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Cost Structure of Irrigation Water in the Sultanate of Oman

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مكونات التكلفة لمياه الري في سلطنة عمان

الملخص : تعتمد الزراعة في سلطنة عمان اعتمادا أساسيا على الري حيث أنها تستهلك أكثر من ٩٤% من مواردها المائيـة. إن الدراسات السابقة اعتبرت مياه الري عنصرا ذا مرونة تامة ، ولذلك فقد ركزت على إدارة المياه من هـذا المنطلـق . فإن هذه الدراسة تبحث في الفرضية المذكورة أعلاه وتكوين معادلة لتكلفة إنتاج مياه الري بصورة منفصلة ، ومدى قابليـة عناصر الإنتاج من رأس مال وعمالة وطاقة، لإحلال بعضها البعض في إنتاج مياه الري . كما تشير النتائج إلـى إمكانيـة الإحلال بين العمالة والطاقة وتبين أن كلفة الإنتاج تكون أقل كلما زاد حجم المزرعة .

ABSTRACT: Agriculture in the Sultanate of Oman depends mostly on irrigation and consumes more than 94% of the national water resources. Previous studies have regarded water supply as perfectly elastic and consequently have concentrated on water management issues. This study relaxes the above hypothesis and constructs a separate cost function for irrigation water. Substitutability among capital, labor and energy in the production of irrigation water was investigated. Results show substitution possibility between labor and energy and reveal the existence of increasing returns to scale in water production.

Traditionally, irrigation water was treated as a simple exogenous input that combines with other conventional inputs to produce a final agricultural output. Production functions for irrigated crops are given in relation to the quantity of water applied (Grimm *et al.*, 1987) and may include physical features of irrigation systems into irrigation choice models (Caswell and Zilberman, 1985; Moore *et al.*, 1991). The assumption underlying these studies is that irrigation water supply is perfectly elastic. In this case, the production function for a particular crop would only assume nonjointness in inputs (Kohli, 1983; Chambers, 1991).

A key issue, however, arises when water is produced on the farm by pumping from a well. In this case, water is no longer exogenous, rather it needs to be treated as an endogenous, intermediate input. Like other intermediate goods and specialized inputs, irrigation water is produced with a high initial fixed cost and a low marginal cost, i.e., with increasing returns to scale (Markusen, 1989). A cost structure embodying increasing returns to scale implies a cost advantage to large farms over smaller sized farms.

In the Sultanate of Oman almost all cultivation depends on irrigation and approximately half of the irrigated area utilizes wells and pumps to extract groundwater (Abdel Rahman and Abdel Majid, 1993; MAF, 1995). The cost of producing water in this system includes high fixed costs as a result of digging and equipping wells, labor cost to monitor and distribute water, and energy cost to run the pumps. These cost components account approximately for 50, 30, and 20%, respectively, of the total volumetric water cost in the case of surface irrigation (Norman *et al.*, 1996).

This paper investigates the cost structure of irrigation water in the Batinah region in Oman. In particular, the substitutability among capital, labor and energy factors in the production of water will be analyzed. The objective of the study was to develop separate cost functions for water as an intermediate input in the production of agricultural products and to apply it to a region of Oman. The paper is organized in the following sequence: First, it lays down the theoretical background to the irrigation water cost function; second, it presents the data and discusses the empirical results; and finally it concludes with policy implications and recommendations.

Theoretical Background

Agricultural production is very often presented as multi-output technology since farmers produce a variety of crops. For any single crop, a separate production function exists if the technology assumes nonjointness in inputs. According to Chambers (1991), a production function in a multi-output technology is nonjoint in inputs if the level at which a product $\mathbf{y}_1$ is developed is independent of the level at which a product $\mathbf{y}_2$ is developed.

For the purpose of this paper we assume an output $\mathbf{y}$ produced with an intermediate input $\mathbf{x}^I$ (water) and other inputs $\mathbf{x}_i$. The input $\mathbf{x}^I$ depends on production factors denoted by $\mathbf{k}_i$ including labor, energy, and capital, with corresponding wages $\mathbf{w}_i$. To be able to write a separate input requirement function for input $\mathbf{x}^I$ we need to assume nonjointness in output quantities. A technology is said to be non-joint in output quantities if there exist individual quasi-convex, non-negative, non-decreasing factor requirement functions such that for every $(\mathbf{x},\mathbf{y})$ there exist $\mathbf{y}_{ij} \geq \mathbf{0}$ such that (Kohli, 1983):

$$x_j \geq g^j (y_{ij},\ldots,y_{1i}) \qquad \sum_j y_{ij} \geq y_i \tag{1}$$

For simplicity of presentation we assume that only one output $\mathbf{y}$ is produced so one can concentrate on the input side.

