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Enhancing Irrigation Water Use Efficiency under Production Risk: Evidence from Wheat Farms in Iran

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Abstract: This study investigates the relationship between water-use efficiency, irrigation technology and production risk and factors affecting water use-efficiency with an application to wheat in Fars province of Iran. The risk-premium associated with the use of water is estimated by applying a moment-based production risk approach to farm-level data that were collected from a sample of 187 wheat farms selected by a two-stage cluster sampling during the years 2004 and 2005. The results showed that the overall physical and economic water-use efficiency for the whole sample are 0.709 and 0.697, respectively, which are less than one, indicating that the farmers over-irrigate their wheat farms. Also, on-farm physical and economic water-use efficiency of farmers adopting new irrigation technology are higher than non-adopters. The results showed that the farmer-specific relative risk premium proxies for the risk attitudes of each farmer have negative and significant effect on the economic water use efficiency. Also, there was a significant positive relationship between new irrigation methods and economic water use efficiency in wheat farms.

Key words: Irrigation water-use efficiency · Irrigation water productivity · Risk attitudes · Wheat · Fars · Iran

INTRODUCTION

Observations in the dry areas of Fars province, Iran indicates that scarce water resources of the region are poorly managed and inefficiently used. When the efficiency of irrigation is low, a significant portion of water leaves the field through runoff and deep percolation. Low irrigation efficiency is normally associated with poor timing and a lack of uniformity in water applications, leaving parts of the field over- or under-irrigated relative to crop needs. As a result, irrigation water is becoming an increasingly scarce resource for the agricultural sector in many regions and water resource management is becoming one of the most important economic and social issues. Improving on-farm water-use efficiency can contribute directly to increased supply of water for other end users. Improving the efficiency of irrigation requires a better matching of water application to crop needs, in terms of both timing and quantity, thus crops will consume applied water more effectively, yields will be increased and the amount of water that the irrigator must divert and deliver to the farm will be reduced [1-3].

Water use efficiency in irrigation has various definitions. Whereas physical efficiency compares the volumes of water delivered and consumed, economic efficiency relates the value of output and the opportunity costs of water used in agricultural production to the value of water applied.

Physical Irrigation Efficiency: Water-use efficiency is an indicator commonly used to evaluate the performance of an irrigation system.On-farm water-use efficiency is defined as the ratio of the required amount of water to produce a specific output level to the actual amount of water applied by farmers. Based on this definition, on-farm water-use efficiency may take the value of less than one, greater than one or equal to one. If the value of on-farm water-use efficiency is less than one, it implies that farmers over-irrigate their crops. Whereas, a value of greater than one implies that farmers under-irrigate the crops. However, if the value of the calculated on farm water-use efficiency is equal to unity, it means that farmers are fully efficient in using irrigation water because the required and applied amounts of water-use are equal [4].

For the purpose of this study, physical on-farm water-use efficiency is defined as the ratio of the required amount of water to produce a target production level to the actual amount of water-used (including the amount of rainfall). The target production level for wheat is

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the yield of the sample farms. The required amount of water to produce the average yield levels obtained from determined water requirements of agricultural crops by soil and water research institute, Islamic Republic of Iran.

In this respect, water (average) productivity, defined as the amount of food produced per unit volume of water used, is more relevant. Because the water-used may have various components (evaporation, transpiration, gross inflow, net inflow and others), it is essential to specify which components are included when calculating water (average) productivity.

Economic Efficiency: Economic efficiency of irrigation water use refers to the economic benefits and costs of water use in agricultural production. As such, it includes the cost of water delivery, the opportunity cost of irrigation and drainage activities and potential third-party effects or negative (and positive) externalities [5]. Economic efficiency can be expressed in various forms, for example, as total net benefit, as net benefit per unit of water, or per unit of crop area and its broader approach compared to physical efficiency allows an analysis of private and social costs and benefits.

Economic efficient allocation of the water resource is defined as the point where the cost of one additional unit of water, C, is equal to the value of the marginal product resulting from that additional unit of water in the production of the crop, ($VMP=P_y.MP=C$) economic water-use efficiency VMP denotes value of marginal product and P_y is price of output. economic water-use efficiency determine by VMP/C. Based on this definition, on-farm economic water-use efficiency may take the value of less than one, greater than one or equal to one. If the value of economic on-farm water-use efficiency is less than one, it implies that farmers over-irrigate their crops. Whereas, a value of greater than one implies that farmers under-irrigate the crops. However, if the value of the calculated on-farm economic water-use efficiency is equal to unity, it means that farmers are fully economic efficient in using irrigation water because the value of the marginal product and the cost of one additional unit of water are equal.

