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Efficiency of Water Use in Groundwater Markets: The case of Peninsular India

A.V. Manjunatha [a], Stijn Speelman [b], M.G.Chandrakanth[c] and Van Huylenbroeck, G.[d]

[a] Institute for Agricultural Policy and Market Research, Justus Liebig University Giessen, Senckenbergstr. 3, D-35390, Giessen, Germany, manjublore@yahoo.com
[b] Department of Agricultural Economics, Ghent University, Coupure links 653, 9000 Ghent, Belgium, stijn.speelman@ugent.be
[c] Department of Agricultural Economics, University of Agricultural Sciences, GKVK, Bangalore 560065, India, mgchandrakanth@gmail.com
[d] Department of Agricultural Economics, Ghent University, Coupure links 653, 9000 Ghent, Belgium, guido.vanhuylenbroeck@ugent.be

Abstract

In the hard rock areas of India, overdraft of groundwater has led to negative externalities, increases costs of groundwater irrigation and causes welfare losses. Groundwater markets are slowly emerging as niche markets to improve water distribution and to mitigate water scarcity by stimulating more efficient use. A sample containing water sellers, water buyers and control farmers was collected to test the hypothesis of more efficient water use. The effect of groundwater market introduction on the efficiency of water use is studied using Data Envelopment Analysis (DEA). The calculated subvector efficiencies for water use show that water buyers use water most efficient. But also water sellers are more efficient in their water use than the control group. Differences in average efficiency between these groups are shown to be significant using a Kruskal-Wallis test. This finding confirms that groundwater markets can add to improving efficiency of water use. Moreover results indicate that the existence of groundwater markets offers access to groundwater to resource poor farmers, the opportunity to benefit from the improved agricultural productivity generated by irrigation. In the light of proposed changes in groundwater legislation and policies for improving water use efficiency these empirical results provide crucial information to policy makers.

Keywords: water use efficiency, groundwater markets, Data Envelopment Analysis, India

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1. Introduction

Evidence from numerous countries shows that irrigation can contribute significantly to household food supply as well as income and employment generation (Lipton, 1996; Merrey, 1997). In India, the green revolution, which was responsible for countering the country's food deficit, has largely been successful due to groundwater irrigation. However, currently effects of overdraft like initial and premature failure of wells, decline in groundwater output and declining water tables are apparent (Chandrakanth, *et al*., 2004; Nagaraj *et al*., 2005). The situation is exacerbated by growth in population and effective demand for groundwater by intensive agricultural production. In the light of this backdrop, this paper examines whether groundwater markets have the potential to contribute to improved efficiency by introducing a price for groundwater. The paper uses DEA to measure the water use efficiency of farmers. The hypothesis is that because of the role played by water markets, water sellers and buyers will operate closer to the efficiency frontier than the control group.

The remainder of the paper has three sections: section two discusses the methodology for estimation of water use efficiencies using DEA, section three presents results and discussion and section four discusses the conclusions and implications.

2. Methodology

Efficiency consists of two components: (i) technical efficiency, which gives the capacity of a firm to achieve the highest output with the given level of inputs and (ii) allocative efficiency, which reveals the capacity of a firm to apply the inputs in optimal quantities at given prices. A combination of technical and allocative efficiency will present a measure of economic or cost efficiency (Coelli, 1996). The performance of a farm can be appraised using these measures (Speelman *et al.*, 2008) and Data Envelopment Analyses (DEA) is a way to do this. The present study on groundwater markets considers the input oriented approach since we are specifically focussing on the use of a particular input namely water. For calculating the water use efficiencies, subvector analysis of water use was applied. The measure thus indicates how much farmer should reduce their groundwater use in order to operate at the efficient level (Lilienfeld and Asmild, 2007). In practice subvector efficiencies, are calculated by considering all other inputs and the output as constant (Speelman *et al.*, 2007 and 2008; Lilienfeld and Asmild, 2007).

Characteristic for DEA is that a piecewise frontier surface is assembled by solving a sequence of linear programming problems, one for each farm and relating each farm to the frontier. The frontier created envelops the observed input and output data of each farm. Simultaneously with the creation of the frontier surface the efficiency measures are obtained. Using the notion of subvector efficiency proposed by Färe *et al.* (1994), the technical subvector efficiency for the variable input k is determined for each farm i by solving following programming problem.