Given the technology embodied in Equation 1, the cost function that corresponds to the input $\mathbf{x}^I$ (water) will be represented as:

$$c\ (k,w) = \sum w_i\ h\ (y) \tag{2}$$

Assuming the technology to be separable in inputs (Chambers, 1991), the output $\mathbf{y}$ could be presented as a function of the input $\mathbf{x}^I$ and inputs $\mathbf{x}_i$:

$$y = y\ (x^I, x_i) \tag{3}$$

So we can represent the cost function, Equation 2, as:

$$c\ (k,w) = (\sum w_i)\ y\ (x^I, x_i) \tag{4}$$

For irrigated crops, there is a strong correlation between the quantity of irrigation water, $\mathbf{x}^I$, and the output $\mathbf{y}$. Thus, we can substitute the quantity of water produced as a proxy variable for the quantity or volume of the output. Finally, the cost function becomes:

$$C\ (k,w) = c\ (w_i, x^I) \tag{5}$$

Equation 5 is a conventional cost function for irrigation water as an intermediate good. It is a function of input prices, $\mathbf{w}_i$, and water quantity, $\mathbf{x}^I$. It is assumed to be continuous and homogenous in input prices, $\mathbf{w}_i$.

A functional form that corresponds to Equation 5 is the translog function, chosen for its popularity in production analysis as it imposes no arbitrary behavioral restrictions and requires only the minimum number of parameters (Christensen *et al.*, 1971).

To investigate the cost structure of irrigation water and the substitutability of inputs in the production of water in irrigated areas, the translog functional form is chosen because it offers sufficient flexibility in modelling technologies with arbitrary partial elasticities of substitution between pairs of inputs (Burgess, 1975; Berndt and Christensen, 1973).

Assuming the minimum cost of producing a unit of the intermediate input, $\mathbf{x}^I$ can be represented by the following translog approximation to the cost function. This incorporates three factors of production, i.e. capital K, labor L and energy E:

$$\begin{aligned} \ln C = {} & \ln \alpha_0 + \sum_{i=1}^{3} \alpha_i \ln w_i \\ & + \tfrac{1}{2} \sum_i^3 \sum_j^3 \beta_{ij} \ln W_i \ln W_j \\ & + \tfrac{1}{2} v_{xx} \ln (x^I)^2 + \sum_i \Pi_{ix^I} \ln w_j \ln x^I \end{aligned} \tag{6}$$

where i = K, L, and E.

Using the duality theorem, known as Shephard's lemma, we obtain the derived demand for each of the three factors, K, L, and E by differentiating the unit cost of function with respect to the price of the corresponding factor:

$$S_i = \frac{\partial \ln C}{\partial \ln W_i} = \alpha_i + \sum_{ij} \beta_{ij} \ln W_i + \Pi_{ix^I} \ln x^I \tag{7}$$

A well-behaved cost function should satisfy the homogeneity condition in factor prices. Linear homogeneity in input prices requires the following restrictions on the parameters:

$$\begin{aligned} \alpha_K + \alpha_L + \alpha_E &= 1 \\ \beta_{KK} + \beta_{KL} + \beta_{KE} &= 0 \\ \beta_{KL} + \beta_{L_L} + \beta_{L_E} &= 0 \\ \beta_{KE} + \beta_{L_E} + \beta_{EE} &= 0 \\ \Pi_{Kx^1} + \Pi_{Lx^1} + \Pi_{Ex^1} &= 0 \end{aligned} \qquad (8)$$

Equation 6 also imposes the symmetry condition, i.e. $\beta ij \approx \beta ji$ for all i, j. The translog cost function specified in Equation 6 is assumed to be an approximation to the true functional form. This suggests that valid analysis requires estimation of the cost function Equation 6 along with the cost-share Equation 7 (Berndt and Christensen, 1973; Burgess, 1975).

However, the cost-shares sum to unit requires that one cost share equation needs to be omitted. The benefit from the joint estimation of the share equations with the cost function is to increase the degrees of freedom. This is feasible since the cost-share parameters are a subset of the cost function parameters (Christensen and Greene, 1976).

