Investigations on the Impacts of China's Rural Water Policies:

From Efficiency and Equity Perspectives

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Abstract

Water policies in China have been traditionally focused on meeting sectoral demands for water by increasing the supply rather than managing demand. However, effective water resource policies that focus on demand management and encourage efficient water use remain the main weakness of China's water policy. Main potential for efficiency gain is the agricultural sector, In this paper we explore the potential for an improvement in policies that address water use efficiency and equity in one of China's rural regions.

Our analysis includes water use efficiency, water pricing and various policy interventions that are aimed at both increasing total welfare and improve income distribution along the canal. Especially we focus on study the impact of canal monitoring system on water resource allocation. We show how important it is for the public agency and the private users to cooperate in order to achieve water use efficiency and equity within the irrigation network. Policies include unregulated case, increased monitoring and enforcement of various water allocation methods, government subsidy to a certain grain products, etc. A General Algebraic Modeling System (GAMS) is employed to achieve the optimization process under the water system constraints and other policy regulation constraints.

Keywords: Water efficiency, Equity, Irrigation water management

1. Introduction

China's water resources are scarce. While its renewable water resources amount to about 2,841 km^3/year, the sixth largest in the world, the per capita availability, is estimated at 2,156 m^3/year in 2007, which is one-fourth of the world average of 8,549 m^3/year (World Bank, 2009). Given its limited water resource, policies in China have been traditionally focused on meeting sectoral demands for water by increasing the supply rather than managing demand. However, effective water resource policies that focus on demand management and encourage efficient water use remain the main weakness of China's water policy. Main potential for efficiency gain is the agricultural sector, which accounts for 75.7 percent of total water withdrawals. Due to major inefficiencies in irrigation water systems only about 53 percent of water withdrawals for agriculture are actually used by farmers to irrigate their crops (Center for Irrigation and Drainage Development, China 2007). In addition to on-farm and water conveyance system inefficiencies, distorted market prices for certain crops my lead to inefficient cropping patterns and water allocations as well. How to optimize water resource allocation and choose the proper cropping pattern in an irrigation area are major goals to achieve. How to do that while addressing equity among users introduces additional challenges.

In this paper we explore impact of policies that address water use efficiency, optimal cropping patterns, and equity distribution in one of China's rural regions. A spatial water allocation model is employed to maximize water use efficiency at both public water conveyance system and private on-farm water use in one of the irrigation districts in Northwest China's Shaanxi Province. Water use efficiency is modeled along with efficient and optimal cropping patterns to be endogenously determined by the decision makers in the region. Water is provided by a government authority via a public canal to farmers. The public water conveyance system has a given efficiency that can be improved with investment to reduce deep percolation. This can be done either by farmers or through cost sharing arrangements between farmers and the government. While each farmer has a water quota, diverting water from the canal is not regulated and the sequencing of the farmers along the canal dictates the access to water by each farmer. Under the unregulated case equity may be the lowest, where the upstream users may divert unrestricted amounts and the downstream users may use the remainder. Increased efficiency of the public canal may lead to more available subsidized canal water available to the upstream and downstream users. In a parallel venue, when on-farm efficiency is improved, less water is returned to the aquifer, leaving less water as a return flow to be available to the downstream water users as ground water. In reality, cropping patterns are chosen by farmers individually. In this paper we assume there is a social planer who is going to optimize both water allocation and cropping pattern simultaneously along the canal, so as to reduce the complexity of the modeling process. Gross margin are calculated for each farm and equity is calculated as a result of the derived welfare by each farm.

Many studies evaluating the policy responses to water scarcity have been carried out around the world. Several approaches to assess and improve the performance of water use in agriculture exist, notably in terms of increasing the water use efficiency, that is, either the economic or the technical efficiency (Rosegrant &Gazmui, 1994; Keller et al., 1996; Wichelns, 1999; Seckler et al., 1999; Cai et al., 2001, Ortega et al., 2003). Other authors have focused on the sustainable use of groundwater sources and on contamination problems (Hellergerset al., 2001; Gayatri & Edward, 2002; Roseta-Palma, 2002). Issues, such as how to utilize limited water resources most efficiently, how to measure the social cost of water price policies and how to protect the environment, have progressively attracted the attention of water researchers as well as practitioners (Dinar, 1993; Burt et al., 1997; Ray & williams, 1999; Heaney et al., 2001; Blanke et al., 2007). Equity considerations in irrigated agriculture were addressed in various studies such as Tsur and Dinar (1995), Sur et al. (2002), and many others they cite.

There has been little quantitative research on analyzing the impact of the joint performances of public and private sectors in general and on China's irrigated agriculture and rural welfare in particular, especially with consideration of multi-cropping patterns choices and equity consequences. For modeling the water movements, this study follows an approach developed by Umetsu & Chakravorty (1998) and Chakravorty &Umetsu (2003) to investigate impacts and options for increasing water use (technical) efficiency in irrigation activities (either from public or private sectors) and to calculate the corresponding investment needs from the public and private sectors, respectively. In parallel, we will consider how social planer allocates the cropping patterns choices under regulated, unregulated and government intervention cases. Issues of efficiency and equity will be addressed via comparison of net income of farms across the public canal.

