Demand for Irrigation Water for Pistachio Production from Depleting Groundwater Resources: Spatial Econometric Approach

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Abstract

Depletion of groundwater resources is an international problem, and groundwater is probably the world's most extracted raw material. The agriculture sector is one of the biggest users of groundwater resources for irrigation activities, and it plays an important role in the depletion of these resources. The estimation of demand function for groundwater resources is the first step toward any policy recommendation in this field of research. However, only scarce attention has been given to empirical studies of the demand structure of groundwater resources by the help of econometrics and considering the quality of the resources in the context of a single aquifer. Therefore, an empirical estimation of the demand function for individual userswhich considers water quality enhances further economic analysis and results in better policy recommendations. In this study, we have analysed the economic factors and the groundwater quality as influencing variables on derived demand function for irrigation water in the pistachio production of the Rafsanjan aquifer in the southeastern part of Iran. The field studywas conducted from November 2008- February 2009. Translog cost function has been applied for the estimation of the derived demand function for groundwater in pistachio production and its shadow price. The spatial econometrics has been aplied to correct the results. Results show that water pumping costsare much less than their shadow prices.
Key words: Groundwater resources, derived demand function, pistachio, Rafsanjan

1 Introduction

During the second half of the 20th century, groundwater withdrawals have increased, up to the point that they now supply half of the world's population with water (UNICEF, 1998). It is said that groundwater is the world's most extracted raw material (Jaroslav and Annukka, 2007). Thisincreased use has caused water table draw downs and depletion of groundwater resources (aquifer[1]) in many parts of the world, which highlights the importance of groundwater management. Intensive use of groundwater leads to a wide array of social, economic

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[1] In hydrology, rock layer that contains water and releases it in appreciable amounts. The rock contains water-filled pore spaces, and, when the spaces are connected, the water is able to flow through the matrix

and environmental consequences such as land subsidence, increases in the vulnerability of agriculture and other uses to climate change, increases in pumping costs, etc. (Burke, 2003, p.70). Combining this fact with the resource's acute scarcity in many parts of the world makes it necessary to develop rules for allocating the resource efficiently among competing uses over time and space (Xepapadeas and Koundouri, 2004, p.1). Economic studies on groundwater resources have focused mainly on comparisons of quantity based management between two regimes: optimal control and competitive pumping. In order to do such a comparison, variables affecting the groundwater use must be defined. As a result, the study of groundwater demand or willingness to pay (WTP) for groundwater is part of a strategy for the management of this resource, in the sense that it provides information about the effects of control variables on groundwater use (Koundouri, 2004, p.716). Estimation of demand for groundwater resources is the main focus of the following paper. As agriculture is the biggest groundwater user in many parts of the world, factors effecting agricultural demand for water is of great interest.

In the FAO database (AQUASTAT), Iran is fifth on the list of the top 20 countries for using groundwater for irrigation (Shah et al., 2007, p.400). Groundwater resources provide more than 60 percent of irrigation water in Iran (Jamab, 2004, p. 4). This accounts for more than 50 km^3 of water (Assadollahi, 2010). Based on Assadollahi (2010), irrigation water accounts for 90% of groundwater withdrawal in Iran. This shows the importance of the groundwater resources and the necessity of economic instruments for resource management, especially in the agricultural sector.

This study has tried to recognize factors affecting groundwater resource demand in the pistachio production of the Rafsanjan aquifer in the southeastern part of Iran. In order to do a better empirical estimation for any further policy recommendations, groundwater quality is considered to be an influencing factor as well as the water quantity, input prices, output level and pistachio garden structure. A field study was done from November 2008 - February 2009. As groundwater is a hydorgeological variable and some level of spatial corrolation is recognised on water use per hectare by farmers, the model has been checked for spatial corrolation, and the results are corrcted for that. Finally, groundwater shadow price and pumping costs elasticities for groundwater and substitution elasticities are calculated in SUR and SAR models.

2 Methodology

The main model follows Nieswiadomy (1988), Halvorsen and Smith (1991) and Koundouri and Xepapadeas (2004) use of the Shephard's lemma. Their approach has been considered for the establishment of the empirical model. Regarding the Shephard's lemma, factor demand could be estimated by deriving the cost function on the factor price.

