0.0311	0.1253

*,**,*** represents significant at 10%, 5%, and 1%, respectively.
Standard errors are reported in parentheses
SUR Model (1) Breusch-Pagan test of independence: chi2(1) =51.066, Pr = 0.0000
SUR Model (2) Breusch-Pagan test of independence: chi2(1) =51.046, Pr = 0.0000
SUR Model (3) Breusch-Pagan test of independence: chi2(1) =49.565, Pr = 0.0000

Table 7.2.4: OLS Regressions with and without Selection Terms for Farmers Adopting Borders or Furrows in Strategy 4 (Dependent variable: adoption area per household)

	OLS w Selection Terms			**OLS w/o Selection Terms**		
	(1)	**(2)**	**(3)**	**(1)**	**(2)**	**(3)**
Environmental						
GROUNDONLY	-0.1194	-0.1149		-0.0773	-0.0834	
	(0.1641)	(0.1611)		(0.1158)	(0.1109)	
NOIRRI	0.2921		0.2757	0.0660		0.1055
	(0.4928)		(0.4862	(0.2735)		(0.2640)
DOWNSTREAM	__0.3188**__	__0.3420**__	__0.3271**__	__0.2557**__	__0.2546**__	__0.2414**__
	(0.1577)	(0.1501)	(0.1553)	(0.1227)	(0.1202)	(0.1194)
NOTDISTRICT	0.1580	0.1617	0.0813	0.1215	0.1288	0.0632
	(0.1764)	(0.1733)	(0.1397)	(0.1424)	(0.1364)	(0.1113)
LOAMSOIL	__0.2796*__	__0.2761*__	__0.3186*__	__0.2612*__	__0.2601*__	__0.2681*__
	(0.1784)	(0.1752)	(0.1680)	(0.1452)	(0.1423)	(0.1432)
CLAYSOIL	0.1617	0.1651	0.1769	0.1160	0.1216	0.1195
	(0.1462)	(0.1435)	(0.1429)	(0.1187)	(0.1140)	(0.1172)
RAINFALL	0.0000	-0.0002	0.0001	0.0001	0.0001	0.0002
	(0.0007)	(0.0006)	(0.0006)	(0.0005)	(0.0005)	(0.0004)
GROWSEASON	0.0012	0.0025	0.0009	0.0008	0.0009	0.0006
	(0.0034)	(0.0025)	(0.0033)	(0.0015)	(0.0015)	(0.0015)
Institutional						
GOVEXTEN	-0.0651	-0.0387	-0.0187	-0.0301	-0.0300	-0.0171
	(0.1358)	(0.1261)	(0.1184)	(0.0997)	(0.0978)	(0.0967)
LOANSUB	0.1797	0.2133	0.1805	__0.2615*__	__0.2628*__	__0.2441*__
	(0.2090)	(0.1977)	(0.2064)	(0.1489)	(0.1458)	(0.1449)
DEMONSTRATE	0.0959	0.1152	0.0767	0.0386	0.0412	0.0338
	(0.1457)	(0.1396)	(0.1415)	(0.1231)	(0.1202)	(0.1215)
Socio-economic						
ARLANDHH	__0.6808***__	__0.6745***__	__0.6608***__	__0.6987***__	__0.6987***__	__0.6848***__
	(0.2691)	(0.2642)	(0.2643)	(0.2372)	(0.2325)	(0.2336)
NONAGINC	0.0042	0.0059	0.0022	-0.0036	-0.0035	-0.0037
	(0.0148)	(0.0143)	(0.0144)	(0.0104)	(0.0102)	(0.0102)
GROUNDTABLE*IRRI	0.0007	0.0005	0.0008	-0.0005	-0.0006	-0.0003
	(0.0016)	(0.0016)	(0.0016)	(0.0010)	(0.0010)	(0.0010)
ELEC*IRRI	0.2015	0.1352	0.1746	0.1480	0.1246	0.1347
	(0.2466)	(0.2159)	(0.2407)	(0.2197)	(0.1931)	(0.2162)
MIDDLEPERC	0.0009	0.0014	0.0005	__0.0035*__	__0.0035*__	__0.0032*__
	(0.0036)	(0.0034)	(0.0035)	(0.0022)	(0.0021)	(0.0021)
Selection term for P1	-0.1392	-0.3795	-0.2897			
Selection term for P3	0.5608	0.5821	0.4550			
Selection term for P4	0.2865	0.2624	0.3556			
Selection term for P5	-1.2557	-0.9584	-0.8488			
Selection term for P6	0.6027	0.5107	0.4322			
Intercept	-0.2671	-0.5447	-0.2074	-0.6371	-0.6373	-0.6645