In this paper, we will focus on both water efficiency and water distribution equity. Water monitoring costs are introduced into the model to capture the impacts of policy intervention on water's distribution so that the equity and efficiency situation may be improved over the entire irrigation area by proper monitoring.

A practical programming model has been developed that is based on collected field data. Instead of using simulated or borrowed relationship between water and crop yields and net revenue, coefficients are derived from an actual irrigation scheme in China by means of an econometric analysis of farmers' behavior. We rather use a discrete choice approach applying difference equations instead of differential equations, which makes the model usable for GAMS (Brooke et al., 1998; McCarl, 2004). The approach offers a wide range of planning opportunities for irrigation management, and allows quick application to other regions.

Since the study establishes a spatial water allocation model, which is based on an empirical study of farmers, specific policy recommendations for best practices and policies in irrigation system can be made. Specific implications of various schemes of cropping patterns, overall welfare, output and water pricing can be studied and assessed. By analyzing different scenarios, this paper tries to demonstrate how land size, cropping pattern, water pricing, resource rents and adoption of water saving techniques interact and how important coordination of private and public investments could be.

The paper is organized as follows. We first provide an overview of the methodology applied in this study, which contains field survey findings and the modeling procedure. Then scenarios analysis and simulation results are discussed. Finally, conclusions and recommendations are presented.

2. Methodology of the study

2.1 Field survey and empirical findings

A field survey was conducted in a typical Chinese watershed in the county of Li Quan (Shaanxi Province) in 2001 and 2008. The irrigation system in the survey area is managed by a public authority. Most of farmers in the county grow apple for food exchange. Since recent years China has placed food security as one of its top national agenda, grain production is strongly encouraged with certain amount of government subsidy. Farmers allocate different land area to different cropping patterns by reckoning their agricultural return and natural condition. Wheat and corn are observed in this area as the 'food security' crops. With the relatively small farm holding in China, better water use efficiency and increased production revenue are essential to maintain and improve farmers' welfare and food security. Since the region is drought-prone, there is a great pressure on farmers to invest in water saving technologies.

Specifically, farmers locate close to head area can access cheaper public canal water, and they can get as much water as they need. These firmest probably have little incentive to increase on-farm efficiency. Their counterparts located at downstream areas are not as fortunate. They may have to face more expensive canal water due to increased maintenance and lifting costs or go for groundwater when canal water is used up (See Figure 1). With a pressure to lower their water costs, downstream farmers usually have much incentive to adopt modern water saving technology as compared with farmers at upstream. One remarkable thing is that the expensive modern technology were adopted mostly by apple growers, since apple can make much better return as compared with wheat and corn production. The higher the water price, the more investment there is in irrigation technology and consequently the less water is consumed per unit of land. Given limited water supply and agricultural return, most of farmers go for apple production rather than grain production. This will be demonstrated by our modeling analysis as well. To reflect the unequal water resource distribution along the canal, water consumption volume based on different locations of farmers will be investigated. Further consequences of price increases and reduced water use are a reduction in the negative effects of excess irrigation as water waste and water logging and hence less salinization.

