Farmers' Adaptation to Irrigation Water User Allocation: The LCC Irrigation System in Pakistan

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Abstract: Pakistan is facing the challenge to cope with decreasing agricultural productivity due to poor water quality (salinity) along the irrigation canal systems. Reallocation of water use between the head, middle and tail reaches of the distributaries in the canal systems can improve the groundwater quality (minimize salinity) as well as maximize crop productivity. This study employed a discrete choice model for analysing the socioeconomic and technological factors that can influence the farmers' adaptation to reallocation of water use (under an optimal water use scenario). Based on farm survey data collected during 2010 and 2012 cropping seasons at the Lower Chenab Canal (LCC) irrigation system in Pakistan, the following question was analysed: Can installation of tube wells at the head reach of the system to extract more groundwater help address the problem of poor water quality at the tail reach? It was found that farmers who have more resources (land holding), experienced (aged) and membership with farmer organisation recognised the need to have more water, available for redistribution, through more groundwater extraction at the head reach of the system. Further the respondents in the study area were also asked to rank the options available to the farmers that can potentially improve their adaptation for the optimal water use scenario (reallocation). The ranking of the options indicated that majority of the farmers think that the best solution to the problem of water scarcity and its quality lies in water reallocation.

Keywords: Groundwater, Water allocation, Farmers' adaptation, PROBIT model, Pakistan

Introduction
Pakistan's economy is mainly depended on agriculture, which contributes for 21% of the GDP and employs 44% of the labour force. Irrigated agriculture supplies more than 90% of agricultural production and around 61% of the rural population are directly or indirectly employed in agricultural sector (GOP 2018). Irrigated agricultural water use is around 151km³/year, which is above 95% of the total withdrawal of water. Water is
increasingly becoming scarce in the
country and the frequent occurrence of
drought poses a threat to the economy.
The agricultural sector is highly depend
on irrigation and it faces the challenges of
low crop yield and an increasing
difference between demand and supply
of agricultural production. This trend is
worsened by inequality of water
allocation among water users at head,
middle and tail reaches of the irrigation
system. The distribution of irrigation
water poses inequality at different levels
of the Lower Chenab Canal (LCC)
irrigation system, i.e. along main canals,
distributaries and within watercourses.

The farmers situated at the head reach of
the irrigation system have access to
sufficient water however the farmers
situated at the middle and the tail reaches
of the irrigation system do not get their
share of water (Hussain, 2005). The
farmers situated at the tail reach of the
system face insufficient water from the
canal system as well as poor quality of
groundwater (saline water) which
reduces the crop yield and also causes
land degradation (Qureshi et al., 2010).
Conjunctive use of surface (canal) and
groundwater is important in the areas
where canal water supply is insufficient,
and increasing groundwater use in these
areas has significantly contributed to
rising agricultural production in the last
two decades. However, in some of these
areas groundwater use has been over-
exploited and due to this trend the
groundwater tables are falling in these
areas with a risk of saline water intrusion
into fresh water aquifers which could
make groundwater as unusable for
irrigation.

Agricultural productivity in Pakistan is
relatively low compared to other
countries and it is limited by availability
of sufficient water and its quality. The
main sources of water for agriculture are
rainfall (10 - 20%), canal (surface)
water (40%) and groundwater (40-50%).
However, water scarcity is a major issue
in Pakistan due to increased crop intensity
which results in over extraction of
groundwater, deepening of groundwater
table and saline water intrusion. The
issues confronted in relation to irrigation
management are estimating (net) water
availability, equitable distribution of
water, and incentives/policy instruments
for capacity building of the water sector
and farmers. Groundwater management
issues are both technical and legal, but
they cannot be dealt without properly
understanding the socioeconomics of
farmers, their perspectives and the
benefits involved. In Pakistan farmers
have ownership of tube wells, however
since groundwater is a common property
resource, the Government can facilitate
its management towards sustainable use.