Estimation and Empirical Results

To estimate the model given by Equations 6 and 7, both quantities and prices of the various inputs (labor, capital, energy) as well as the quantity of water are needed. The data used in this study are cross-sectional collected through a farm survey composed of twenty seven farms located in the Batina region in the Sultanate of Oman. The quantity of water is assessed by the irrigation schedule (interval and period of irrigation) and the flow rate.

For drip irrigation, drips are adjusted to deliver a flow rate of four litres per hour. This flow is assumed to be constant for all farms in the sample. In the case of surface irrigation, the pumping rate and irrigation schedule were measured and used to determine the annual quantity of water pumped.

The three factors used in the cost of irrigation water are capital, labor and energy. Capital costs are assessed from the initial cost of construction of wells and accessories as well as the cost of pumps. A straight-line depreciation method was adopted to calculate annual costs. The amount of labor used in irrigation and wage rate was measured through a questionnaire. Finally, the cost of energy (diesel or electricity) was measured from monthly expenditures. Total cost was then calculated by summing the three cost components.

The cost function and both the labor and capital-share equations are estimated simultaneously. The parameters of the third cost-share equation will be derived using the linearity and symmetry conditions in Equation 6. To estimate this system of equations we used the iterative seemingly unrelated regression (SUR) suggested originally by Zellner (1962) and by Christensen and Greene (1976). This procedure

TABLE 1

Translog parameter estimates for irrigation water (t-statistics between parenthesis)

Parameter	Model		
	A	B	C
α_0	11.718[a] (2.04)	2.756[a] (2.78)	0.660[a] (2.44)
α_K	0.281[a] (3.01)	0.343[a] (5.33)	0.384[a] (5.96)
α_L	0.347[a] (5.50)	0.377[a] (7.18)	0.395[a] (7.65)
α_E	0.371[a] (2.82)	0.278[a] (3.35)	0.219[a] (2.69)
v_w	-1.938 (1.77)	-0.311[a] (1.62)	0.099[a] (2.50)
v_{ww}	0.093[a] (1.72)	0.019[a] (2.11)	-
β_{KK}	0.853[a] (3.41)	0.024[a] (1.95)	-0.033[a] (2.81)
β_{KL}	-0.382 (1.68)	-0.0 (0.04)	-0.0 (0.02)
β_{KE}	-0.471[a] (5.02)	0.025 (1.63)	0.033[a] (2.31)
β_{LL}	-0.477[a] (4.55)	0.013 (0.81)	0.020 (1.27)
β_{LE}	0.948[a] (4.92)	-0.030 (1.23)	-0.053[a] (1.80)
β_{EE}	-0.477[a] (4.55)	0.013 (0.81)	0.020 (1.27)
π_{Kx}^1	-0.440[a] (1.76)	-	-
π_{Lx}^1	0.205[a] (3.58)	-	-
π_{Ex}^1	0.234[a] (4.15)	-	-
R^2	0.99	0.99	0.99
RSS[b]	0.045	0.099	0.099
df	12	15	16
F-test	-	4.8	0.36

[a] Denotes parameter significant at 5% level
[b] Residual sum of squares

ensures efficient parameter estimates that are invariant to the omitted equation.

To test for homogeneity of degree one in prices and for homogeneity of the cost function, we estimated three versions of the model. Model A is the non-restricted model, i.e. including all parameters. In Model B we applied the homotheticity condition by setting all $\Pi_{ix'} = 0$ (I = K, L, E). Finally, we considered homogeneity conditions in Model C.

Results of the estimation appear in Table 1. The adjusted R^2 is very high for all three models. Parameter estimates in Model A are all significant at 5 % (10 parameters) or 10% (3 parameters) except one. The conventional F-test was used to check the homogeneity and homotheticity conditions. Both tests (Table 1) show that these restrictions cannot be rejected at the 1% level.

Model A is used to derive the elasticities of substitution among the three factors of production, capital K, labor L and energy E for the translog cost function. The Allen partial elasticities of substitution (AES) between any two pairs of factors **i, j** can be expressed in terms of the parameters of the translog function in the following form (Johnston, 1984):

$$\sigma_{ij} = \frac{\beta_{ij} + S_i S_j}{S_i S_j}, \quad i \neq j$$
$$\sigma_{ii} = \frac{\beta_{ii} + S_i^2 - S_i}{S_i^2} \qquad (9)$$

The measure σ_{ij} indicates the degree of substitutability between input **i** and input **j** in response to a change in factor prices, holding input constant. The value of σ_{ij} lies between zero and infinity. Positive (negative) AES values indicate that inputs are substitutes (complements).