$$Min_{\theta\lambda}\theta^{k},$$

Subject to:

$$-y_i + Y\lambda \geq 0$$

$$\theta_k x_i^{k} - X^{K}\lambda \geq 0$$

$$x_i^{n-k} - X^{n-K}\lambda \geq 0$$

$$N1'\lambda = 1$$

$$\lambda \geq 0$$

The model is presented here for a case where there is data on *K* inputs and *M* outputs for each of the *N* farms. For the i-th farm, input and output data are represented by the column vectors x_i and y_i, respectively. The *K* by *N* input matrix, X, and the *M* by *N* output matrix, Y, represent the data for all *N* farms in the sample. θ^{k} is the input *k* subvector technical efficiency score for the i^{th} farm. The terms x_i^{n-k} and X^{n-K} in the third constraint refer to x_i and X^{k} with the exclusion of the k^{th} input. It is furthermore important to mention that the model presented above is the Variable Returns to Scale specification (VRS). This specification of the model includes the convexity constraint ($N1'\lambda = 1$). In this constraint N1 is an N×1 vector of one's. This specification is often used for agricultural production because in general farmers may not operate at the optimal scale due to imperfect competition, constraints on finance etc. The VRS specification will permit for the calculation of technical efficiency devoid of scale efficiency effects (Coelli, 1996; Johansson, 2005; Baris and Nilgun, 2007). Without this constraint the Constant Returns to Scale model would be obtained. This is actually only applicable when all farmers are operating at the optimal scale. The VRS approach forms a frontier of intersecting planes which envelope the data points more tightly than the CRS frontier. Therefore, it provides efficiency scores which are higher than or equal to those obtained using the CRS specification.

The survey data pertained to period 2007-2008. A simple random sampling procedure was adopted to select the 90 sample respondents comprising following categories :(i) **A control group:** 30

farmers who own tube wells and are not involved in either selling or buying of groundwater for irrigation, (ii) **Water sellers:** 30 farmers who own tube wells and sell part of the groundwater to neighbouring farmers and (iii) **Water buyers:** 30 farmers who buy water for agriculture from neighbours. They may also own tube wells.

3. Results and discussion

Efficiency of groundwater use

When comparing subvector efficiencies for water use (WUE), the average subvector efficiencies are highest among the water buyers (0.77 and 0.84 under CRS and VRS specification respectively), followed by the water sellers (0.73 and 0.77 under CRS and VRS specification respectively). The control group has the lowest WUE (respectively 0.67 and 0.72). This is apparent from table 1 where the farmers are divided into different efficiency classes.

Table 1: Distribution of water use efficiency scores over different farmer groups

	Farm category					
	Control group (# farmers)		Water sellers (# farmers)		Water buyers (# farmers)	
Efficiency classes	WUE (CRS)	WUE (VRS)	WUE (CRS)	WUE (VRS)	WUE (CRS)	WUE (VRS)
<50%	4	2	3	1	4	1
50-59%	3	3	4	4	0	2
60-69%	12	11	4	4	6	2
70 -79%	5	7	8	7	8	5
80-89%	3	2	7	6	2	8
90-99%	3	1	1	4	5	5
100%	0	4	3	4	5	7
Average score	0.67	0.72	0.73	0.77	0.77	0.84

Using a DEA approach, poor water use efficiency was also found by Speelman *et al*. (2008) among smallholder irrigators in South Africa and by Lilienfeld and Asmild (2007) who detected excess water use in irrigated agriculture in Western Kanvas of USA and proposed market mechanism could possibly help to bridge the efficiency gap.

Kruskal-Wallis tests are used to see if the observed difference in water use efficiency among the different categories in this study is statistically significant. The results of the Kruskal-Wallis tests are presented in table 2. It is shown that the WUE under CRS is significantly different at the critical 5 percent level while this value under VRS is significantly different at the critical 1 percent level.

Table 2: Kruskal-Wallis tests for differences in water use efficiency

Efficiency measure	Hypothesis	CRS		VRS	
		χ^2 value	P-value	χ^2 value	P-value
Technical Efficiency (groundwater)	$H_0 : \theta_w^{\,1} = \theta_w^{\,2} = \theta_w^{\,3}$; $H_1 : \theta_w^{\,1} \neq \theta_w^{\,2} \neq \theta_w^{\,3}$	6.646	0.0360	9.455	0.0088

Note: 1= control farmers, 2= water sellers and 3=water buyers;

θ_w = technical sub-vector efficiency for water

In sumary, water buyers have the highest WUE compared to water sellers and the control group. The fact that these farmers are paying for water induces them to use it more efficiently. The DEA furthermore shows that although water sellers use more water than the control group, they use it more efficiently. The possibility to sell the saved and surplus water is an economic incentive for the water sellers category to use water more efficient. In this way this is a perfect case of how markets and competition promote efficiency in the use of resources.

4. Conclusion

Water markets are believed to improve water productivity through the transfer of water to users who can obtain the highest marginal return from using it (Nieuwoudt and Armitage, 2004; Gillit *et al*., 2005; Bruns and Meinzen-Dick, 2005; Zekri and Easter, 2007). This would be apparent in an increased water use efficiency. Moreover in the case of groundwater markets in India an additional advantage of water markets is that it offers poor farmers, who do not have the financial means to invest in their own tubewell, with an opportunity to achieve higher agricultural productivity by using irrigation water. In this way water markets can contribute to equity. Using a DEA approach this study confirms both benefits of groundwater markets.

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