An economic modelling approach for
different water use scenarios have been
developed to address the problem of
inequality in water use and the impact of
salinity on crop yield (such as wheat) along the head, middle and tail reaches (locations/distributaries) of the Lower Chenab Canal (LCC) irrigation system in Pakistan. A multistage stratified random sampling method was conducted to collect data from 256 farm households during 2010-2011 and 2012-2013 cropping sessions, respectively in the LCC irrigation system. The models were estimated by regression analyses for the effect of water quality on crop yield under different water use scenarios. For each scenario, the canal and groundwater use were defined as the percentages of total water use. The base scenario for instance included 60:40, 50:50, and 30:70 percentages of the canal and groundwater use at the head, middle and tail reaches, respectively. The optimal water use scenario implies that more groundwater should be used at the head reach (distributary) of the canal system (30:70) while more canal water should be used at the tail reach (distributary) of the canal system (70:30). The economic modelling approach and the alternative water use scenarios developed have been presented at the ICDA 2019 conference (Culas, 2019) as well as reported in Culas and Baig 2020.

Methodology and Data Analysis

The study area is in Punjab province, Pakistan and situated in the Lower Chenab Canal (LCC) irrigation system (Figure 1). A baseline socioeconomic survey of irrigators along the head, middle, and tail reach of the LCC East irrigation system was conducted during 2010-11 and 2012-13 cropping sessions, respectively, as part of an ACIAR funded project (Culas et al., 2015). Three distributaries of the LCC East irrigation system, namely, Bhalak, Tarkhani, and Khikhi have been selected for the head, middle and tail reaches, respectively.

Table 1 presents the optimal water use scenario designed for the redistribution of water allocation following the economic modelling approach reported in Culas and Baig 2020. The optimal scenario suggests that when water use can be reallocated in terms of the percentages given for the canal and ground water, the following question (dependent variable), Can installation of tube wells at the head reach of the system to extract more groundwater help address the problem of poor water quality at the tail reach? The results are discussed in relation to various socioeconomic and technological factors (explanatory variables) that can improve the current water use pattern and for the farmers' adaptation behaviour towards more equitable and sustainable water use practices.
Figure 1: Location of the selected distributaries in the LCC East irrigation system

impact of salinity on the crop yield can be minimized (avoided). The base scenario included 60:40, 50:50, and 30:70 percentages of the canal and groundwater use at the head, middle and tail reaches (distributaries), respectively. Whereas the optimal water use scenario implies that more groundwater should be used at the head distributary (30:70) and more canal water should be used at the tail distributary (70:30).

Table 1: Optimal water use scenarios (base scenarios are given in brackets) (%)

<table>
<thead>
<tr>
<th>Scenario 3</th>
<th>Bhalak</th>
<th>Tarkhani</th>
<th>Khikhi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canal (surface) water</td>
<td>30 (60)</td>
<td>40 (50)</td>
<td>70 (30)</td>
</tr>
<tr>
<td>Ground water</td>
<td>70 (40)</td>
<td>60 (50)</td>
<td>30 (70)</td>
</tr>
<tr>
<td>Total water use</td>
<td>100 (100)</td>
<td>100 (100)</td>
<td>100 (100)</td>
</tr>
</tbody>
</table>

Source: Culas and Baig (2020)
Following the economic modelling approach and the optimal water use scenarios developed, as reported in Culas and Baig 2020, a discrete choice (PROBIT) model was empirically analysed for the farmers' adaptation behaviour. The PROBIT model is a type of regression where the dependent variable can take two values (1 = Yes, 0 = No).

The purpose of this model is to estimate the probability that an observation with particular characteristics will fall into a specific category (choice); moreover, an estimated probability greater than half is treated as classifying an observation into a predicted category. The PROBIT model is a type of binary classification and based on the cumulative normal probability function defined as:

\[ P_{1/i} = F(\alpha + \beta X_i) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} e^{-\frac{u^2}{2}} du \]  

Where:
- \( P_{1/i} \) = probability a certain practice/technology will be adopted by the \( i^{th} \) individual,
- \( F \) = cumulative normal probability function,
- \( U \) = standard normal deviate with mean zero and variance of one,
- \( \beta \) = vector of unknown parameters, and
- \( X_i \) = vector of independent variables.