Table 2 presents the AES measures at the mean value along with the corresponding t-statistics. AES between capital (K) and labor (L), and between capital and energy (E) are both negative with the t-statistics being significantly larger than the critical value at the 5% level. This implies that the inputs are complements for each other. The AES values, however, are relatively small (0.27 and 0.32, respectively). Only the AES between energy and labor is positive which implies that energy could substitute labor.

The fact that capital is not a substitute for any of the two other inputs (energy or labor) may result from the high sunk costs of digging wells and the cost of pumps. These high costs are usually accompanied by related labor and energy costs to function the pump and channel, and distribute water from the wells to the cropping areas. Labor, however, is found to be a substitute for energy. More labor may lead to a better water management, and reduce water leaching and waste which result in less water use and less pumping time. Further, it was shown that water-distribution labor is conversely related to irrigation pumping rate (Norman *et al.*, 1996). The utility of exchanging labor for water and vice-versa among small irrigated and labor-intensive farms has also been documented in other countries (Norman and Walter, 1996).

TABLE 2

Allen elasticities of substitution at the mean value derived from model A

AES	Value[a]	AES	Value
σ_{KL}	-0.27 (5.41)	σ_{KK}	1.62 (0.15)
σ_{KE}	-0.32 (3.83)	σ_{LL}	-4.00 (2.48)
σ_{EL}	0.96 (4.75)	σ_{EE}	-4.70 (1.60)

[a] t-statistics in parenthesis

Table 2 also presents the own price elasticities of derived demand for the three factors. The own price elasticities measure the response of derived demand to a change in the own price of the factor while holding output and other input prices constant. Only the price elasticity for labor, σ_{EE}, is found to be significantly different from minus one at the 5 level. This implies that farmers can respond to changes in labor wage. One way to do so is to substitute energy for labor as revealed by the AES. The derived demand for energy and capital, however, is not affected by changes in their factor prices.

Another important measure that could be derived from the cost function is the scale elasticity. Scale elasticity expresses the returns to scale exhibited by the function. It is defined as the percentage change in total cost resulting from one percent increase in output holding the input process unchanged. Christensen and Greene (1976) provide a measure of scale economies based on the cost-function Equation 6 as follows:

$$SE = 1 - (\partial \ln C / \partial \ln x^{l}) \qquad (10)$$
$$= 1 - (v_{x^l} + v_{x^l x^l} \ln x^l + \sum_i \pi_{ix^l} \ln w_i)$$

where I = K, L, E. SE is positive when the technology exhibits economies of scale or increasing returns to scale. Negative values of SE, however, indicate diseconomies of scale or decreasing returns of scale.

The estimate of SE is found to be equal to 2.01 which indicates significantly positive economies of scale.

As defined in Equation 10, SE refers also to the elasticity of cost with respect to output (Chambers, 1991). As such, economies of scale imply that large-sized farms are more cost-effective than smaller ones. In the case of irrigation, economies of scale may result from the high fixed costs of well construction.

Conclusions

The cost of irrigation water has been a major policy issue in the Sultanate of Oman. The Government has looked at water as a principal component of industrial production in a country characterized by an arid climate. There are at least two aspects that show the importance of water cost in Oman. First, agriculture consumes about 94% of the total water available in the country. This reveals the problem of allocation of water resources among the different sectors of the economy. Second, since most crops are irrigated, the cost of water is linked to problems of optimum use of water resources.

The Government has implemented extensive subsidies to encourage the use of modern irrigation systems. These subsidies amount to 75% for farms of less than 4.2 ha, 50% for farms of 4.2 to 21 ha and 30% for farms greater than 21 ha. Currently, the subsidy programs are being reduced substantially and are expected to be removed altogether shortly. Thus a study of the cost structure of irrigation water is important to enlighten policy-makers about some vital issues related to the removal of subsidies.

This study reveals some preliminary results about the above issues. It is found that irrigation is related to significant economies of scale. This means that large farms are more cost-effective than the smaller counterparts which leads to a rethinking of the rationale behind investments to construct wells in small farms. Allen elasticity of substitution indicate that energy and labor factors are not substitute for capital. The only possible substitution is found between labor and energy. The implication from these results is that an increase in the cost of capital will not be accompanied by an increase in energy and labor expenses. However, an increase in the cost of energy would result in reduced pumped water requiring more management and labor hiring. This means that the increase in the cost of energy could be absorbed by an increase in labor hiring. Finally, if the subsidy on energy and capital is removed, the demand for these factors will not be affected, as documented by the own-price elasticities.

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