Modelling Water Allocation Decisions: A Conjoint Analysis Approach

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EXTENDED ABSTRACT

The principles set for the design of the irrigation water delivery system (i.e., *warabandi*[a]) of Pakistan does not effectively meet the needs of the existing situation. The farmers with the assistance of irrigation official have prevented the ongoing implementation of irrigation water delivery system rules. They have set their own rules that meet their crop-water demand (Bandaragoda 1996). Thus there is need to develop a decision support systems that can incorporate the needs of farmers regarding canal water supplies. Thus in this study a novel concept of water allocation based on multiple criteria has been employed. Given this, it is essential to know what factors or criteria influence water demand so that a decision support system can be developed to improve the productivity of scarce water resources.

Water allocation based on multiple criteria (attributes) maximizes the multiple benefits gained from the use of a unit amount of scarce water. In this study, we have applied the traditional conjoint analysis method (from marketing) and have determined the relative importance of five important water allocation attributes (net farm income, percent of family working on the farm, amount to irrigation agency for water share). Part-worths (utilities) for attribute levels were also estimated from the preferences on five water allocation attributes obtained in face-to-face interviews with sixty-two respondents. The survey was completed in selected parts of Sanghar and Nawabshah districts (Lower Indus River of Pakistan). The conjoint survey results revealed that the respondents prefer the 'annual net farm income' a the most important attribute in water allocation decisions. 'Water use efficiency' was the second most important attribute of water allocation. The vast majority of the respondents overwhelmingly placed the 'water price' charged by the local irrigation agency in the last category.

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a Warabandi is a rotational method for equitable distribution of the available water in an irrigation system by turns fixed according to a predetermined schedule specifying the day, time and duration of supply to each irrigator in proportion to the size of his landholding in the outlet command (Malhotra 1982).

1. INTRODUCTION

In fact, any water allocation decision based on a single criterion does not improve the water productivity as the multiple factors (attributes) are involved. However, water allocation decision based on multiple factors could maximize the water productivity and enhance the water use efficiency. Thus, in this paper we have considered multiple factors thought to be important in any water allocation decision. It focuses on the process of estimation of relative importance among the important water allocation attributes. This relative importance could be used to interpret which attribute should be dropped and which attribute should be given importance in water allocation decisions. Conjoint analysis is a technique for establishing the relative importance of different attributes (in a conjoint analysis study, criteria or factors are called attributes) in the provision of a good or a service (Pol and Ryan 1996). It has its origin in market research where it has been used to establish what attributes influence the demand for different commodities, and thereby what combinations of such attributes will maximize the benefits of a good or service. It has also been widely used in transport literature (JTEP 1988) and environmental literature (Desvousges *et al.* 1983; Opaluch *et al.* 1993). However, to date its application in the area of water resources management is very limited. The next section describes the conjoint analysis method and data collection process for this study. Following this, results are presented and discussed, and the conclusions are drawn concerning the relative importance of water allocation attributes.

2. DESCRIPTION OF CONJOINT ANALYSIS METHOD

Conjoint analysis is a multivariate technique developed specifically to understand how respondents develop preferences for any type of object (product or service or idea). It is based on the simple principle that respondents evaluate the value of an object (real or hypothetical) by combining the separate amounts of attribute values (Hair *et al.* 2006). Conjoint analysis is an appropriate research methodology for the study where multiple attributes are taken into account and a tradeoff between the attributes is made. It is unique among multivariate methods in that the researcher first constructs a set of real or hypothetical objects by combining selected levels of each attribute. Conjoint analysis, compared to other multivariate techniques, has few statistical assumptions, and accordingly, it is basically founded in theory when it concerns such issues as its design, estimation, and interpretation (Hair *et al.* 1998).

There are six stages in the design of a conjoint analysis study:

1. Establishing the attributes
2. Assigning attribute levels
3. Deciding which profiles to present to respondents
4. Establishing the preferences
5. Choosing a presentation method
6. Selecting a method for part-worths estimation

These six conjoint study stages within the context of water allocation study are explained as follows:

2.1. Establishing the attributes

The first stage in a conjoint analysis study is to decide the attributes that could be included. The selection of attributes is a very important stage in conjoint study as the final output of the study entirely depends on the included attributes. Initially ten water allocation attributes were discussed with a focus group of 20 people belonging to an agricultural decision body. These people were actively involved in farm and water management decisions as most of them were managing their own agricultural farms. Some of them were running their own agro-based business. The discussion with the focus group ended with the selection of five attributes that thought to be the most important water allocation attributes and were included in this conjoint analysis study. The attributes included were: percent of individual farmer's family working on the farm, the amount paid to Provincial Irrigation Department (PID) for weekly water share, the annual net farm income, water use efficiency in terms of 'value of water', and the groundwater quality beneath the farm.