Another point is the non market character of the groundwater which is owned in common. Therefore, the price for groundwater is unobservable. Halvorsen and Smith (1991) used duality theory and derived the relationship between gross and final resource indirect cost function for unextracted ore in the Canadian metal mining industry. Duality theory suggests

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of the rock. An aquifer may also be called a water-bearing stratum, lens, or zone (Britannica On-line Encyclopedia) that the wealth maximization problem of vertically integrated agricultural firms corresponds to the following unrestricted cost minimization problem (Koundouri and Xepapadeas, 2004):

$$min\, P_pX^p + P_wX^w + \mu\,[W\,(X^w, H, T)]\; s.t\, Y(X^w, W, T) \geq Y \tag{1}$$

where Xp is the quantity of other inputs, P is the price of other inputs, W is the extracted water, Xw is the quantity of inputs used for extraction of water, Pw is the price of other inputs used for extarction of water, H is the groundwater level and Y is the production level. μ is the Lagrange multiplier and in situ of the shadow price of groundwater. As information on μ can not be achieved from the market, Halvorsen and Smith (1991) considered the auxiliary problem of minimizing the total cost of all inputs used in production process (excluding groundwater in our case) given H, Y, W each time. In this restricted auxiliary problem, Y* and W* are the solution to the firm's wealth maximizing problem.

$$min\, P_pX^p + P_wX^w\; Subject\, to\, W\,(X^w, H, T) \geq W* \; and\, Y(X^p, W, T) \geq Y* \tag{2}$$

Each individual firm will not explicitly solve the equation. It will be solved simultaneously for the wealth maximizing quantities of output and the rate of groundwater extraction, together with the quantities of agricultural inputs that minimize the total costs. The solution to the equation 2 results in the restricted minimum cost function (Koundouri and Xepapadeas, 2004):

$$C = C(Y, W, H, P_p, P_w)$$

where C is variable cost. The accounting price of the groundwater stock of the renewable common pool aquifer used for agricultural irrigation is:

$$\frac{\partial C}{\partial W} = -\mu$$

An additional factor is water salinity. In general, the structural cost function literature treats product quality as exogenous and it remains unobserved in the analysis because it is unobservable in most cases. Quality is usually assumed to be unrelated to the other endogenous variables in the analysis. This is often done because of the difficulties in collecting data on product quality, which can be quite costly . In many analyses, however, the assumption of exogenous, unobservable quality is incorrect because the products are differentiated on some quality attribute. This creates biases in the parameter estimates, which can lead to inaccurate inferences (Boland and Marsh, 2006). Therefore, salinity (EC) is considered as an index for water quality which affects the overall approach towards using other inputs and the level of output. Therefore, the main short run variable cost can be rewritten as follows:

$$C = C(Y, W, H, P_p, P_w, EC)$$

Empirical model

By considering Guyomard and Vermersch (1989) and Halvorsen and Smith (1991), the empirical translog cost function has been developed as follows:

$$\begin{aligned} lnCR \quad &= \quad a_0 + a_1(lnY) + \frac{1}{2}a_2(lnY^2) + b_i \sum_{i=1}^{5} lnW_i + \frac{1}{2}c_{ij} \sum_{i=1}^{5}\sum_{j=1}^{5} lnW_i lnW_j + \\ & \quad d_i \sum_{i=1}^{5} lnY lnW_k + e_k \sum_{k=1}^{3} lnZ_i + \frac{1}{2} f_{kg} \sum_{k=1}^{3}\sum_{g=1}^{3} lnZ_i lnZ_j + \theta_{ik} \sum_{i=1}^{5}\sum_{k=1}^{3} lnW_i lnZ_k \\ & \quad + \gamma_k \sum_{k=1}^{3} lnY lnZ_k + DFD + MD + u_{CR} \end{aligned} \tag{3}$$

where CR is the restricted cost; Y is the output (pistachio); W_i is the variable input prices (i=1 is the manure, fertilizer and sand price index, i=2 is the water pumping price , i=3 is the labor price index, i=4 is the machine operation price index, i=5 is the pesticide price index); Z_i is water (i=1), EC (i=2) and number of trees per ha (i=3), and DFD is a dummy for dividing dry and fresh production. MD is another dummy reflecting farms with heavy manure use in 2008. Symmetry is imposed on the parameters c_{ij} and f_{kg}. Shephard's lemma gives the cost share equation, on which we add a disturbance, ϵ_i to reflect errors in optimization:

