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Estimation of farmers' willingness to pay for water in the agricultural sector

Omid Bozorg-Haddad (Professor)[a,*], Marzie Malmier (Ph.D. of Water Resources Engineering)[a], Sahar Mohammad-Azari (Ph.D.)[a], Hugo A. Loáiciga (Professor)[b]

[a] *Department of Irrigation & Reclamation Engineering, Faculty of Agricultural Engineering & Technology, College of Agriculture & Natural Resources, University of Tehran, Karaj, Tehran, Iran*

[b] *Department of Geography, University of California, Santa Barbara, CA 93106, United States*

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ABSTRACT

Increasing the reliability of irrigation water raises the cost of water storage and the price that farmers must pay for water. Evaluating farmers' willingness to pay (WTP) for water is key to determining the reliability of irrigation water achievable. This paper presents a probabilistic optimization method for estimating the WTP to avoid water shortage. A nonlinear programming model was formulated to model water use and estimate a single farmer's WTP when water shortage occurs. The model was subsequently expanded to include the WTP of a group of farmers relying on Monte Carlo simulation. Results show that low water prices do not have any effect on water use when there is no shortage of water. Facing water shortage, farmers employ irrigation systems with high efficiency to reduce the use and cost of irrigation water. They also change the cropping pattern to cultivate crops with low water requirements. The farmers' WTP for irrigation water during shortage is assessed probabilistically and is found to be highly variable.

1. Introduction

Determining water's economic value is a useful tool to improve water allocation, reduce wasteful use, and to achieve sustainable water management. In spite of various studies about water pricing in the agricultural sector, determining the economic value of water in the agricultural sector remains elusive for decision makers. In this respect, the farmers' willingness to pay for water reflects its value from the farmers' viewpoint. The WTP is the maximum amount that an individual agrees to pay for a product or service. It can be used for determining water price (Baghestani and Zibaei, 2010). There have been a few attempts to estimate the WTP for water in the agricultural sector. Most of these studies were empirical and applied either price elasticity or the contingent valuation method (CVM).

The CVM is applied by asking questions to farmers about their WTP for water use (Mitchell and Carson, 1989). This method requires an initial experimental survey followed by a detailed survey, both of which may be costly. Respondents (farmers) might not have a clear concept about the actual value of water, and their estimates may be more or less than the actual value. Nevertheless, the CVM has been applied by several authors. Baghestani and Zibaei (2010) estimated farmers' WTP for groundwater using the CVM and showed that farmers that use surface and ground water conjunctively have lower WTP compared with farmers that used groundwater as the only source of water. Rasekhi et al. (2012) implemented the CVM for estimating tourists' WTP for the recreational use of the Khazar coastal region (Iran). Their results showed that the educational level of tourists had a significant effect on their WTP for recreational amenities. Kwak et al. (2013) applied the CVM to determine the economic benefits of improving the quality of tap water in Pusan, Korea. Markantonis et al. (2013) used the CVM to evaluate the environmental cost of floods in the Evros river (Greece). These costs were evaluated by asking hunters, farmers, and local authorities about their WTP to avoid the effects of floods on soil and the environment. Results demonstrated the usefulness of the CVM in flood risk management. Tang et al. (2013) estimated farmers' WTP for water with the CVM. Results showed that the current price of water in the agricultural sector is low, and the

* Corresponding author.
E-mail addresses: OBHaddad@ut.ac.ir (O. Bozorg-Haddad), Mrzh_Malmir@yahoo.com (M. Malmier), Sahar.MAzari@ut.ac.ir (S. Mohammad-Azari), Hugo.Loaiciga@ucsb.edu (H.A. Loáiciga).

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major reason for this is that farmers are reticent to pay for irrigation water. Musavi (2015) applied the CVM to estimate the value of Khafr waterfall and recreational facilities. Results indicated that 75% of visitors agreed to pay for the use of the waterfall. Their age, education, and revenue had significant effect on the tourists' WTP.

Approaches other than the CVM have also been reported to estimate the WTP. Lund (1995) and Wilchfort and Lund (1997) introduced a two-stage optimization model to estimate households' WTP for water. Griffin and Mjelde (2000) applied the CVM for valuing water supply reliability. Salman and Al-Karablieh (2004) reported a linear programming model with an objective function of maximizing the benefits of crops' production to determine farmers' WTP for water. Chandrasekaran et al. (2009) determined water's economic value by researching the farmers' WTP for increases in the reliability of water supply. Falsafi-Zadeh and Sabouhi (2010) estimated the farmers' WTP with the choice experiments method. Results showed that farmers' WTP is between 10 to 15 percent of water charges. Hadadin et al. (2010) focused on water shortage in Jordan. They presented recommendations addressing water resource shortage in the kingdom and highlighting the importance of conservation of water and discussing the basics of sustainable solution. Medellin-Azuara et al. (2012) investigated the effect of water rationing, pricing and subsidies on water use in the agricultural sector. Policy simulation in this study included increase in subsides and water price rationing, w which indicated that subsidies may have little effect on total water use and may not promote water conservation without incentives. Adeniji et al. (2013) investigated strategies to cope with water supply shortages to households in Nigeria. Alarcon et al. (2014) investigated beneficial ways of allocating water during water shortage for irrigation. Onyango et al. (2014) researched the factors influencing farmers' WTP for water use in Kenya.