2.2. Assigning attribute levels

After the selection of attributes, available choice levels for the attributes are assigned. The attribute levels should be plausible, actionable and capable of being traded-off (Pol and Ryan 1996). In this conjoint study, the attribute levels are based on the survey data analysis gathered from 184 farms situated in Sanghar and Nawabshah districts of Sindh, Pakistan. The first and the third levels of each attribute were decided on the minimum and maximum values of that attribute obtained from the survey. For example, on the average, minimum and maximum amount paid to the PID for weekly water share was found as USD 13 and USD 25 per hectare per year respectively. These figures were assigned Level 1 and Level 3 to that particular attribute. The average amount paid to PID was determined as about USD 18 per hectare per year. Thus, Level 2 of that particular attribute was decided as 13-25 USD/ha per year. On the similar principle, the levels to other attributes were determined. The attributes and levels included in the conjoint analysis study are shown in Table 1.

Table 1. Attributes of water allocation and their levels

Attributes	Units	Level 1	Level 2	Level 3
Percent of family working on the farm	%	<50	50-80	>80
Amount paid to PID for weekly water share	USD/ha	<13	13-25	>25
Water use efficiency (value of water)	%	<40	40-70	>70
Annual net farm income	USD/ha	<500	500-1,250	>1,250
Groundwater quality beneath the farm	----	Fresh	Marginal	Saline

2.3. Deciding which profiles to present

Having established the attributes and their levels, hypothetical profiles (scenarios) with different combinations of attributes are presented to individuals. The attributes and levels chosen in this study gave rise to 243 possible profiles for the water allocation problem (i.e., 3^5). Obviously, it would have been impractical to ask individuals their preferences for so many profiles. Many methods exist to reduce the number of profiles to a manageable level. These include the use of fractional factorial designs; removing options that will dominate or be dominated by all other options; and dividing the possible options into blocks and establishing respondents' preferences for a block of possible profiles. It was decided to use a fractional factorial design using the statistical package Orthoplan provided in SPSS 11.5 (SPSS Inc, 2000). The use of Orthoplan results in an orthogonal main-effects design, thus ensuring the absence of multi-collinearity between attributes. This also assumes no interaction between the attributes. Using orthogonal main-effects design, 243 possible profiles were reduced to 16. The description of each profile presented to the respondent is shown in Table 2. The aggregate preferences for each profile assigned by 62 survey participants are shown in the last column of Table 2.

Table 2. List of profiles presented to the survey participants

Profile No.	Percent of family working on the farm (%)	Amount paid to PID for weekly water share (USD/ha)	Water use efficiency (value of water) (%)	Annual net farm income (USD/ha)	Ground water quality beneath the farm	Aggregate preferences on 5-point rating scale (n=62)
1	>80	<13	40-70	500-1,250	Fresh	2.25
2	50-80	<13	<40	>1,250	Marginal	4.35
3	50-80	13-25	40-70	<500	Fresh	4.10
4	<50	<13	>70	500-1,250	Saline	7.80*
5	>80	13-25	40-70	<500	Fresh	4.00
6	>80	>25	<40	>1,250	Saline	3.50
7	50-80	13-25	>70	<500	Fresh	2.75
8	>80	<13	40-70	<500	Saline	2.15
9	>80	13-25	40-70	>1,250	Fresh	8.18*
10	<50	<13	>70	>1,250	Marginal	3.92
11	50-80	13-25	<40	500-1,250	Saline	3.40
12	<50	<13	<40	<500	Fresh	1.55
13	50-80	>25	40-70	500-1,250	Fresh	4.12
14	>80	<13	<40	<500	Saline	3.00
15	<50	>25	40-70	<500	Fresh	1.60
16	50-80	13-25	40-70	<500	Marginal	3.74

*For these two profiles, a bias in rating was observed as they had more chances of rating in a pairwise comparison approach

2.4. Establishing preferences

After the design of attributes, attribute levels, and the profiles to be presented to individuals, next step is to obtain the preferences for profiles from the respondents. The decision on the type of preference measure to be used must be based on practical as well as conceptual issues. Many researchers favor the rank-order measure because it depicts the underlying choice process inherent in conjoint analysis. From a practical perspective, however, the effort of ranking large numbers of stimuli becomes overwhelming. On the other hand, the ratings measure has the inherent advantage of being easy to administer in any type of data collection context. Because of this characteristic, a rating preference measure was selected for this study to determine the respondents' preferences between nominated profiles. Each respondent was asked to rate the profiles on a scale from one to five (1=equal importance; 2=weak importance; 3=strong importance; 4=very strong importance; 5=absolute importance) in a pairwise comparison approach.