$$M_i = P_i X_i / CR = b_i + c_{ij} \sum_{j=1}^{5} lnW_j + \theta_{ik} \sum_{k=2}^{2} lnZ_k + u_i \tag{4}$$

by consideration from the begining , $\sum_{i=1}^{5} M_i = 1$. The addiditivity constraint implies:

$$\sum b = 1, \sum c = \sum f = \sum \gamma = \sum \theta = 0$$

by the estimation of this model, it will be possible to estimate the shadow price of water by

$$\frac{\partial CR}{\partial Z_i} = \left[e_k + f_g \sum_{g \neq i} Z_g + \theta_{ik} \sum lnP_i \right] \left(\frac{CR}{Z} \right)$$

and the short run Hicksian price elasticity of the water pumping can be estimataed by:

$$\begin{aligned} \epsilon_{ij}^{-SR} &= (c_{ij} + M_i M_j)/M_i \\ & \qquad\qquad\qquad\qquad \forall i, \forall j, \quad i \neq j \\ \epsilon_{ij}^{-SR} &= (c_{ij} + M_i M_j)/M_i \end{aligned}$$

3 Field study and data

3.1 Study area

Field work was conducted for almost three and a half months from November 2008-February 2009 in the Rafsanjan county in the southeastern part of Iran. The main reason for selecting Rafsanjan was its unique agricultural production pattern and its size. Table 1 shows some general characters of the Rafsanjan aquifer. This aquifer is divided into three parts which are

Table 1: General information about the Rafsanjan aquifer

County's total area	12000 km^2
Population	290000
Crop production	Only Pistachio
Estimated planting area	Estimated 80000-100000 ha
Area of aquifer	4108 km^2
Annual extraction	680 million m^3
Share of agriculture	660 million m^3
Storativity coefficient	5%
Annual drop of water level	72 cm
Aquifer condition	Red Zone
Average height from sea level	1609 m
Average depth of water table	55 m

source of data: The Office of Basic Water Resources Studies
last access 28.09.2010, http://217.66.216.141/tolidat/ab-zirzamini.asp

connected from the bottom, but each part has a bit of a different storativity coefficient. In addition, the underground water flows from south to north. Since the last hydro-geological report (Kamab, 2002), there has been an inflow of 136 million m^3 and an outflow of 31 million m^3 from the aquifer. The general hydrograph of Rafsanjan shows an annual drop of 72 cm on average.

There are more than 1300 deep active wells in the Rafsanjan plain. Most of them provide irrigation water for pistachio gardens, and very few are used for other usages. It is almost impossible to add new wells to the system, and the aquifer has been shared by almost the same operators during last 20 years. Since there is no permanent river in the area, irrigation depends solely on groundwater. This area is borders the desert and has a very arid climate. According to the Iran Meteorological Organization, annual precipitation in Rafsanjan is almost 90 mm. Combining water-level data with satellite radar observations provides evidence for an annual 50 cm of land subsidence and land deformation in the Rafsanjan aquifer as a result of intensive groundwater use (Motagh et al., 2008).

3.2 Field work

Rafsanjan was selected for the field study because of the high price of pistachios and the unique pattern of water use in the area. A two-stage random sampling was used for gathering data. Considering the different water quality that can be found in the study area and the high cost of water quality studies, a random sample of 60 wells that was already available from the Rafsanjan Water Authority (RWA) was considered as the first-stage sample selection. The RWA controls wells seasonally by randomly selecting 60 agricultural wells around the aquifer and checking them for chemical and quality factors such as EC, PH, SAR, etc. The quality change factors of the aquifer can therefore be observed. I could acquire this data for a period of 4 years.

The survey was done by using two different types of questionnaires. The questionnaire concerning wells was designed and checked with irrigators, pumpers and well representatives. This questionnaire contains information covering the well ownership, technical aspects, historical trends, well management, labor force, energy consumption, maintenance, water charge and property value. The household questionnaire contains questions about garden management, garden structure, the harvest value of crops, household socioeconomic structure, inputs, garden operational costs, processing costs, water provision costs and water trade. I could cover the cost items for a period of one year of agricultural production and two years of crop yield levels and selling prices. The goal was to design a production-cost questionnaire which could cover both big and small farmers.