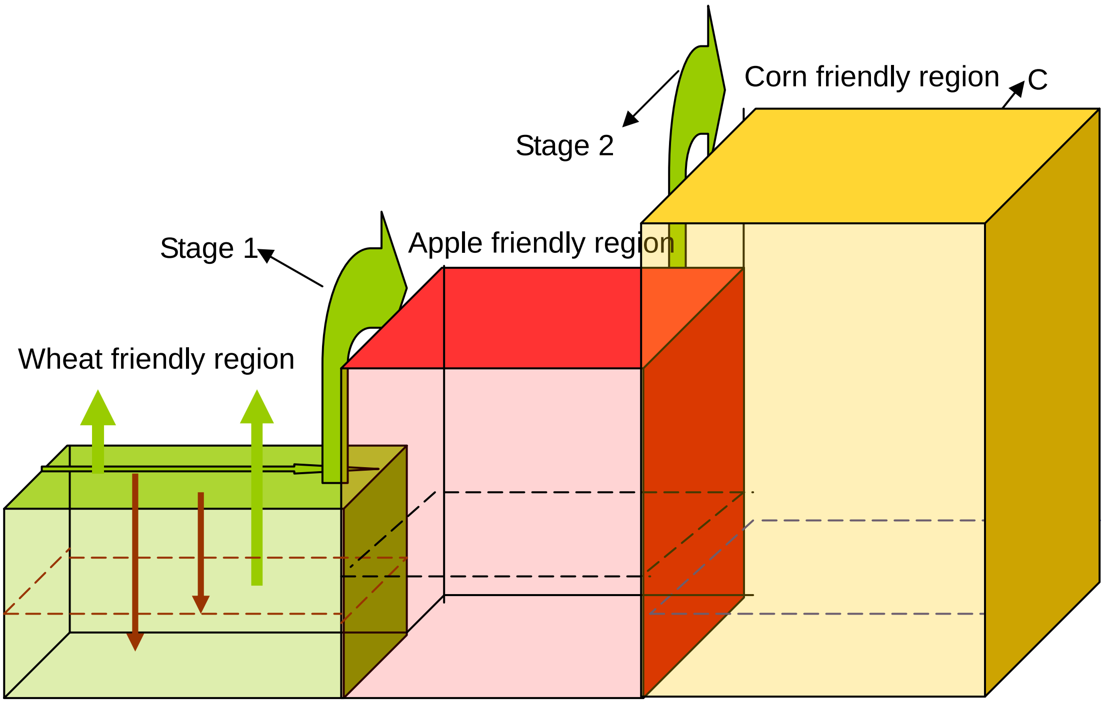
2.2 Layout of the irrigation area

The layout of the irrigation area is shown in Figure 1. There is a social planer who is responsible for optimizing water resources and cropping patterns over the entire area. The area is 7,500m long and 200m wide. So we got an area of 150 hectares which is translated into 150 locations in our modeling process. We regard this small area as a representative, since Chinese farm size is very small. The natural conditions, such as soil, climate etc., is assumed identical and variations are not included in the model. All variables and parameters of the model are location-wise (spatially) variable.

We include multi-cropping patterns under regulated and unregulated cases for canal water management and endogenous investments for irrigation. The irrigation system in the model is assumed to be a relatively closed water cycle system, instead of an open river basin and, importantly, it contains controlled inflows and outflows. For a further understanding, farmers are located sequentially along a public canal. They produce wheat, apple and corn using irrigation. The water use of each farmer along the canal is conditioned by the use of upstream farmers. There is a limited amount of surface water available for the analyzed area and it is not sufficient for the entire irrigation area. Additional quantity is amended by pumping groundwater.

As shown in the figure 1, conjunctive water use is taken into consideration. There are three blocks in the irrigation area. All farmers have access to public canal water and groundwater. Farmers extract water from the canal to irrigate their land. Meanwhile, water can be lost from poorly maintained water conveyance system or farmers' field. For those situated at plain area, where winter wheat is grown, they have better access to abundant and cheap public canal water. The lowest water price might lead to overuse of water at the head area. For those farmers living at hilly, higher elevation areas, where apple production is dominating, they get water from public canal with a higher price due to an additional (stage 1 station) lift-height pumping cost. At last, water will be delivered to mountainous area where corn is grown. A stage 2 lift-height pumping station lifts the water again to irrigate the corn's fields. Consequently the water price is almost 6 folds of the original water price at the plain area. Corn needs less water than wheat and apple. Farmers may reduce their water costs either by reducing canal water application, groundwater pumping, and dry land farming or by changing cropping pattern. A canal controller or examiner will be introduced to canal management. The corresponding canal monitoring costs enables us to analyze the impacts of regulation on water use and equity distribution.

Figure 1: Water flow and potential cropping pattern allocation in the survey area



Source: Authors

We assume that a point C, as shown in Figure 1, will emerge somewhere in watershed, at which farmers stop using canal water and switch to groundwater. It is choice dependent. Point C (stretch of canal, see results) depends on the efficient use of water.[1] It is endogenous to the system and it will be determined by the model. This implies that, farmers located prior point C, extract water from the public canal rather than from the groundwater aquifer. This is reasonable since the cost of canal water is much lower than that of groundwater pumping. Canal water is provided by the public water supplier with government subsidy. The canal water price for farmers cannot cover its actual production and conveyance costs. Groundwater costs normally depend upon the well depth. The deeper the well is, the more expensive the groundwater will be. For simplicity we only consider the pumping costs, that is, electricity costs for groundwater, even though it is still much higher than canal water costs. Around point C, the groundwater supply gradually becomes the dominant water source up to the tail area. Importantly, relatively expensive groundwater should encourage farmers to adopt modern irrigation technologies to save water and lower the costs (Fang, 2004). In our model, the pumping costs vary with distance. This means that with increasing distance from the last water delivery from the canal, the water table falls gradually and this increases extraction costs. Apparently this is approved by empirical observations in the researched watershed. Water price will affect farmers' behavior, either at water consumption level or

[1] We should mention that point C may occur, under extreme situations, in the second irrigation area.

cropping pattern choices.

For methodological reason, the adoption of different types of irrigation techniques is an important factor that needs to be considered. In this study, we adopt the most continuous presentation of space and types of technologies rather than a discrete choice of technology selection. In previous studies, researchers often regarded technologies to be discrete and exogenous, rather than making them choice variables (Caswell & Zilberman, 1985; Chakravorty *et al*., 1995; Umetsu & Chakravorty, 1998; Chakravorty & Umetsu, 2003). One argument of this study is that all kinds of techniques are in a continuous set and choice depends on monetary costs and benefits rather than a kind of fixed technical coefficient. Apparently we have discrete technologies, but we should look at the variation in water use efficiency and investment from a functional view point. We can categorize technologies along a track of marginal costs (production function). Our water efficiency function is a quadratic one and we consider investment in technologies as occurrences along a continuous line. By this approach the model can optimize technologies and corresponding investments endogenously instead of exogenously fixing them.