2.5. Choosing a presentation method

There are three methods by which the profiles are presented to the respondents in a conjoint analysis study. These presentation methods are: Trade-off, full-profile, and pairwise comparison (Orme

2002). In this study, a pairwise comparison was selected as a profile presentation method. The 16 profiles produced by the SPSS orthogonal design were randomly split into two equal groups, each with 8 profiles. Within each group one profile was randomly chosen, and each of the remaining 7 profiles was compared to this chosen profile. These two groups formed the basis of two separate conjoint analysis questionnaires consisting of 7 pairwise choices. Subjects were randomly allocated between these two questionnaires. An example of one of the pairwise choices is shown in Figure 1. A five-point rating scale was used to show the preference for one profile relative to the other. Along with the pairwise comparison of different profiles, some demographic information questions were also included in the questionnaire.

Q: Which profile do you think should get more priority in water allocations?

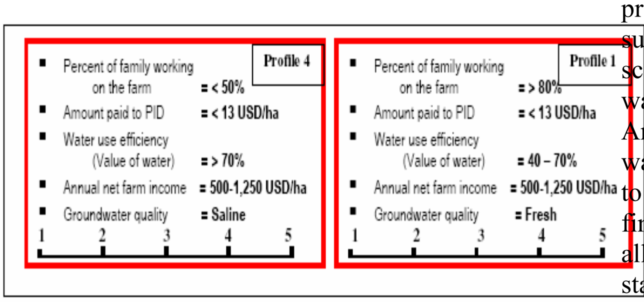

Figure 1. An example of pairwise comparison of profiles

2.6. Selecting method for part-worth estimation

Estimating the part-worths for each attribute level and the relative importance of the various attributes are two main objectives of a conjoint analysis study. To achieve those objectives, the researcher has to specify a relationship between the attributes and utility. The simplest and most commonly used model is the linear additive model which assumes that the overall utility derived from any combination of attributes of a given profile is given by the sum of the separate part-worths (utilities) of the attributes. Research has shown that other models (for example, interactive model) rarely result in a better fit than the linear additive model (Emery and Barron 1979; Pol and Ryan 1996). The linear additive model is specified as:

$$U = \beta_0 + \beta_1 \text{ Family} + \beta_2 \text{ PID} + \beta_3 \text{ Income} + \beta_4 \text{ Efficiency} + \beta_5 \text{ Quality}$$

Where

U = utility or preference score for a profile with a given level of each attribute;

β_0 to β_5 = the coefficients of the model to be estimated; and

Family, PID, Income, Efficiency, and Quality = the attributes included in this conjoint study as shown in Table 1.

3. QUESTIONNAIRE DESIGN AND DATA COLLECTION

The results from the preliminary survey regarding the ranking of ten water allocation attributes from 20 decision makers suggested that individuals understood the questionnaire and showed their preferences in a meaningful way. However, some respondents felt difficulties in assigning the rankings to the attributes and suggested that the preferences scale should be flexible. Based on their suggestions and grievances regarding the ranking scale of preferences, a rating scale of preferences was selected for the final conjoint questionnaire. Another problem faced by the survey participants was the large number of attributes they were asked to rank. In order to minimize that problem in the final conjoint questionnaire, the size of water allocation attributes was reduced to five. At this stage, less important attributes were dropped and only the five most important attributes were included in the final version of the conjoint questionnaire. These water allocation attributes include: labor employed in the farming, farmer' income, revenue generated by PID, water use efficiency, and groundwater quality beneath the agricultural farm. Three levels of each attribute were then specified. The attribute levels were selected to capture the full range of values for each attribute and to vary sufficiently so that respondents can detect differences. A face-to-face survey was conducted with 62 decision makers in Lower Indus River Basin of Pakistan (parts of districts Nawabshah and Sanghar). Each respondent was asked to assign ratings to the alternative (profile) he prefers in water allocations in a pairwise comparison. Each profile was displayed on a sample card that contained a different mix of the levels for the five water allocation attributes shown in Table 2. Only one level of each attribute was presented in a single profile. An SPSS orthogonal sample design was used to select the particular levels to be included on each card to allow estimation over the entire range of profiles. Sixteen profiles were produced. A full-profile approach (combining with pairwise comparison) to data collection was used in this research. Profiles were presented to decision makers. Decision makers were asked to rate each scenario on a 5-point scale.

