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Estimation of Water Demand of Agriculture Sector by Water-Yield Function (Case Study: Sistan Province)

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Abstract

In this study, yield-water and profit function was used to obtain water demand function in agriculture sector. The results showed that the ratio of actual to potential Evapotranspiration had positive, significant effect on the ratio of actual to potential yield for wheat and barley. Also, square ratio of actual to potential Evapotranspiration had negative, significant relationship. After estimation of product function, water demand function for agriculture sector was obtained by profit function. Price elasticity of water demand for agriculture was -1.10 being less than -1 and showing that price policies can be an important factor in the control of non-optimum use of their valuable inputs.

Keywords:
Barely, Demand function, Profit function, Water- yield production function, Wheat

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INTRODUCTION

All living species need water for their survival. In addition, water is of vital importance in industrial, agricultural, metabolism, and other applications. The highest water consumption in Iran is in agriculture sector up to as high as about 90% (Amirnejad, 2006). As Iran is placed in a dry and semi-dry region, it suffers from water deficiency and it is necessary to consider the issue of water and especially water consumed in agriculture sector.

The two large components of agricultural water demand are irrigation demand and stock water demand. In this study, the former component was only considered. The most common methods for estimating agricultural demand are regression analysis and mathematical programming (Hooker and Alexander, 1998). This study uses non-linear programming models to estimate agricultural demand functions for irrigation districts in Sistan area. These programming models are used to predict optimal farm plans based on assumed input costs, product prices, and water-yield production functions. While programming models are one approach to estimate irrigation demands, an analogous approach in microeconomic theory would be to formulate the problem as a profit maximization problem and to derive a continuous factor demand for irrigation water using duality theory. The programming approaches have the advantage of explicit assumption about the interaction between inputs and outputs, and different types of technologies.

Mahan (1997) used nonlinear programming models to estimate agricultural demand function for irrigation districts in Southern Alberta. Wang (2005) used Irrigation Water Planning Model (IWPM) for deriving benefit functions of irrigation water which maximized the total profit of irrigated crop productions. When field survey data are limited, the economic benefit functions for irrigation water use may be derived using this model. In this study, water demand in agricultural sector was estimated by crop-water function and profit function in Sistan area.

MATERIALS AND METHODS

Crop production functions can be identified as having four categories: evapotranspiration and transpiration models, simulation models, estimated models, and hybrid models (Montazer and Riazy, 2008). Evapotranspiration models utilize linear yield-evapotranspiration relationships. Although evapotranspiration and transpiration models capture important aspects of crop-water relationships, they have limited ability to capture the impacts of non-water inputs and are of limited use for policy analysis. The simulation models simulate the crop production process in detail, while hybrid models combine aspects of the other three types. Among these model types, estimated production functions are more flexible than other types of models, and polynomial or quadratic functions are most widely used. In the present study, estimated models were used to estimate the production function. All irrigated crops in the region have their own water-crop functions. These functions are estimated by regression methods.

The quadratic polynomial form of crop production functions proposed by Dinar and Letey (1996) is expressed as follows

$$Y_a/Y_m = f(w) = a_0 + a_1 w + a_7 w^2 \quad (1)$$

Where, *Ya* is the actual crop yield (metric tons (mt)/ha); *Ym* is the maximum potential crop yield (mt/ha); $w = WA/ETm$, is the ratio of the total available water *WA* (mm) to maximum seasonal potential evapotranspiration of the crop *ETm* (mm); the total water available to a crop includes effective rainfall, water irrigation and soil moisture (Mahan *et al*., 2002). Assuming that the crop areas and irrigation efficiency are constant throughout the growing season, we have

$$WA_{j,cp} = SM_{j,cp} + EP_{j,cp} + EI_{j,cp} \quad (2)$$

Where, $WA_{j,cp}$ is the total water available to a crop field during whole growing season (mm); $SM_{j,cp}$ is soil moisture in the root zone at the beginning of the crop growing season (mm); $EP_{j,cp,t}$ is effective precipitation (mm) and $EI_{j,cp}$ is effective water applied to a crop field during period t (mm). Actual evapotranspiration is estimated based on the sum of spring soil moisture, effective precipitation during the growing season and the level of effective irrigation during the

growing season that depends on timing and irrigation technology (Mahan, 1997).