2.3 Econometric model

This study builds a comprehensive mathematical modeling framework to carry out data processing and social welfare optimization. The framework contains two packages, an econometric model of regression analysis and a programming model (General Algebraic Modeling System-GAMS). Natural conditions, such as soil, climate etc., are assumed similar across the watershed and excluded from model. All variables and parameters of the model are location-dependent (spatially) variables.

Our econometric model framework contains several functions, including effective water demand function; on-farm water efficiency function; canal water loss rate function; and monitoring costs function. 149 farmers were interviewed along the canal and their production data was recorded, we also had interviews with officials from local water authority so as to collect some data related to public investment for canal water conservation.

Based on our field survey data and related literature, we e estimated three effective water demand function for apple production, wheat production, and corn production, respectively, using linear regression approach

$$EW1 = 60.26 - 4.1*10^{-2}*I - 3.2*CWP \qquad (1)[2]$$

$$EW2 = 84.63 - 7.4*10^{-2}*I - 7.152*CWP \qquad (2)[3]$$

$$EW3 = 51.22 - 5.4*10^{-2}*I - 6.5*CWP \qquad (3)[4]$$

Where, EW is the effective water consumption per Mu (Mu is Chinese land measure:15 Mu=1 ha), I is an annual investment per Mu in water saving technologies. And CWP is canal water price, which varies over location. . Effective water consumption can be calculated by total water consumption multiplied by on-farm water use efficiency. On-farm water use

[2] Statistical parameters for equation (1) are t = 23.61, t = –2.85, t = -3.61, n = 141, R^2 = 0.359, F = 39. 3 *sign.F* = 0.0000

[3] Statistical parameters for equation (1) are t = 26.50, t = –3.305, t = -4.767, n = 141, R^2 = 0.347, F = 36.634 *sign.F* = 0.0000

[4] Statistical parameters for equation (1) are t = 22.8, t = –3.45, t = -4.11, n = 141, R^2 = 0.36, F = 38. 5 *sign.F* = 0.0000

efficiency will be presented later.

These demand functions are interacting with irrigation investment I, canal water price CWP as well as on-farm water efficiency. We are only concerned with the canal water price rather than groundwater price, since it is a factor that can affect farmers' behaviors much as compared with groundwater price. Groundwater costs vary with location. The pumping costs in the highest elevation are the most expensive.

Since on-farm water efficiency is one of the key measurements of optimal water resource allocation, it is essential to introduce it as a coefficient in the water demand function. To do so, we specified the coefficient of water use efficiency as a proportional factor ($0<h<1$). The empirical analysis of the farm water use efficiency function, as dependent on investments, is presented in equation (4). It is quadratic and is derived from individual farm calculations of water balances (Fang, 2004). Note that the efficiency is calculated as a net efficiency without precipitation:

$$h = 0.48 + 0.0025 \times I - 2.94 \times 10^{-6} \times I^2 \qquad (4)$$ [5]

Specifically h depends on investments and can be interpreted as an individual on-farm water use efficiency, which is a percentage of water utilized to water applied. I is private investment/Mu and other factors are assumed constant and are captured by the intercept.

A canal water loss measure "a" is a coefficient describing the efficiency of public water management (also for programming). It is used to evaluate the efficiency of a conveyance system. The canal water loss function depends on public investment (mainly lining and maintenance-cleaning) and is based on the field survey data as well as relevant literature. The function has been estimated as:

$$a = -0.000405K + 5.25 \times 10^{-7} K^2 + 0.74 \qquad (5)$$ [6]

Again, our regression analysis suggests that "a" (the canal water loss rate, in % per km) depends on K, which is the public investment. Equation (5) reveals significant impacts of K. Hereby, we follow a strategy of having non-discrete investment types, although building canals is normally discrete with concrete or tubes. (Observations and decision are modeled as continuous investment opportunities.)

The canal water monitoring costs function is highly dependent on the location and water consumption volume. Upstream farmers have more opportunities to extract much water from the public canal as they can, but such a possibility for downstream farmers will be lower. Further, the more water is consumed, the more monitoring is needed. For canal monitoring, the costs would be high at upstream and low at downstream. The function is specified as below:

$$M(j)=547-1.8*\mathrm{ord}(j)-0.45*\mathrm{cw}(j) \qquad (6)$$ [7]

Where $M(j)$= monitoring costs at location j

ord(j) = order of the location j

cw(j)=canal water demand at location j

2.4 Mathematical programming model

To deal with the programming aspect of the approach, an objective function and several constraints are to be constructed. In our case the objective function is designed by a

[5] Statistical parameters for equation (4) are t = 66.12, t = –11.98, t = 18.76, n = 141, R^2 = 0.840, F = 361.13, *sign.F* = 0.0001

[6] Statistical parameters for equation (5) are t = –5.019, t = 3.534, t = 6.903, n = 30, R^2 = 0.745, F = 19.02, *sign.F* = 0.0001

[7] Statistical parameters for equation (6) are t=22.55 t=-8.86 t=-3.24 n=58, R^2=0.89, F=234.61 sign.F=0.0001

constrained gross margin depending on scarcity in water allocation. More specifically, farmers produce different crops with irrigation and maximize gross margins.