4. RESULTS AND DISCUSSION

4.1. Estimation of Part-worths

The preferences assigned to sixteen profiles were analyzed with the conjoint procedure (available only through command syntax in SPSS 11.5 standard version) to estimate the part-worths for each level of each attribute. The estimated part-worths, analogous to regression coefficients of the linear multiple regression method, provide a quantitative measure of the preference for each attribute level, with larger values corresponding to greater preference. Part-worths are expressed in a common unit, allowing them to be added together to give the total utility, or overall preference, for any combination of attribute levels. In SPSS conjoint procedure, two water allocation attributes, i.e., groundwater quality and income to PID, were assumed as discrete data and a linear relationship was assumed for other water allocation attributes. The estimated part-worths for each attribute level along with the relative importance of attribute are shown in Table 3. Figure 2 shows the trend of estimated part-worths for each level of five water allocation attributes.

4.2. Relative importance of attributes

As the estimated part-worths are on a common scale, so the relative importance of each attribute can be computed directly. The importance of an attribute is represented by the range of its levels (i.e., the difference between the highest and lowest values of part-worths) divided by the sum of the ranges across all attributes. This calculation provides a relative impact or importance of each attribute based on the size of the range of its part-worth estimates. Attributes with a larger range for their part-worths have a greater impact on the calculated utility values and thus are deemed of greater importance. The relative importance weights across all attributes will total 100 percent. The relative importance of the five water allocation attributes is shown in Table 3 and Figure 3.

The sign of the part-worth coefficients in Table 3 indicates the direction in which the attributes influence preferences. A more positive (or negative) part-worth coefficient indicates, other things being equal, a higher influence of that attribute on the overall preference or utility value.

Table 3. Estimated part-worths and relative attribute importance

Attributes	Attribute levels	Estimated part-worths	Range of part-worths (highest part-worth – lowest part-worth)	Relative attribute importance
Percent of family working on the farm (%)	<50 50-80 >80	0.37 0.74 1.10	1.10-0.37=0.73	(0.73/3.84)*100 = 19.0%
Amount paid to PID for weekly canal water share (USD/ha)	<13 13-25 >25	0.16 -0.20 0.04	0.16-(-0.20)=0.36	(0.36/3.84)*100 = 9.0%
Water use efficiency (%)	<40 40-70 >70	0.41 0.83 1.24	1.24-0.41=0.83	(0.83/3.84)*100 = 22.0%
Annual net farm income (USD/ha)	<500 500-1,250 >1250	0.75 1.50 2.25	2.25-0.75=1.5	(1.5/3.84)*100 = 39.0%
Quality of groundwater beneath the farm	Fresh Marginal Saline	-0.25 0.08 0.17	0.17-(-0.25)=0.42	(0.42/3.84)*100 = 11.0%

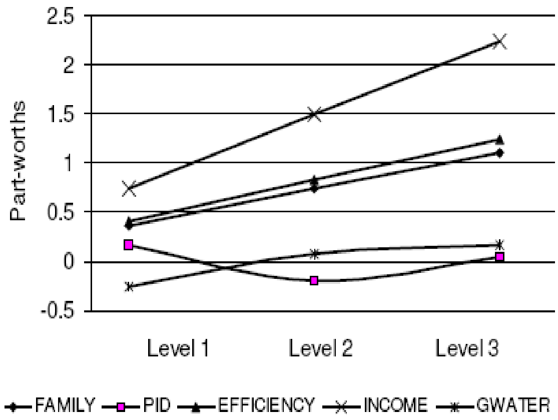

Figure 2. Plot of estimated part-worths

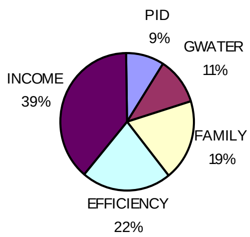

Figure 3. Relative importance of water allocation attributes

The higher range of part-worths for 'annual net farm income' attribute indicates that respondents consider this an important attribute in water allocation decisions. The positive value of 2.25 for Level 3 of ‘annual net farm income’ attribute means that a unit increase in annual net farm income (for instance from Level 2 to Level 3) will increase the preference or utility value of ‘annual net farm income’ by 2.25. On the other hand, the negative signs on the coefficients of Level 2 of ‘amount paid to PID’ (i.e., -0.20) and for the ‘fresh’ quality of available groundwater (i.e., -0.25) suggest that those two levels did not influence the respondents’ preferences given to the profiles and were not very important in any water allocation decision.