Economic (marginal) productivity or marginal productivity is defined as the change in the of total product to a unit change in the irrigation water, keeping all other inputs constant at some prespecified levels. Mathematically,

$MP = (\partial Y/\partial W)$, where MP denotes marginal product, Y is the output and W is the amount of water irrigation.

Lynne *et al.* [6] showed that the management of soil moisture in the crop root zone differs for the objectives of optimal physical and economic irrigation efficiency. Once optimal physical efficiency is achieved, economic efficiency can be improved based on the selection of the frequency of water applications. The frequency is determined by selecting the optimal Management Allowed Deficit (MAD), which is expressed as a percentage of the available moisture capacity. MAD is the difference between the full water requirement and the amount of water applied that allows for maximum economic efficiency.

Sutton and Jones [7] showed, based on an agronomic-economic simulation model for lettuce, that optimal physical efficiency could differ from optimal economic efficiency under various physical conditions and economic incentives. The authors expressed physical efficiency as crop production per unit of water applied, which is identical to classical irrigation efficiency assuming that crop yield is proportional to crop evapotranspiration. Economic efficiency was defined as net profit per unit of area. They find that optimal physical efficiency was achieved at a lower relative water supply than optimal economic efficiency.

Finally, if improvements in physical efficiency lead to environmental or ecological damage, for example, a reduction in water quality levels, waterlogging and salinization, or other negative externalities and third-party effects, they can actually decrease economic efficiency levels [4].

Economic and social commission for western Asia (ESCWA) and international center for agricultural research in the dry areas (ICARDA) [8,9] assessed on-farm water-use efficiency in agriculture using five case studies in Syria, Iraq, Jordan and Egypt. Their results showed that on-farm water-use efficiency in Radwania in Syria, for instance, were 0.61 for wheat, 0.45 for barley and 0.75 for cotton. Their estimates indicated that farmers over-irrigate wheat by 39 per cent, barley by 55 per cent and cotton by 25 per cent respectively. Other case studies provide similar information regarding the excessive use of irrigation water by crop producers.

Economic and social commission for western Asia (ESCWA) and international center for agricultural research in the dry areas (ICARDA) [10] indicated that of the total wheat farmers in Ninavah province in Northern Iraq during the 2001-2002 season, 80 per cent of them have on-farm water-use efficiency of less than one, indicating that these farmers over-irrigate their wheat crop. Meanwhile, the water-use efficiency of 20 percent of the farmers was greater than one, implying that these farmers under-irrigate wheat crop by 10 per cent. The overall water-use efficiency for the whole sample was 0.77, which was less than one, indicating that the wheat producers over-irrigate their crop by 23 per cent. Farm size was an important factor in explaining the variation in on-farm water-use efficiency among wheat producers. The water-use efficiency of small size farmer holders was 0.77, implying that small farmers over-irrigate wheat production by 23 per cent. The water-use efficiency improved as the farm size increases. The water-use efficiency of medium farms (10.1-20 hectares) was 0.81. With the increase in farm size above 20 hectares the water-use efficiency decreased. The water-use efficiency of large farms was 0.72, indicating that large farms exceed water requirements by 28 per cent. They believed that improvement in water management and irrigation as well as in technologies has the potential to optimize water-use efficiency at the farm levels. Sound extension strategies and the provision of pertinent advice to farmers will be instrumental (a) in optimizing water-use efficiency at the farm levels and (b) in reducing the adverse effects of salinization and water-logging on the productivity of land which are caused by over-irrigation.

In this study, the main objective is to assess the current status of on-farm water-use efficiency (technical and economic) of wheat under specific farm conditions in Fars province. For the purpose of this analysis, flexible estimation of the stochastic technology is used to evaluate individual risk preferences which then with other explanatory variables can be used to evaluate economic water use efficiency and irrigation water (marginal) productivity of wheat farmers.

MATERIALS AND METHODS

To determine farmer's economic water use efficiency and water (marginal) productivity used Transcendental production function is then given by:

$$Y = a\prod X_i^{\alpha i}.e^{\beta i \Sigma Xi} \qquad (1)$$

Then, water (marginal) productivity, MP and water-use efficiency, VMP/C, obtained by:

$$MP = Y.((\alpha.1/x) + \beta)) \qquad (2)$$

$$VMP/C = P_y.MP/C \qquad (3)$$

One of variables that affect farmer's economic water use efficiency and water (marginal) productivity farmer's is attitudes towards risk that these derived farm-specific relative risk premia. The risk-premium associated with the use of water is estimated by adapting the Antle [11,12] and Kim and Chavas [13] approaches by using a moment-based approach [11-13].