The gross margin is calculated as the revenue minus the expenditure on water conservation and other water-related costs. Non water costs are not included, such as fertilizers, labor, etc. The constraints include the land constraints, water constraints, water demand function for different crops, on-farm water use efficiency function, canal water loss rate function and two sets of equations of motion for canal water and groundwater movement. When the regulated case is considered, monitoring costs function will be incorporated to the objective function. In particular, the equations of motion are the most important constraints in the spatial model. Then, owing to the high non-linear characteristics of the objective function and constraints, the model was solved by using GAMS solver Conopt.

All variables and parameters of the model are location specific (spatially differentiated) variables, while the locations are connected through a new dimension: the direction and length of the canal. In such a case the mathematics of control theory, which is found in dynamic optimization, can be applied to space. Normally space is a continuous dimension. For technical reasons, our model is discrete It splits a potential distance of 7.5 km, for a canal, in 150 locations (each of 50 m length along the canal given by the size of a farm). Then, if the watershed has a width of 200 m, it means each farm (a discrete choice unit along the distance of canal) has 1 ha (200 m × 50 m). By this spatial framing, the objective function of the spatial programming fits into a set-up that maximizes the overall gross margin of 150 farmers living in a survey area. Mathematically the sum of individual functions gives the gross margin (social welfare) of farms in the watershed. The gross margin objective function is the sum of all farmers' revenues at each location *j* minus costs for water procurement, costs from investing in water saving technologies and costs for monitoring the canal.

By focusing on individual efficient uses of water on farms and in the watershed, the gross margin of the project area is maximized summing up over the distance of the canal.

Then, in line with a mathematical formulation the objective function can be presented as:

$$Max\ G.M. = (900*X_w + 4000*X_A + 1500*X_C) - 15*(\sum_j I_j + \sum_j CWP_j \times CW_j + \sum_j GWP_j \times GW_j) - \sum_j M_j - 0.05\sum_j K_j \tag{7}$$

Where

j = location, ranging from 1 to 150 in the model, since it represents a stretch every 50 m along the canal, that is, the total length of irrigation system is 10 km (Notely in the following equations of motion, we will let j start from 2-150 for modeling the water movement).

G.M. =overall gross margins over the irrigation area

X_w=land for growing wheat

X_A=land for growing apple

X_C=land for growing corn

I_j = annual private investment in technology in Yuan/Mu at location *j*

K_j = annual public investment in water conveyance in Yuan/km at location *j* (*K* is measured in Yuan/km, one unit of *j* (50 m) is equivalent of 0.05 length of one kilometer, so it has a coefficient 0.05)

CWP_j = price of canal water at location *j*

GWP_j = price of groundwater at location *j*

CW_j = canal water consumption at location j
GW_j = groundwater consumption at location j
M=monitoring costs at location j, which was achieved based on location j, no need to convert by 15.
(Note: the objective function becomes Mu-related by employing a coefficient of "15". It converts Chinese land measures "Mu" to 1 ha (15 Mu are equal to 1 ha).
Land constrains:

$$X_w+X_A+X_C \leq 2250 \tag{8}$$

Water constrains (include canal water and initial groundwater stock):

$$TW \leq 20100 \tag{9}$$

Next, following the notation of dynamic optimization, equations of motion are the constituting constraints in a spatial-dynamic model (now to be interpreted as spatial movement from the head to the tail of the watershed: 7.5 km). In this model, equations of motion are transformed to a location specification. Technically one can speak of difference equations. For us, they are central elements to solve a location problem. Since canal water is moving with location and groundwater stocks are also changing, water flows can be expressed as difference equations of spatial motion. Remember, an equation of motion (now spatial) is a classical concept in dynamic optimization procedures (Chiang, 1992). Our equation of motion for canal water flows given the modeling framework is expressed as fulfilling GAMS model requirements (McKinney & Savitsky, 2003; Dellink *et al*., 2001). It can be specified, as below, with the initial condition:

$$crem_1 = cw_0 - 15 \times cw_1 \tag{10}$$

and discrete flow motion:

$$crem_j = (1 - a_{j-1}) \times crem_{j-1} - 15 \times cw_j \tag{11}$$

where additionally:
$crem_j$ = canal water at location j
a_{j-1} = canal water loss rate at location j–1
Note: j starts from 2 to 150

Equation (10) is the initial condition for canal water flows, where cw_0 represents the external water supply for the irrigation scheme. "cw_1" is the quantity of canal water consumed by the first farmer within the first 50 m and $crem_1$ is therefore the canal water that remains after the first extraction. This remaining water then passes down to the next farmer. In total we have 150 decision-making units for a potential distance of 7.5 km which are connected through the flows. If enough water is available and water is not merely used at the head area, all farmers might receive water, but this is hypothetical. Overuse at the head will normally result in no water for those living at the tail.

Equation (11) describes the amount of canal water that remains at location j. As a general function of motion, equation (11) is expressed as a volume of water that remains from the previous location, j–1, minus water consumption at the present location, j. Note that $crem_j$, which represents remaining canal water, that is the canal water stock at location j, is not only a technical matter. We introduce a water loss rate a_{j-1}, defined as previous behavioral equation; it represents a canal water loss rate at location j–1.