5. CONJOINT RESULTS INTERPRETATION

From the relative importance weights for each attribute, it can be seen that the respondents gave more importance to the ‘net farm income’ attribute compared to other water allocation attributes by assigning 39% as relative weight to that particular attribute out of 100% relative importance (last column in Table 3). It means the respondents preferred to allocate water to the higher income farmers. The respondents considered ‘water use efficiency’ the second most important water allocation attribute (with relative weight equal to 22.0%) followed by the ‘percent of family working on the farm’ attribute (19%). The least important attribute to the respondents was ‘amount paid to PID’ (with relative importance of 9.0%). An individual was willing to improve water use efficiency rather than to engage more family members to participate in farming (as Table 3 shows that the part-worths for each level of ‘ water use efficiency’ are higher than the part-worths for each corresponding level of ‘family working on the farm’). In comparison to the groundwater quality attribute with the remaining water allocation attributes, the respondents prefer water allocations to go to the less efficient water users, lower income earners, and the districts where very low amount was paid to PID for water supplies rather than to the areas where ‘fresh’ groundwater is available. Respondents gave equal priority in water allocations to the saline groundwater areas and the areas where the farmers were on average paying <13 USD/ha to PID for their water share (0.17 and 0.16 part-worths respectively for saline groundwater and paying <13 USD/ha to PID). Respondents could not differentiate water allocations between Level 1 of ‘annual net farm income’ (i.e. <500 USD/ha) and Level 2 of ‘percent of family working on the farm’ (i.e. 50-80%); the part-worths were 0.75 and 0.74 respectively.

If the farmers were asked to choose one from two options of: either to raise their farm income from the existing income of ≤500 USD/ha to ≥1,250 USD/ha or to increase their family input in the farming from an existing percent of family working on farm of ≤50% to ≥80%, the farmers would be twice as attracted to raise the net farm income than putting more family members into farming - as the part-worths difference between two extreme levels of net farm income was 1.5 (2.25-0.75 = 1.5) and the part-worth difference between lowest and the highest levels of ‘percent of family working on farm’ attribute was 0.73 (1.10-0.37 = 0.73). The conjoint analysis findings indicate that when rating the alternative water allocation profiles, the respondents attached the highest value to the “>1,250 USD/ha” level of farm income, “<13 USD/ha” of amount paid to PID, “>70%” of water use efficiency, “>80%” level of family working on the farm, and “saline” groundwater quality. Thus, the total utility of an ideal agricultural farm would be: U = 2.25 + 0.16 + 1.24 + 1.10 + 0.17 = 4.92

6. CONCLUDING COMMENTS

The application of conjoint analysis in determining the importance of different water allocation attributes is a novel approach. We considered only five water allocation attributes for the current conjoint study because the traditional conjoint analysis method was selected and applied to the survey data. If advance conjoint analysis method (for example, adaptive conjoint analysis) was chosen to analyze the conjoint data then it would be possible to include more than five water allocation attributes. Thus the interpretation of conjoint results is more specific to the attributes included and the levels of attributes selected for this conjoint study. The results of this conjoint analysis study give some insight into respondents’ preferences for water allocation attributes. Five water allocation attributes that were determined as the most important attributes from the results of a preliminary survey were included. The levels for each attribute were decided from a larger size of survey data gathered from 184 farms located in the Lower Indus River of Pakistan. Sixty-two respondents filled the conjoint questionnaire and showed their preferences on five water allocation attributes. The conjoint data analysis reveals that the respondents were more attracted to the ‘net farm income’ attribute than any of other attributes. The respondent gave equal importance to ‘water use efficiency’ and ‘family working on the farm’ attributes by assigning relative weights to 22 and 19% respectively. ‘Amount paid to PID’ and ‘quality of groundwater’ attributes were assigned the lowest preferences.

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