Equation 1 states that \( P_{1/i} \) is the area under the standard normal curve between \(-\infty\) and \((\alpha + \beta X_i)\). The greater the value of \((\alpha + \beta X_i)\), the more likely is the chance that the \( i^{th} \) individual will adopt the practice/technology. The PROBIT model (linear model) can be derived by applying the inverse \( F^{-1} \) of the cumulative normal probability function of equation 1. The left-hand side of equation 2 increases in value from - to + as \( P_{1/i} \) increases from 0 to 1.

\[ F^{-1}(P_{1/i}) = (\alpha + \beta X_i) \]  

PROBIT models have been employed in a number of studies where the dependent variable is dichotomous in nature. For example, Bhandari and Pandey (2006) used PROBIT model to study the adoption of shallow tube wells in Nepal Terai; Khair et al. (2012) analysed PROBIT models to study the socioeconomic characters of farmers and groundwater markets in Balochistan, Pakistan.

**Empirical Model and the Results**

The empirical model analysed is detailed below. Farmers' response was recorded in terms of a binary response variable taking the value of '1' and '0' (as dependent variable). The models contain a list of explanatory variables where some of them are qualitative variables constructed in shape of dummy variables while the others are quantitative variables.
**Dependent Variable (1 = Yes, 0 = No)**

Can installation of tube wells at the head reach of the system to extract more groundwater help address the problem of poor water quality at the tail reach? This would make extra surface water available for the tail reach of the system. This option was put in front of the respondents and they were asked to show their willingness for this option. The response of the farmers was analysed by using discrete choice model thus enabling the water savings. The respondent was given a value of '1' if the above option (in relation to the optimal water use scenario) was acceptable to him while he was given a value of '0' if the base scenario (current pattern of) water use was acceptable to him.

**Qualitative Explanatory Variables**

**DWCL:** This dummy variable was based on the location (water course) of the farm with respect to head, middle or tail region of the each distributary. So if the respective water course of the farming household was located at the tail region of the distributary, the respondent was given a value of '0' while it was given a value of '1' otherwise (i.e. respective water course is located at the head or middle region of the distributary).

**DWCT:** The dummy variable DWCT was based on the response of the respondent with respect to the use of water conservation technologies. Farmers having deepest water table and marginal quality of water are more likely to adopt water-smart practices for groundwater management (Hussain *et al*., 2017; Zulfiqar and Thapa, 2018; Imran *et al*., 2019). Respondents were given multiple options to choose between them. Respondents who were using these technologies or ready to use these technologies were given the value '1' while rests of the respondents were given value '0'.

**DACM:** This is a quantitative variable developed from an index based on the ranking of the information sources (media) used by respondents. If respondent scored three or more, he was assigned a value '1' indicating access to the media while respondents scoring less than three were assigned a value '0' indicating no access to the media. In India, a positive and significant relationship between access to information and farm income was reported by many researchers (Birthal *et al*., 2015; Aryal *et al*., 2018; Sapkota *et al*., 2018) and Pakistan (Abid *et al*., 2015; Culas *et al*., 2016).

**DFO:** Farmer organization were introduced in the area to take care of the operation and maintenance of the irrigation channels (from distributary to canal onward) in different irrigation circles in Punjab. These organizations were meant to make farmers responsible for handling the water related issues and can serve as a good proxy for the level of social responsibility and interaction among the farmers (Culas *et al*., 2016; Aryal *et al*., 2018). So if the farmer was a
member of the farmer organization, he was assigned a value of '1' while a value of '0' was assigned otherwise. This variable served as a proxy for farmers' social mobility and influence in the area.

DCREDT: The dummy for access to credit was also used in the analysis as a proxy for the access to the resources and social status of the respondents. It is generally thought in Pakistan that more resourceful and powerful class has more access to the credit sources as compared to the poor and low income groups (Culas et al., 2016; Aryal et al., 2018). The binary response variable was developed on the basis of respondent's access to the formal credit sources. Respondent having access to these sources were assigned a value of '1' while the remaining were assigned a value of '0'.