Since equation (11) is the basic concept for canal water flow, in principle, a similar equation of motion applies to groundwater motion: see equation (12) and equation (13) below. At an initial point, in equation (12), groundwater stocks start to build up from the head of the survey area. This implies that there is an initial condition for groundwater stock at the water source, that is, at location 0. We assume $gw_0 = A.$ where A is given as a scalar in the model. Then "$grem_1$" is the groundwater remaining at the first location. In terms of the terminal condition, however, groundwater is free of restrictions; it only has to be given a lower bound of zero in the optimization process.

It is important to recognize that groundwater aquifers are recharged by water seepage from the canal and deep percolation from farmer's fields. The model therefore suggests that groundwater stocks will increase from point zero to C owing to a recharge from both sources, canal seepage and field deep percolation, apparently without any extraction before point C (in Figure 1). The reason for no-extraction is that canal water is cheaper than groundwater. Farmers have no need and incentive to pump groundwater before point C, though technically they could supplement canal water with ground water. After point C, there is less water flowing in the canal, thus groundwater extraction starts from this point and supplements canal water. This implies that recharges from canal water become zero. From point C the groundwater can only be recharged by seepage from farmers' fields. The mathematical formulation of the equation of motion for groundwater change is presented below in Equations (12) and (13):

Initial condition:

$$grem_1 = gw_0 + \beta \times (1 - h_1) \times 15 \times tw_1 - 15 \times gw_1 \qquad (12)$$

Discrete flow motion:

$$grem_j = grem_{j-1} + \beta \times a_{j-1} \times crem_{j-1} - 15 \times gw_j + \beta \times (1 - h_j) \times 15 \times tw_j \qquad (13)$$

where additionally:

$grem_j$ = groundwater at location j

h_j = on-farm water efficiency at location j (note 15 is a correction for area measurement in Mu and ha)

β = recharge rate

Note: j starts from 2 to 150

The first part is similar to the previous explanation. For a further understanding of the equations, the second part is the fraction of groundwater recharged. From the first farmer's field no charges occur (in equation 12). β is defined as the recharge rate for groundwater, tw_1 is the conjunctive water used at the first location and h_1 is the water efficiency in the first location as well. Finally, gw_1 is the groundwater consumption at the first location. Then equation (12) gives the change of groundwater stock at any location except the first location. The variable $grem_j$ represents the groundwater remaining from the previous farmer to the next farmer at location j; here j starts from farmer 2. Since β is the recharge rate for groundwater, $\beta \times a_{j-1} \times crem_{j-1}$ represents the fraction of water loss from the canal and it can be recharged to the aquifer at the location j–1. At any location water can be recharged to the aquifer. The element gw_j is the groundwater quantity extracted by an individual farmer at location j. The last fraction $\beta \times (1 - h_j) \times 15 \times tw_j$ represents the joint water volume, that is, pumped groundwater and surface water losses from a field, which recharges the groundwater aquifer at location j.

In the current study, the equations of motion for groundwater calculats groundwater stock in terms of cumbic meters rather than groundwater depth.

To complete, water balances are given for each location, they are dynamically modeled by equation (11) and (13). The sets of equations serve as important constraints in the spatial model. In combination with above presented equations and the objective function, we can build a concise model of spatial water and allocation. The numerical models are programmed in GAMS and presented as scenarios.

3. Scenarios analysis and simulation results

Three scenarios are designed to test the impacts of different policies on overall gross margin of the irrigated area, water allocation and equity distribution of net income in the study area. The first two scenarios are focused on the performance of canal monitoring system. The third scenario evaluates the impacts of government food security policy, captured by a subsidy to grain production. In the first scenario an unregulated canal system serves as our benchmark. It indicates that farmers, especially those situated at head area, can take water as much as they need/want. In the second scenario we analyze the impacts of canal regulation system. Since total water capacity in the study area is constrained and insufficient for all farmers, it is essential, as an equitable policy, to ensure that as many farmers as possible benefit from cheap public canal water. To achieve this, we introduce a canal examiner to regulate farmers' behavior on water diversion. In the third scenario, we analyze the impacts of government subsidy to grain production.

3.1. Unregulated canal management scenario (UCM)

To derive comparisons, the results of UCM scenario are used as a benchmark or baseline scenario. From this benchmark other scenarios can be evaluated. This scenario assumes that farmers at the previous locaiton have the priority to take water as much as they need. The public investment K and private investment are endogenous variables in the UCM scenario. The recharge rate for groundwater is 0.3, which is at a low permeability rate and we operate 150 potential locations. Essential model results are presented in Table 1 which shows drastic changes if other policies occur. The major findings will be explained in comparison with the other scenarios.

3.2. Regulated canal management scenario (RCM)

To analyze the impact of monitoring system, we introduced a canal monitoring function into the model. All the other variables and parameter are kept the same as in the UCM case. Results and a comparison of both scenarios are given in Table 1.

Table 1: Comparison of indicators between unregulated (UCM) and regulated canal management (RCM) scenarios.