Effective precipitation is zero for both wheat and barley in Sistan and since there was no information about the amount of moisture in the soil of this region, it was ignored in the calculations and it was assumed to be hidden in the effective irrigation.

Actual evapotranspiration was effective irrigation during the growing season. Potential evaporation was calculated by the use of monthly meteorological data for 26 years and CROPWAT software package and Penman-Manteith method. In Penman-Manteith method, potential evaporation is calculated on the basis of a daily or monthly period. In the present study, monthly evaporation was calculated as follows

$$Et_a = K_c \times ET_o \quad (3)$$

Where, ET_a is the amount of actual evaporation, K_c is crop coefficient which is different for various crops, and ET_o is potential evaporation (Alizadeh, 1995).

Demand function is estimated by profit function. Therefore, given the production function, the total profit of irrigation water use at demand site j was calculated based on the empirical seasonal crop-water yields functions, which is expressed as follows (Wang *et al*., 2006)

$$\widetilde{B}_j = \sum pcp_{j,cp}.Ya_{j,cp}.AF_{j,cp} - \sum vc_{j,cp}.AF_{j,cp} \quad (4)$$

Where, $pcp_{j,cp}$ is the crop price, $cc_{j,cp}$ is the cultivation cost, and $vc_{j,cp}$ is the variable cost. The objective function is specified as

$$\begin{aligned} &\max \quad \widetilde{\beta}_j \\ &s.t: \quad \sum_{cp} AF_{j,cp} \le A_j \qquad \forall j \\ &AF^{l}{}_{j,cp} \le AF_{j,cp} \le AF^{u}{}_{j,cp} \qquad \forall j,cp \\ &\sum_{cp} EI_{j,cp}.AF_{j,cp} \le Q \qquad \forall j \end{aligned} \quad (5)$$

Where, A_j is land area (ha) in region j, $AF^u_{j,cp}$ and $AF^l_{j,cp}$ are minimum and maximum area limits for each crop, respectively, $EI_{j,cp}$ is effective irrigation during growing season (m³/h), and Q is total water volume limit in site j. The demand function is estimated by solving model for various levels of effective irrigation water availability and plotting the corresponding shadow prices. The shadow prices of the water availability constraint measures the change in the objective function caused by a slight relaxation of the resource constraint. It can be interpreted as measuring the marginal value of water. Algebraically, the shadow price can expressed as follows (Mahan *et al*., 2002)

$$MVW_j = \Delta\pi_j / \Delta Q_j \quad (6)$$

Where, MVW_{ij} denotes the marginal value of water (IRR/m³) in site j, $\Delta\pi_{ij}$ is the change in profit (IRR) for a slight change in Q in region j, and ΔQ_j denotes the change in the total quantity of effective irrigation water in region j.

RESULTS AND DISCUSSION

Sistan area in the north of Sistan and Baluchestan Province is located to the southeast of Iran between the longitudes of 60°15' and 60°50' and latitudes of 30°50' and 31°28' (Kehkha *et al.*, 2004). The Hirmand river, which originates in Afghanistan, is the main water provider for this region and second most important border river of Iran among 26 border rivers (Ministry of Agriculture, 2000).

The average rainfall of the Sistan region is about 100 mm/yr as compared with an evaporation rate of about 4000 mm/yr. With about 245 000 ha of cultivable land, Zabol is the agricultural centre of the province (Ministry of Agriculture, 2000). The cultivation area depends on the Hirmand flow. The most important crops are wheat, barley, watermelon, melon, alfalfa, clover, and sorghum in the order of importance.

The agricultural water is solely supplied by the branches of the Hirmand river as well as the Sistan and Parian rivers. According Ministry of Agriculture (2000), about 82 500 ha of districts are irrigated by the Sistan river called Chah-Nimeh Irrigation Network. Ministry of Agriculture (2000), also, reports that annually about 1 250 million m³ of the total incoming water from the Sistan river and the canals of the common Parian river and also Chah-Nimeh water reservoir are used for agriculture. This varies from 900 million m³ to 1500 million m³ per year. About 177 million m³ of 1250 million m³ are supplied by the Chah-Nimeh reservoir (Kehkhah *et al.*, 2004).