Following Antle [11,12], the farmer's objective can be written as:

$$\text{Max: } EU(\pi) = F[\mu_1(X), \mu_2(X),..., \mu_m(X)], \qquad (4)$$

Where; μj, $j = 1, 2,..., m$ is the j^{th} moment of profit and $\pi = A\times(P\times Y - C)$. A denotes acreage of rice, P is price of output, Y is yield per ha and $C = c(Y(X_i, t, e), X_i, t, e))$ is cost per ha of rice production depending on input choices X_i, technology t and production uncertainty e.

The cost of private risk bearing can be measured by the sure amount R satisfying:

$$EU(\pi) = U[E(\pi) - R] \qquad (5)$$

Where; $[E(\pi)\text{-}R]$ is the certainty equivalent of profit [14,15]. R is the risk premium measuring the largest amount of money that decision maker is willing to pay to replace the random variable π by its expected value $E(\pi)$. Risk aversion implies that $R > 0$ and corresponds to a concave utility function: $\partial^2 U/\partial\pi^2 < 0$ [14]. In general, the certainty equivalent, $E[\pi(x, t,.)] - R(x, t)$, depends on input use x and technology t.

In a similar fashion, Kim and Chavas [13] proposed to investigate the effects of technological change on risk exposure. They indicated that the risk premium can be approximated by:

$$R_I = 1/(A \cdot U^1) \cdot [-\Sigma\, (U^j/j!) \cdot (A^j \cdot \mu j_\pi)] \qquad (6)$$

Where; $U^j = (\partial^j U/\partial\pi^j)(E(\pi))$ is the jth derivative of U with respect to profit π, evaluated at $E(\pi)$, $j = 1,...,m, m = 2$. Note that μj_π is the jth central moment of π. Thus, expression (6) provides an approximate measure of the risk premium as a function of the first m moments of profit. When $m = 2$, this gives the approximation obtained by Pratt [14-16].

Farm-level data were collected from a sample of 187 wheat farms located in the three major districts of Fars province of Iran: Darab, Fasa and Sarvestan was selected by a two-stage cluster sampling during the years 2001 and 2002.

Data were then collected using designed questionnaires. The survey provides detailed information about production patterns, input use, wheat production yields, prices of inputs and output, social and personality characteristics of farmers and their families, structural characteristics during the 2 years of survey.

RESULTS AND DISCUSSION

Data Description: Tables 1 indicate descriptive statistics of physical water use efficiency and water (average) productivity.

The overall physical and economic water-use efficiency for the whole sample are 0.7089 and 0.697 respectively, which are less than one, indicating that the wheat producers over-irrigate their wheat crop. Meanwhile, the maximum of on-farm physical and economic water-use efficiency are greater than one (in order to 1.48 and 5.27), implying that this farmer under-irrigate wheat crop. The findings of these tables indicate that on-farm physical and economic water-use efficiency of farmers adopting new irrigation technology are higher than non-adopters. The overall water (average and marginal) productivity for the whole sample are 0.7562 and 0.493, respectively. Meanwhile, the maximum of on-farm water (average and marginal) productivity are greater than one (in order to 1.67 and 3.7). The findings of these tables indicate that on-farm water (average and marginal) productivity of farmers that have been adopting a new irrigation technology are higher than non-adopters. As table 2 indicates descriptive statistics of economic water use efficiency and water (marginal) productivity.

Economic Implications: This section discusses the economic implications of our econometric estimates. First, we explore whether new irrigation technology is a risk-increasing or risk-decreasing input. Finally, we decompose the risk premium into two parts: one due to the second moment (variance) and the other due to the third moment (skewness) of wheat profit. This provides some insights on the relative role of variance versus downside risk exposure (as captured by the third moment) in the evaluation of the cost of risk. We examined the statistical significance of the new irrigation technology *T* on the relative risk premium by regressing relative risk premium on the new irrigation technology at each mentioned districts. The results about relationship between relative risk premium and new irrigation technology *T* are presented in Table 3.

Table 1: Descriptive statistics of physical water use efficiency and water (average) productivity

Variables	Minimum: Adopters of new irrigation technology	Minimum: Non- Adopters of new irrigation technology	Maximum: Adopters	Maximum: Non- Adopters	Mean: Adopters	Mean: Non- Adopters
Farmer's Water Use Efficiency	0.20	0.23	1.4800	1.18	0.7598	0.6538
	0.20	1.48	0.7089			
Farmer's Water Productivity (Kg/m^3)	0.17	0.19	1.6700	1.47	0.7767	0.7342
	0.17	1.67	0.7562			

Table 2: Descriptive statistics of economic water use efficiency and water (marginal) productivity

Variables	Minimum: Adopters	Minimum: Non- Adopters	Maximum: Adopters	Maximum: Non- Adopters	Mean: Adopters	Mean: Non- Adopters
Farmer's Water Use Efficiency	-0.14	-0.26	5.2700	4.42	1.1091	0.321
	-0.26	5.27	0.6997			
Farmer's Water Productivity (Kg/m^3)	-0.09	-0.18	3.700	3.10	0.7800	0.226
	-0.18	3.70	0.493			