Items	UCM	RCM	RCM to UCM%
Gross margin (Yuan)	8,745,003	8,623,621	-1.39
Land for wheat (Mu)	0	0	
Land for apple(Mu)	2,250	2,250	0.00
Land for corn (Mu)	0	0	
Total canal water consumption (m3)	200,000	199,858	-0.07

Total groundwater consumption (m3)	28,280	1,142	-95.96
Total water consumption (m3)	228,280	201,000	-11.95
Capacity of water supply (m3)	201,000	201,000	0.00
Total public investment (Yuan)	37,158	43,505	17.08
Switch point (Location)	126	149	18.25
Total monitoring costs(Yuan)	0	55,669	
Area irrigated by canal water (Mu)	1,890	2,235	18.25
Area irrigated by groundwater (Mu)	345	30	-91.30
Total private investment (Yuan)	7,460	13,084	75.39

Notes: UCM indicates unregulated canal management scenario; RCM indicates regulated canal management scenario
Source: Model calculations

In the unregulated canal management scenario UCM, the gross margin over the irrigation area reaches 8,745,003 Yuan, which is slightly 1.39% more than regulated case. With the allocation of optimal cropping pattern, the model results show us that all farmers go for apple production. A total 2250 Mu of land are grown apple, no matter if the canal is regulated or unregulated. However, other indicators in the regulated case show considerable improvement as compared to the unregulated case. Though total canal water consumption at both scenarios almost reached the limit 200,000m^3, the impacts are much different. In unregulated case, the canal water can flow to location 126, it means the only farmers prior 126 locations can get access to public canal water, the rest 24 locations farmers have no access to canal water, since the water has been used up by previous farmers. In this case, area irrigated by canal water is 1,890Mu which is 18.25% less than a regulated canal. Meanwhile, area irrigated by groundwater is 345 Mu, which is 91.30% more than RCM, since more farmers have to pump groundwater to irrigate their land. As a comparison, in a regulated canal, canal water can reach to location 148, it implies that only the last two location farmers has to pump groundwater. With the extended water flowing in the canal, public investment in the regulated case is important in improving the efficiency in the public canal system. The public investment is about 17% more than in the unregulated case. The private investment has significant improvement as well which is about 75% more than unregulated scenario. The monitoring forces upstream farmers to take less canal water and adopt water saving technology to lower their water application. Meanwhile, the monitoring system makes more farmers benefit from public water system.

Besides the above mentioned indicators, we may see some sequential change at each location by observing some figures. Figure 2 shows a comparison of canal water consumption in the unregulated and regulated scenarios. The blue line represents the canal water consumption along the canal. Since each farmers will take water as much as they can, it is clearly seen the figure, canal water is used up quickly. At location 126 farmers have to switch to groundwater use, since no water left in the canal. But in regulated case, things can be improved a lot. The pink line represents the water consumption in regulated canal. We see that canal water can extend to 148th location, almost reaching the end of the canal. Therefore, most of farmers benefit under regulation.

Figure 2: Comparison of canal water consumption in unregulated (UCM) and regulated (RCM) scenarios

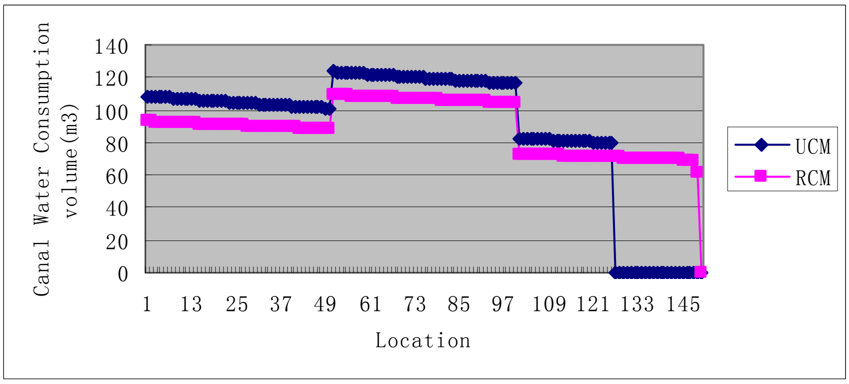


Figure 3. Comparison of investment in irrigation technology in unregulated (UCM) and regulated (RCM) scenarios