Areas studied in this research included Shipap and Poshtab in Sistan region. Their water re-

quirement for agriculture is met by the reservoirs of Chah-Nimeh. They were selected for the study because they have same water supply sources. Also only wheat and barley were chose to avoid large model given the fact that they have the largest area under cultivation and the importance in the region.

Water-yield function estimated for wheat and barley was as follows

$$Ya/Ym = -0.97 + 0.16W - 0.067W^2$$
$$R^2 = 0.38 \qquad D.W = 1.7 \qquad F = 3 \qquad \text{ForWheat} \quad (7)$$

$$Ya/Ym = -0.6 + 0.1W - 0.0037W^2$$
$$R^2 = 0.40 \qquad D.W = 2 \qquad F = 3 \qquad \text{For barely} \quad (8)$$

Equation (7) indicates water-yield function for wheat and Equation (8) shows water-yield function for barely. The results indicate that the ratio of actual evaporation to potential evaporation has positive and significant effect on the ratio of actual yield to potential yield and the square ratio of actual evaporation to potential evaporation has negative, significant relationship.

Water demand function of agricultural sector

Demand function was estimated by profit function according to Equation (4). The benefit functions of agricultural demand sites are estimated by Irrigation Water Planning Model (IWPM) with different annual water availabilities. These programming models are used to predict optimal farm plans based on assumed input costs, product prices, and water-yield production function.

After the estimation of profit function, irrigation water demand of agriculture sector can be estimated by shadow prices obtained from profit function. The shadow price of the water availability constraint measures the change in the objective function caused by a slight relaxation of the resource constraint. It can be interpreted as measuring the marginal value of water at the corresponding level of resource availability. Therefore, the right side of water resources limitation was changed and a shadow price was obtained for each change in the limitation of water resources. The shado price was obtained as 1.50 (thousand IRR) for water. One unit increase in water amount, the profit is increased by 1.50 thousand IRR.

Also, 50 price-quantity pairs were estimated and then irrigation water demand was obtained by fitting regression equations to these demand schedules. Functional form was estimated including translog. In the model, the demand function is a function of price. Irrigation water demand is indicated in Graph 1 and Equation 9.

$$Q = 1.45 \times 10^{11} P^{-1.10} \qquad (9)$$

The results showed that the quantity of water demand is inversely related to the price of water so that higher water price results in lower demand for water.

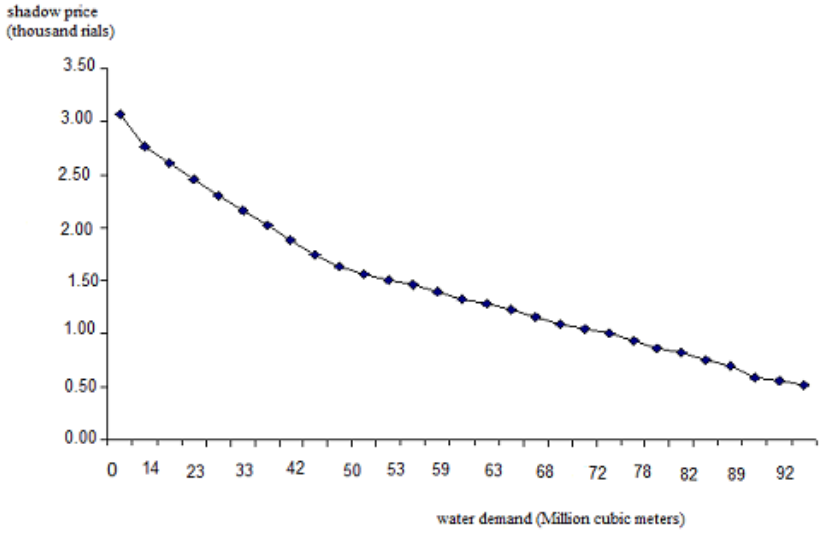

Figure 1: Irrigation water demand

The coefficient estimated for water price in demand function shows water price elasticity. The elasticity of water consumption in agriculture is -1.10. The elasticity of >1 showed high importance of pricing policy in the controlled use of this input in order to optimize the use.

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