Table 3: Relationship between relative risk premium and new irrigation technology

Location	Constant	T	Adjusted R^2
Darab	9.96 (5.54)*	-9.8 (4.037)**	0.78
Fasa	0.776 (0.413)*	-0.24 (0.105)**	0.65
Sarvestan	4.56 (2.023)**	-3.69 (1.963)*	0.57

Note: Standard errors are given in parentheses. * Denotes significant at the 10% level. ** Denotes significant at the 5% level

Table 4: Estimation of parameters of economic water use efficiency and water irrigation (marginal) productivity of wheat farms

	Water Use Efficiency		Water Productivity	
Variables	Coefficient	T-Value	Coefficient	T-Value
Constant	0.718	3.069***	1.7450	7.081***
Relative Risk Premium	-0.043	-2.309**	-0.0201	-2.02 **
New Irrigation Method (0, 1)	0.093	2.180**	0.1630	2.095**
Number of Irrigation	-0.025	-2.459**	-0.0480	-2.885***
Wheat Acreage	0.004	1.759*	0.0030	0.759 ns
Delivery Ratio	-0.263	-4.157***	-0.4240	-4.414***
Planting Depth	0.251	1.185*	0.1720	0.722 ns
Quality of Tillage Practices	0.015	3.018**	2.0290	2.329 **
Land Leveling	0.082	1.670*	0.0560	1.713 *
Amount of Applied Seed	-0.001	-2.485**	-0.0020	-2.099**
Seed Varieties	0.019	2.301**	0.0110	2.19**
Amount of Applied Nitrate Fertilizer	0.000	0.638 ns	0.0010	2.349**
Farmer's Age	-0.004	-2.290**	0.0000	-0.062 ns
Farmer's Education	0.008	1.685*	0.0070	1.769 *
Statistics	Adjusted R2= 0.723		Adjusted R2= 0.813	
	F=15.87		F=26.95	

Note: * Denotes significant at the 10% level. ** Denotes significant at the 5% level. *** Denotes significant at the 1% level. ns Denotes non significant

The coefficients associated with new irrigation technology *T* are statistically significant and have expected signs that indicate new irrigation technology is a risk reducing in three mentioned districts.

Factors Affecting Farm Economic Water-Use Efficiency and Water (Marginal) Productivity: In this section the effect of some physical, institutional and personal factors on on-farm economic water-use efficiency and water (marginal) productivity were estimated. They are: relative risk premium, new irrigation method, number of irrigation, wheat acreage, land ownership, delivery ratio (farmer's share of common water source), distance of water resource from wheat field, land slope, water logging, number of land parcels, timeliness of planting date, planting depth, quality of tillage practices (on wet or dry soil), land leveling, new seed varieties, applied fertilizers, times number of applied urea, farmer's age, farmer's education, farmer's experience, participation times in extension classes and the location of the farm (that is farms facing higher average temperature and lower annual precipitation such as first dummy variable D1 that denotes to Darab respect to Fasa and Sarvestan and second dummy variable D2 that denotes to Fasa respect to Sarvestan). Table 4 reports the effects of all variables on the water-use efficiency and irrigation water productivity.

The results showed that the farmer-specific relative risk premium proxies for the risk attitudes of each farmer have negative and significant effect on the economic water use efficiency. The findings showed that there was a significant positive relationship between new irrigation method, wheat acreage, planting depth, quality of tillage practices (on wet or dry soil), land leveling, new seed varieties, farmer's education and economic water use efficiency. In contrast there was a significant negative relationship between amount of applied seed, number of irrigation times number of irrigation, delivery ratio, distance of water resource from wheat field, land slope, number of land parcels, timeliness at planting date, farmer's age and economic water use efficiency.

The findings showed that there was a significant positive relationship between new irrigation method, quality of tillage practices, new seed varieties, amount of applied nitrate fertilizer, farmer's education and water (marginal) productivity. In contrast there was a significant negative relationship between relative risk premium, number of irrigation times, delivery ratio, amount of applied seed and water (marginal) productivity.

As the participation of the farmers to extension classes does not have significant effect on economic water use efficiency and water (marginal) productivity. This maybe due to the fact that extension classes are more related to high yield varieties, chemical materials and their use methods, planting date, rotation and tillage methods and less about the application of new irrigation technologies.

So, for improvement of the water use efficiency, diffusion and learning, education and extension about proper application of new irrigation technologies according with pertinent technical factors and of the dominant conditions ruling over the farms was recommended that core elements are:

- Learning which improves the farmer's ability to implement the new irrigation technologies.
- Learning which reduce farmer's facing risk and allows the farmer to make better decisions about the new technology.

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