DTRC: Wealth and assets play an important role in determining the impact of technology on resource use and management practices. To determine the wealth status of the respondents, a proxy variable was developed based on the ownership of tractor. Wealthier farmers are supposed to own a tractor so the owners of the tractors were assigned a value of '1' while the poor farmers for non-ownership of the tractor were assigned a value of '0'.

Quantitative Explanatory Variables
Apart from the qualitative variables that have been explained above, the quantitative variables included in the analysis are explained below.

AGE: Age of the farmer is an important socioeconomic variable which has been widely used in the economic analysis to capture the social status of the respondent (Culas et al., 2016; Hussain et al., 2017; Abbas et al., 2017; Aryal et al., 2018). Many researchers have already explained the role of the age in decision making process and ability of the respondent to adapt to the changes. Age of farmer (in years) is used as a proxy for the experience of the farmer.

NSYEAR: Education has widely been accepted as a pivotal factor in influencing the adaptation, decision making and management skills of the respondent (Abbas et al., 2017; Aryal et al., 2018). Number of schooling years of the respondents was included in the analysis as a proxy for education.

FSZE: Family size is another important social indicator that has been included in the analysis. The impact of family size on behaviour and adaptation pattern has already been reported in literature ((Mponela et al., 2016, Nkomoki et al., 2018; Kharti-Chhetri et al., 2016; Imran et al., 2018). Number of the dependent family member of the respondents has been included in the analysis to capture their impact on the dependent variable.

LANDHOLDING: The other important variable that was included in the analysis was the size of operational land holding
of the respondent. Rosenzweig and Evenson (1977) and Tiwari et al. (1999) determined that landholding is an important variable that affect the farming patterns and adaptation practices. In present analysis, operational agricultural landholding (in acres) of the respondent was included in the analysis.

The descriptive statistics of the quantitative variables are given in Table 2.

**Table 2:** Descriptive statistics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGE</td>
<td>15</td>
<td>96</td>
<td>59.58</td>
<td>13.146</td>
</tr>
<tr>
<td>NSYEAR</td>
<td>0.00</td>
<td>16.00</td>
<td>4.8585</td>
<td>4.9660</td>
</tr>
<tr>
<td>FSZE</td>
<td>1.0</td>
<td>15.0</td>
<td>4.454</td>
<td>3.2531</td>
</tr>
<tr>
<td>Landholding (Acres)</td>
<td>0.00</td>
<td>2018.50</td>
<td>16.7377</td>
<td>141.1942</td>
</tr>
<tr>
<td>EAGRIC</td>
<td>-</td>
<td>-</td>
<td>40.340</td>
<td>17.711</td>
</tr>
</tbody>
</table>

Source: Survey data

The results for the PROBIT model are given in Table 3. The results are presented in relation to various socioeconomic factors that can potentially improve the current water use patterns and farmers' adaptation towards more equitable and sustainable water management practices in relation to the optimal water use scenario (reallocation) detailed above.

**Table 3:** Results of the PROBIT Model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>Std. Error</th>
<th>Z</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>PROBIT a</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DWCL</td>
<td>-.119</td>
<td>.087</td>
<td>-1.369</td>
<td>.171</td>
</tr>
<tr>
<td>DWCT</td>
<td>.083</td>
<td>.063</td>
<td>1.312</td>
<td>.190</td>
</tr>
<tr>
<td>DACM</td>
<td>-.663</td>
<td>.095</td>
<td>-6.971</td>
<td>.000</td>
</tr>
<tr>
<td>DFO</td>
<td>.540</td>
<td>.072</td>
<td>7.467</td>
<td>.000</td>
</tr>
<tr>
<td>DCREDT</td>
<td>-.278</td>
<td>.234</td>
<td>-1.190</td>
<td>.234</td>
</tr>
<tr>
<td>DTRC</td>
<td>.062</td>
<td>.061</td>
<td>1.018</td>
<td>.309</td>
</tr>
<tr>
<td>AGE</td>
<td>.005</td>
<td>.002</td>
<td>2.143</td>
<td>.032</td>
</tr>
<tr>
<td>NSYEAR</td>
<td>-.003</td>
<td>.006</td>
<td>-1.458</td>
<td>.647</td>
</tr>
<tr>
<td>FSZE</td>
<td>-.026</td>
<td>.010</td>
<td>-2.667</td>
<td>.008</td>
</tr>
<tr>
<td>Landholding</td>
<td>.001</td>
<td>.000</td>
<td>3.524</td>
<td>.000</td>
</tr>
<tr>
<td>Intercept</td>
<td>-2.088</td>
<td>.192</td>
<td>-10.853</td>
<td>.000</td>
</tr>
</tbody>
</table>