In order to carry out the survey, I contacted the wells' representatives first and interviewed them with the questionnaire concerning wells. I then contacted the farmers. Interviews with large landlords were usually conducted with their representatives in the office or in the field. As for the small landholders, I randomly interviewed some of the farmers who were using the same well based on the size of the farms. As mentioned above, the ownership pattern is very diverse. There are cases where two or three wells belonged to one landlord and others where one well is owned by 200 people. Finally 57 wells' representatives were interviewed with more than 157 farmers whose farms are dispersed around the aquifer. It must be added that due to the Law of Fair Distribution of Water (1983) in Iran, people receive legal permission to use groundwater, and it is a public good. However, this permission is a form of property ownership and has a very high value according to water quality and the amount charged for water from wells.

3.3 Description of data

The detailed cost data regarding the pumps and the farms are extracted from the questionnaires. Pumps and farms are dealt with separately. In the following paragraphs, some of the data structure and variables which are used in the model for estimation are described. Table 2 shows a summary of variables used in the establishment of the model. It must be added that some other variables which explain the condition in the study area are also added to the table. Some modifications are also considered for the model variables.

Irrigation water and pumping costs The variable cost of pumping is calculated using the variable cost of wells. As the pumps do not have a water contour, the questionnaire asks about the flow rate of the pumps (Lit/S) and this number was later checked. Then by considering the number of "off days", the total size of pumped water is calculated as follows for one year:

$$WaterFlow * WorkingDays * 24Hours * 3600Second$$

By considering each farmer's share of the well, each farmer's annual share of the above pumped water is calculated and considered the water input level of the farm (or farm water quota). If the farmer bought or added any extra water to this amount, that is also considered in the water amount. It must be mentioned that farmers have a specific quota for the amount of water they can take from each well. Their quota has been defined as a fixed factor and calculated as

$$WaterFlow * 365Days * 24Hours * 3600Second * FarmerShareFromWell$$

As the off days and pumping costs are management issues, the formula is considered to be the water quota and a fixed factor.

Production Level There are different types of pistachios available in the study area, and many farmers process, dry and separate good- and bad-quality pistachios. Some farmers do only the processing and drying but not the separation, and some large farmers sell the whole crop fresh without doing any processing. Many farmers produce different brands at the same time. Since this madethe cost spent for each brand almost impossible to calculate, the aggregate level of pistachio production is considered as the production level of each farm.

The target area was unusually cold during the spring of 2008. In spite of all costs which farms have paid for operations during the 2007-2008 agricultural year, the crop production of the summer of 2008 was reduced dramatically. Therefore, 2007's high yield production has been used with expenditures during 2007-2008 for establishing the cost function, and, as a result, the factor demand function. It must be added that there were some young gardens in the sample which showed no crop production.

Manure and fertilizer costs and prices Farmers use many different types of chemical fertilizer (phosphate, nitrate, sulphate, etc.), manure (cow, sheep, chicken or fish) or natural fertilizers (agribiosol, agrihum, etc.). Sand distribution among trees is another operation. These operations can be substituted. There are farmers using all of the above-mentioned elements, and there are farmers using only some of them. In order to have a price index representing sand, manure and fertilizer prices in a cost function without having any zeros on the right side of the equation, an aggregate price index has been established for sand-manure-fertilizer by considering cost share weight (Diewert, 1981; Pope and Chambers, 1989). The following aggregation formula has been used to establish the price index for manure, chemical fertilizers and natural fertilizers as well as sand use for each farmer (Lapp and Smith, 1992)(Lapp and Smith, 1992):

$$PriceIndex = \sum_{i=1}^{n} w_i (P)_i \tag{5}$$

where $w_i = \frac{P_i X_i}{\sum_{i=1}^{n} P_i X_i}$ is weight which adds up to one. X_i is quantities, and P_i is the price of that quantity (fertilizer or manure in this case) paid by the farmer.