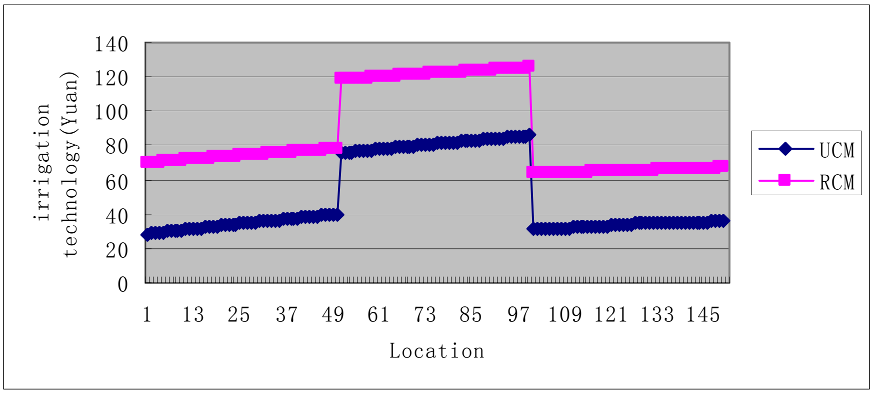
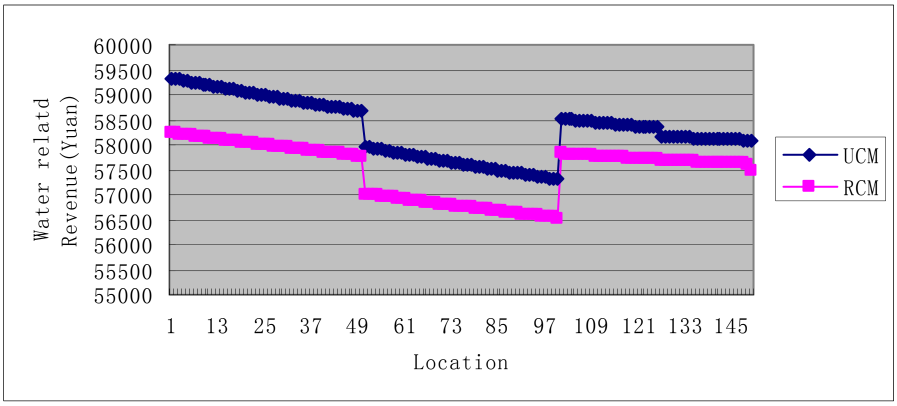


Figure 3 suggests that all farmers under the regulated case will invest more on irrigation technology as compared with the unregulated case, since their water volume is limited. They have to use their water more efficiently. It is a great positive impact that regulation will force farmers to use their water more efficiently rather than taking water as much as they can. On the other hand, as shown in Figure 4, farmers may get less water related revenue under the regulated scenario, since they spend more on water saving technology and they are forced to pay for the monitoring costs as well. The water costs burden becomes higher for them, compared with the unregulated case. Nevertheless, these costs can be considered the social payment for equity improvement in the watershed. As is shown in Table 1, the amount reduced by monitoring costs accounts for only 1 % as compared to the gross margin of the irrigation area. The social cost of achieving equity in a society is reasonable and acceptable in our opinion.

Figure 4. Comparison of water related revenue in unregulated (UCM) and regulated (RCM)

scenarios



3.3 Government subsidy to wheat scenario (GSW)

Apple is chosen by social planer in the previous two scenarios, since it can maximize profit. What will happen if the government makes efforts to support wheat production? We assume that wheat growing may have the same profit as apples does (meaning that the government is interested in food security and subsidizes grain production), then we see the results is shown in Table 2. The social planner did change the cropping pattern allocaiton. Land for wheat is 1127 Mu, as compared with no wheat in scenario UCM. And apple still captures 1123 Mu due to its high return. Since this is an exogenous change, we cannot see any other impacts on the remaining indicators. The clear result is that government's subsidy will directly affect the farmer's cropping pattern's distribution.[8]

Table 2: Comparison of indicators between UCM and GSW to wheat scenario (GSW).

Items	UCM	GSW	GSW to UCM %
Gross margin (Yuan)	8745003	8745003	0
Land for wheat (Mu)	0	1127	
Land for apple(Mu)	2250	1123	-50
Land for corn (Mu)	0	0	
Total canal water consumption (m3)	200000	200000	0
Total groundwater consumption (m3)	28280	28280	0
Total water consumption (m3)	228280	228280	0
Capacity of water supply (m3)	201000	201000	0
Total public investment (Yuan)	37158	37158	0
Switch point (Location)	126	126	0
Total monitoring costs(Yuan)	0	0	
Area irrigated by canal water (Mu)	1890	1890	0
Area irrigated by groundwater (Mu)	345	345	0
Total private investment (Yuan)	7460	7460	0

Notes: UCM indicates unregulated canal management scenario; RCM indicates regulated canal

[8] While apple is a perennial crop and wheat and corn are annual crops, our model is a planning model, which assumes that once a land allocation decision is made it will be kept for long time period.

management scenario; GSW indicates the government subsidy to wheat production scenario
Source: Model calculations

4. Conclusions and recommendations

Based on the model and simulation results, the following conclusions can be drawn. First, Water regulation is essential and helpful for water resource management. From a point of view of equity, it enables more farmers get access to public water; so that the equity situation over the irrigation area can get improved. From the point view of efficiency, it can foster farmers to adopt modern irrigation technology, since it affects their behaviors regarding water application. As rational consumers, they have the incentive to use their water more efficiently. Although regulation creates a certain costs for society, in our analysis it is certainly within a reasonable range that improves both efficiency and equity in an irrigation system.

China is placing food security as one of its national top policy agenda. To make sure that performance of a policy of prompting grain production have positive impacts overall, it is essential to have a proper subsidy policy which should be strong enough to affect farmers' decision on cropping pattern allocation, water use efficiency and distributional equity.

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