**a.** PROBIT model: \( \text{PROBIT}(p) = \text{Intercept} + BX \)

**b.** Model is statistically significant at 0.1 level by Pearson Goodness-of-Fit Test
The implications of the results are that farmers recognise that the “equity” issue is there in relation to the current pattern of water user allocation among the distributaries (Razzaq et al., 2019), that the farmers who have more resources (land holding), experienced (aged) and membership with the farmer organisation recognised the need to have more water, available for redistribution, through more groundwater extraction from the distributary located at the head of the canal system (Culas and Baig, 2020). However, the farmers who have no access to media or information and large families seem to be concerned about the above (i.e. extracting more groundwater from the distributary located at the head of the canal system).

**Farmers’ Adaptation Options (Ranking)**
The respondents in the study area were also asked to rank the alternative options (choices available) for improvement in the base scenario water use pattern if it was unacceptable to them. Six different options to improve the water distribution were offered to the respondents so that the equity issue in water use among the distributaries can be addressed. These options were ranging from less canal water use at the head distributary to water trading and pricing option.

Table 4 presents the ranking of the options offered to the farmers based on their opinion. The table is only showing the first ranked option by the respondents. The ranking shows that majority of the farmers think that the best solution to the problem of water scarcity and distribution in water use lies in water reallocation (Mekonnen et al., 2016).

**Table 4: Ranking options offered to the farmers**

<table>
<thead>
<tr>
<th>Scenario Options</th>
<th>Bhalak</th>
<th>Tarkhani</th>
<th>Khikhi</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%</td>
<td>Rank</td>
<td>%</td>
<td>Rank</td>
</tr>
<tr>
<td>Less canal water at head</td>
<td>42 I</td>
<td>32 II</td>
<td>37 II</td>
<td>39 II</td>
</tr>
<tr>
<td>More conjunctive use for middle</td>
<td>41 II</td>
<td>40 I</td>
<td>43 I</td>
<td>41 I</td>
</tr>
<tr>
<td>More canal water use for tail</td>
<td>12 III</td>
<td>14 III</td>
<td>8 III</td>
<td>10 III</td>
</tr>
<tr>
<td>Changing the water rotation</td>
<td>2 IV</td>
<td>6 IV</td>
<td>4 IV</td>
<td>4 IV</td>
</tr>
<tr>
<td>Water trading</td>
<td>0 V</td>
<td>4 V</td>
<td>5 IV</td>
<td>4 IV</td>
</tr>
<tr>
<td>Economic incentives</td>
<td>2 IV</td>
<td>4 V</td>
<td>3 V</td>
<td>3 V</td>
</tr>
</tbody>
</table>

Source: Survey data
Conclusion
Pakistan is facing the challenge to cope with decreasing agricultural productivity due to poor water quality (salinity) along the irrigation canal systems. This study analysed a discrete choice (PROBIT) model to identify the variables that can influence the farmers' adaptation to reallocation of water use (optimal water use scenarios developed as reported in Culas and Baig 2020). It was found that farmers who have more resources (land holding), experienced (aged) and membership with farmer organisation recognised the need to have more water, available for redistribution, through more groundwater extraction from the distributary located at the head of the canal system. Further the ranking of the options available to the farmers made it clear that majority of the farmers were also not satisfied with the existing water use pattern (base scenarios) and they desired for improvement in the situation by adapting to alternative water use pattern (reallocation of water use as suggested by the optimal scenarios).

Acknowledgement
This paper is an outcome of the ACIAR funded projects in Pakistan (LWR/2005/144 and LWR/2015/011).

References


Culas, R.J. 2019. User allocation and implication on water quality and farm