Pesticide price Farmers use different pesticides in their gardens such as amitraz, endosulfan and herbicides at different volumes. Therefore a single aggregate price index has been established for pesticides and herbicides together. Divisia price index formula has been used with the help of the equation 5.

Machinery cost and price There are different types of machinery used in the pistachio gardens which can be categorized as machinery for pesticide distribution, hole digging, soil ploughing, soil rotating, etc. Costs for these different machines vary. Therefore, an aggregated price index has been established for Machinery with the help of the equation 5.

Labour cost and labour price The cost of labour that farmers pay also varies, especially depending on what type of labour it is (such as pruning, manure or fertilizer distribution, harvest, processing, irrigation, etc.). Large farms employ annual labour with specific insurance in accordance with the Iran Labour Law. The aggregate price index is established for the labour force as a daily price. The annual labour cost has been changed to a daily labour cost. Extra costs for daily or annual labour, such as food, are also considered.

Variable cost Variable cost as a dependent variable consists of fertilizer, manure, sand distribution, machine work, labour, water pumping and irrigation, pruning and almost all possible costs concerning agricultural operations for the period of one year (2007-2008) in the study area.

Other variables The number of trees per hectare, the trees' age and the depth of water are three indices which have been considered as factors representing garden structure in the cost function. But as trees' age and depth of water are not significant, they are not considered in the model.

Table 2: Descriptive Summary of the variables

Variables	Mean	sd	Min	Max
Pistachio Product per ha (2007)-kg	1583	946,12	0	5133
Fertilizer Manure sand divisia price index (Rial / kg)	1001,59	1607,59	23,75	12759,97
Labour price (Rial / day)	101809	16578,7	58053	144383
Mashin price index (Rial/hour)	61767	28037,46	20000	197403
Pesticide price index (Rial/kg)	124153	205951,72	19097	1406325
Farm Size (ha)	9,6223	25,23	0,1125	224,9325
PH	7,566	0,38	6,7	8,6
EC	6453	3885	1314	21000
No of tree per ha	48,66	34,55	14,29	204,69
Age of trees (year)	25,66	8,96	5	65
No Of Pieces of gardens	3,503	2,59	1	15
Water pumping cost (Rial / cubic meter)	375,1	356,43	59,7	1649,5
Water use per ha (cubic meter)	8985	3859,81	2326	20982
Water head (m)	62,95	30,7	14,83	138,02

4 Econometric estimation

The translog cost function and its Shephard's lemma equations are estimated simultaneously with the help of seemingly unrelated regression (SUR). As we have imposed the $\sum_{i=1}^{5} M_i = 1$ restriction on the model, the problem of singularity has been solving by normalizing the all prices with the pesticide price and estimating the normalised Shephard's lemma equation

(Berndt, 1996, p.472). As groundwater is a hydrogeological variable, the possibility of any spatial dependance in the model is considered. A spatial weight matrix (W) has been made by considering the inverse distance in the area of 18.5 km. This distance has been selected in order to avoid having an island and separating the second and third parts of the aquifer from each other. There is a mountain between these two parts which separates any hydrogeological or social connections between these two areas. The spdep package in R statistical software is used for the estimation of the weight matrix. A spatial autocorrelation framework is required for correcting the model. Applying Kelejian and Robinson (1992) spatial autocorrelation test for the residuals of each equation, we found a significant spatial correlation in water pumping and translog cost equations. To obtain a consistent estimation of the spatial error parameter, we used Kelejian and Prucha (1999) Generalised Method of Moment (GMM) approach on the residuals achieved through SUR estimation of the two mentioned models. With respect to the taxonomy of spatial simultaneous equation systems (Rey and Boarnet, 2004), there is no reason to think about the theoretical availability of feedback simultaneity, spatial autoregressive lag simultaneity or spatial cross regressive lag simultaneity in the translog cost function and its Shephard's lemma equations. Therefore, Kelejian and Prucha (2004) approach for estimating the spatial simultaneous equation systems is not required. We then used the resulting spatial autocorrelation parameter estimates to do spatial Cochrane-Orcutt transformation on each of the original equations (recognising their different spatial lag lengths), and estimated the transformed system of equations, using SUR, to generate consistent estimates (Cohen and Paul, 2007). The estimated spatial autocorrelation parameter is 0.26 for the translog cost equation and 0.30 for the pumping equation. All of the analysis has been done in R with the help of a systemfit package (Henningsen and Hamann, 2007) in order to manage the simultaneous system equation estimation.