Recently developed statistical and optimization techniques in different field of water resources investigations (Ashofteh et al., 2013, 2015a,b,c; Beygi et al., 2014; Bozorg-Haddad et al., 2013, 2014, 2015a,b; Bolouri-Yazdeli et al., 2014; Fallah-Mehdipour et al., 2013; Orouji et al., 2013, 2014; Shokri et al., 2013, 2014; Soltanjalili et al., 2013) have not addressed the estimation of farmers' willingness to pay for water in the agricultural sector, which is the subject of the present study.

Unlike the methods that have been used to estimate farmers' WTP for water, the probabilistic optimization approach considers shortages occurring during water supply in the agricultural water sector and the determination of the water price and water rationing effects on the WTP, which sets it apart from other approaches. Furthermore, the probabilistic approach incorporates water shortage probabilities in the optimization model, which better captures actual hydrological conditions.

This study implements the method reported by Garcia-Alcubilla and Lund (2006) to estimate farmers' WTP to avoid water shortage. The latter authors applied a linear optimization model to estimate the WTP in the residential sector. This paper's nonlinear optimization model deals with the agricultural water sector. The Monte Carlo simulation method is applied to assess the uncertainty in model parameters and to derive water-demand curves of farmers.

1.1. Measuring the willingness to pay

Techniques for measuring the WTP are classified as those involving revealed preferences (RP) and those involving stated preferences (SP). The RP method derives the price of a product or service by observing individuals' behavior in markets. The SP method derives prices directly by asking individuals about their preferences. The advantage of the SP method is that it estimates 4 use and non-use values, while the RP estimates the use value of a product or service. The use value of water for residential, industrial, and agricultural customers is obvious, while its non-use value stems from its physical and cultural characteristics.

The most commonly used method for WTP estimation is the CVM, which is determined from surveys aimed at users of a good or service (water for irrigation in this case). This work relies on an indirect method for WTP estimation.

2. Materials and methods

This study applies a probabilistic optimization model to estimate farmer's WTP. Maximization of farmer's revenue from crop production is the objective function of the optimization model when there are shortages in water supply.

The goal of farmers is to maximize their income at any level of probabilistic shortage when there is water rationing for irrigation. The economic incentives for water conservation involve water pricing and rationing. Two types of decision variables are considered in the optimization model to evaluate farmers' response to incentives and derive their WTP. These decision variables include water conservation options that farmers implement to avoid shortage, such as optimizing the cropping pattern and deploying irrigation systems with high water efficiency. The first-type of variables is made of long term conservation options that must be implemented before water shortages. The second type of variables includes short-term conservation options treated as probabilistic shortage levels. The farmers responses to water prices, water rationing, and conservation options to reduce water shortage are determined in this study.

A second optimization model is herein considered that does not consider rationing policy. The results of the two optimization models, the first with water rationing and the second without it, are implemented to estimate the farmers' WTP by the difference between the values of their objective functions. The uncertainty in model parameters (such as costs, benefits,. . .) and its influence on farmers' WTP is addressed with Monte-Carlo simulation that generates the means and variances of uncertain model parameters.

This work's probabilistic optimization model is described by Eqs. (1)–(7) presented below. Water price is part of the model and it varies with each shortage level. In fact, a hypothetical currency price in the range of 0 through 0.2 is considered. This price range is applied to water supply costs. At low water prices there is no reduction in water consumption, because farmers' revenue is negligibly dependent on water price. As the water price increases so does the crop production cost, in which case short-term conservation options are applied. More efficient irrigation systems and changes in the cropping pattern are considered as long and short term conservation options, respectively, in this work.

Eq. (1) denotes the objective function of the optimization model that maximizes revenue from crop production under different shortage levels. The decision variables in the objective function are the area devoted to a crop and the amount of water used.

$$MaxZ = \sum_{k=1}^{nk} f_k \left[\sum_{i=1}^{ni} \sum_{j=1}^{nj} A_{ijk} (B_i Y_{ik} - PC_i) - P_{Q_k} Q_k \right] - \sum_{j=1}^{nj} C_j SA_j \tag{1}$$

in which Z = expected value of farmer's total annual revenue; f_k = probability of shortage event k; A_{ijk} = area of crop i with irrigation system j under shortage event k; B_i = price for one unit of crop i; Y_{ik} = yield of crop i under shortage event k; P_{Qk} = price of one unit water under shortage event k; PC_i = annual cost of production inputs for crop i (excluding water charges and land lease); Q_k = amount of water use under shortage event k; C_j = annual cost of irrigation system j, and SA_j = total area under irrigation system