*,**,***, represents significant at 10%, 5%, and 1%, respectively. Standard errors are reported in parentheses
OLS Model (1): R2=0.5066, F(16,23)=1.48, Prob>F=0.1922
OLS Model (2): R2=0.5054, F(15,24)=1.63, Prob>F=0.1372
OLS Model (3): R2=0.4971, F(15,24)=1.58, Prob>F=0.1537

CHAPTER EIGHT: CONCLUSIONS AND POLICY IMPLICATIONS

Although water shortages are becoming a severe problem in Northern China, the agricultural sector, China's biggest consumer of water in the nation, uses water inefficiently. Adopting water-saving land improvement technologies may help to alleviate water shortages in Northern China. Determinants for farmers' choice of water-saving land improvements in Northern China are analyzed with a sample survey of 401 villages. The analysis focuses on two aspects of adoption, whether or not to adopt and if a technology is adopted, how much land to which to apply the technology.

The main objective of this study is to determine what influences farmers' adoption of water-saving land improvements and what incentives might increase their adoption of water-saving land improvements. The econometric results of this study indicate that farmers are willing to adopt water-saving land improvements and change water use behavior when water is less abundant. Water availability has a positive impact on both the probability and the intensity of adoption of water-saving land improvements. Government interventions such as extension service, demonstration fields, or provision of subsidies or loans boost the adoption of water-saving land improvements. In addition, farmers with more arable land are less likely to adopt traditional water-saving land improvements and more likely to switch to modern water-saving land improvements. Another interesting finding in this study is that while the amount of arable land per household is negative and significant in the discrete choice model on the choice of traditional water-saving land improvements, it is positive and significant in the continuous choice model, which implies a threshold value for arable land per household.

This study is limited in several aspects. First, the data is at the village level, not at the household level. Household level data would provide micro information for specific plots of land such as field slope, soil type, crop choice, and also farmers' characteristics and actual water cost paid by each household. These variables will also affect the technology adoption and would improve the empirical results. Second, only the adoption extent of traditional water-saving land improvements is analyzed. While modern water-saving land improvements are more efficient in saving water and are paid more attention by the government, the adoption extent of modern water-saving land improvements was not conducted due to the limited number of villages adopting these. Extending the continuous model to modern water-saving land improvement would make this study more applicable. Third, analysis of the diffusion of water-saving land improvements could not be conducted because there are no time-dependent variables in this dataset. In addition, in this paper only water-saving technologies that improve the crops utilization of irrigation water and rainwater and land quality are included. Other water saving technologies that improve water conveyance such as lining canals, and water-saving agronomic technologies such as mulching, plastic sheeting, conservation tillage, and growing drought resistant crops are not included. Addressing these limitations offer directions for the future study.

Nonetheless, this study provides some policy implications for the Chinese policy makers. Although the adoption rate of water-saving land improvements in Northern China is relative low, with the right incentive farmers are willing to switch to more efficient water-saving land improvements. Government can subsidize or issue loans to induce the adoption of modern water-saving land improvements which require a sizable upfront investment that Chinese farmers usually cannot afford to. Demonstration fields also provide an effective way to encourage farmers' adoption of water-saving land improvements. The land rental market which emerged in rural China starting in the 1990s can induce land circulation and the achievement economies of scale in farming and in turn increase the adoption of more efficient water-saving land improvements. Finally, the nine-year compulsory education program in China will benefit farmers and likely increase technology adoption. Continued government support of each of these programs will encourage increased adoption of water-saving land improvements.

Although whether or not adopting modern water-saving land improvements such as sprinkler or drip irrigation conserves water is still debated as mentioned in Chapter Two, Caswell and Zilberman (1986) found that switching to sprinkler or drip irrigation from border or furrow irrigation saves water at the field level under certain circumstances. Therefore, under some hydrologic conditions, adopting water-saving land improvements, either traditional or modern may, lead to water saving in the field.

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