5 Results and conclusion

Table 3 shows the results of SUR and its spatial correction for water pumping equation[2]. Table 4 shows the shadow prices of groundwater, the water deamnd elasticities and their correction with SAR. Most of the factors in water pumping equation are significant[3]. The water quality variable was not significant, but we can not eliminate it from the model as it has improved the model. The spatial correction is improved the explanatory power of the main translog cost function .By concentrating on the results of the water pumping cost, it can be recognized that water demand in regards to pumping cost per cubic meter of water is inelastic. The same thing can be recognised for the demands elasticity of pumped water and other input prices. The low coefficient estimate of water quality can be a signal that water quality is not as important in the whole demand structure as we originally thought. The estimated shadow price for groundwater is almost six times higher than the average pumping cost per cubic meter in the sample size (360 rial / m^3) in SUR model. The spatial correction has improved the whole model, and shadow prices also increased as can be recognised

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[2] Because of the space limitation the whole translog cost function is not presented in this paper. They can be provided by authors by the request.

[3] The variables in table 4 are the as explained in empirical model. It must be added that the W is refering to normalised prices.

Table 3: SUR and SAR estimation of water pumping Shephard's lemma equation

	SUR			SAR		
Variables	Estimate	Std.Error	tvalue	Estimate	Std.Error	tvalue
(Intercept)	0,4079	0,1135	3,5940	0,1393	0,0703	1,9825
W21	-0,0126	0,0029	-4,4109	-0,0099	0,0029	-3,4191
W22	0,0775	0,0034	22,8063	0,0805	0,0044	18,1920
W23	-0,0454	0,0067	-6,7580	-0,0439	0,0070	-6,3080
W24	-0,0132	0,0043	-3,0501	-0,0165	0,0044	-3,7331
z1	0,0221	0,0046	4,8473	0,0245	0,0042	5,7776
z2	-0,0084	0,0085	-0,9875	0,0081	0,0089	0,9142
z3	0,0040	0,0087	0,4645	0,0166	0,0080	2,0872
y	-0,0126	0,0033	-3,7965	-0,0146	0,0033	-4,4624
Residual standard error		0,054418			0,052467	
Degrees of freedom		148			148	
Multiple R-squared		0,517			0,44	
Adjusted R-squared		0,491			0,41	

Table 4: SUR and SAR estimation of water demand elasticities and shadow prices

	SUR		SAR	
	mean	sd	mean	sd
Sadow Price (rial / m^3)	2264,16	1503,06	3014,1	1956
Water demand elasticity to pumping price	-0,153	0,6123	-0,124	0,638
Water demand elasticity to fertilizer,manure and sand price	0,056	0,2072	0,108	0,173
Water demand elasticity to labor price	-0,39	0,7946	-0,361	0,769
Water demand elasticity to mashin price	-0,195	0,2257	-0,260	0,282
Water demand elasticity to pesticide price	-0,068	0,1159	-0,142	0,179

from Table 4. The inelasticity estimation of the water shows the importance of water in this specific area and the low effect that other changes may have on water consumption. On the other hand, the spatial dependence shows that any collective action which does not cover the whole aquifer and the neighbourhoods probably does not have much of an effect on water consumption or water saving practices. The difference between shadow prices and pumping costs probably won't be corrected, not even by the government's new price policy plan for energy subsidies. The difference shows the difficulties in following any approach to control and administrate the irrigation practices in this area.

In this paper, factors affecting the demand function for irrigation water from depleting groundwater resources has been analyzed. Not only economic factors but also hydrogeological and water quality factors are considered in this study. The results show a big gap between average pumping costs and estimated shadow price for irrigation water. This somehow justifies the high depletion rate of the aquifer. The spatial approach which we have employed is not generally followed in the literature, but it shows the importance of spatial dependence on water demand issues from depleting aquifers. It must be added that the next steps in improving the model are to consider adjustment costs and dynamic cost function and to impose the dynamic elements of groundwater extraction to the demand system.

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