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Impact of groundwater markets in peninsular India on water use efficiency: A Data Envelopment Analysis approach

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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

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). Historically, staple food production has been dependent on irrigation and it is estimated that irrigated production contributes 60 percent of worldwide agricultural output (Meinzen-Dick and Rosegrant, 2001). India is no exception to this. 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). Despite improvements in groundwater extraction and water use technologies, the situation is further 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. In practice, water markets have been gradually expanding due to increasing scarcity (Saleth, 2004).

The paper uses DEA to measure the water use efficiency of farmers belonging to three groups: a control group, water sellers and water buyers. 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

2.1 Measures of efficiency

Efficiency in production is achieved when a farmers' output is produced in the best and most profitable manner (Johansson, 2005). Estimation of efficiency began with the work of Farrell (1957) who explains the concept of a firms' efficiency considering multiple inputs (Johansson, 2005; Coelli, 1996). 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. DEA was introduced by Charnes *et al.* (1978) extending the past work of Farrell (1957) (Lilienfeld and Asmild, 2007). It is a deterministic approach, non-parametric in nature, which applies mathematical programming to measure efficiency. In contrast with the Stochastic Frontier Approach, no assumptions regarding the functional form of the production function or the distribution of the error term need to be made (Subhash, 2004; Coelli, 1996; Cooper *et al.*, 2007; Andreu and Grunnewald, 2006). A disadvantage of the DEA method is that it is sensitive to measurement errors. In the present study, DEA is used because of its flexibility to estimate subvector efficiencies (Speelman *et al.*, 2008).

In general measuring technical efficiency using DEA can take two forms: (i) input-oriented in which the potential of farms to reduce input use for producing a given level of output is measured and (ii) output oriented in which the potential of increasing output with the given level of input use is measured (Coelli, 1996; Johansson, 2005). 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).

2.2 The use of Data Envelopment Analysis (DEA) to measure subvector efficiency

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 (eq 1)

$$\text{Min}_{\theta^k} \theta^k,$$

Subject to:

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

$$\theta^k x_i^k - X^k \lambda \geq 0$$

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

$$N1' \lambda = 1$$

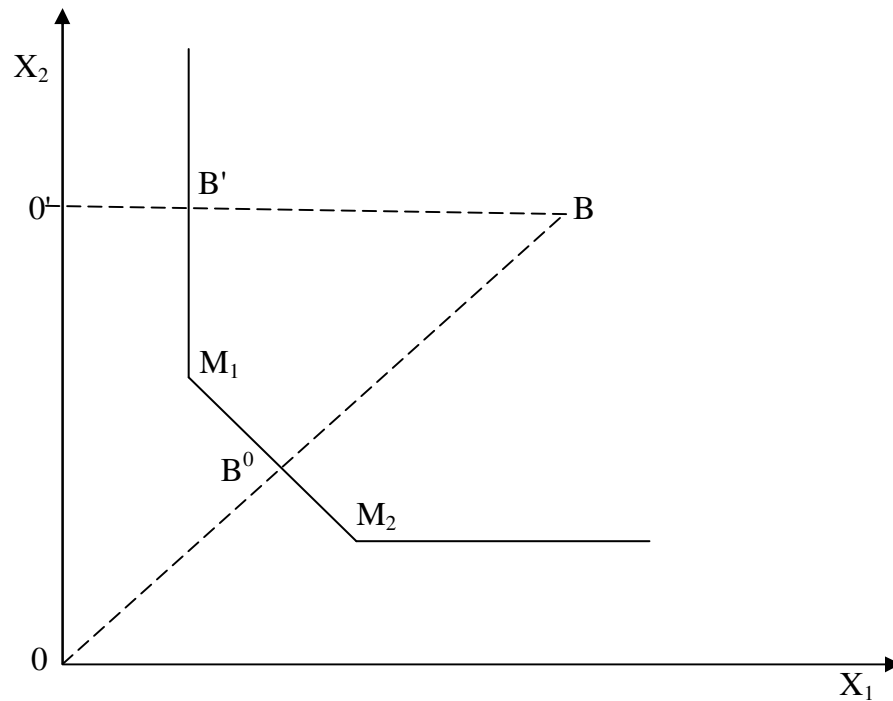
$$\lambda \geq 0$$

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^k 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 $N \times 1$ 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 measurement of subvector efficiency using DEA is shown in figure 3.2. The problem takes the i -th farm B and then seeks to contract the use of input X_1 as much as possible, while holding X_2 and output constant and remaining within the feasible input set. The inner-boundary of this set is a piecewise linear isoquant determined by the frontier data points (the efficient farms in the sample are M_1 and M_2). The contraction projects point B to B' and the sub-vector efficiency is given by the ratio $\theta' = O'B'/O'B$.



Source: Adopted from Oude Lansink *et al.* (2002)

Figure 1: Measurement of overall technical and sub-vector efficiency with two inputs and one output using DEA

2.3 Analysing efficiency values

The statistical significance of the difference in subvector efficiency among the three groups in the sample is estimated using a non-parametric Kruskal-Wallis test. This test was applied since the efficiency scores are situated between 0 and 1. P- values less than 0.01, 0.05 and 0.10 indicate that differences are statistical significance at the critical values of 1, 5 and 10 percent level (Oude-Lansink and Bezlepkin, 2003).

2.4 Data collection

The survey data were collected in 2008 and the information pertained the period 2007-2008. A simple random sampling procedure was adopted to select the sample respondents. A total of 10 villages was selected randomly out of the 306 villages in Malur taluk of Karnataka state. From each of these 10 sample villages, 9 to 10 farmers were randomly chosen for the study to make up the pre-determined 90 sample respondents comprising following categories:

-A control group: This group includes 30 farmers who own tube wells and use the water of the wells for irrigation. They are not involved in either selling or buying of groundwater for irrigation.

-Water sellers: This subsample includes 30 farmers who own tube wells and who do not only use part of this water for irrigation of their land but also sell part of the groundwater to neighbouring farmers. Usually they are paid for this water in terms of crop share. Typically $1/3^{\text{rd}}$ of the value of gross returns realized by using the purchased water is paid to the water sellers.

-Water buyers: This subsample includes 30 farmers who buy water for agriculture from neighbours. They may also own tube wells, but these do not yield sufficient groundwater for their irrigation activities.

3. Results and discussion

3.1 Farmer's characteristics and input and output variables used in DEA

Size of the landholding is one of the important factors for determining the economic status of the farmers. The average landholding size of sellers (7.8 acres) is almost twice that of buyers (3.8 acres). Considering the economic profile of the farmers selling groundwater, 83% of them are large farmers. From the farmers buying groundwater, 61% are small farmers. This indicates that groundwater sale for agriculture is dominated by large farmers, although small farmers also actively participate in selling groundwater for farming. Tomato, potato, carrot and mulberry (host plant of silk worms) are the major irrigated crops in all categories of sample farmers. However, the irrigated area is higher with sellers and control farmers than buyers because of the availability of groundwater.

Table 1 gives an overview of the input and output variables used in the DEA model. Water sellers and control farmers mean water use is respectively 64% and 29% higher compared to water buyers. Water sellers and control farmers appear to consume more water than water buyers because they own their own water source. It is logical that water buyers, who are the only ones who have to pay for water, use water more economically than the other groups. However a multidimensional measure such as the DEA subvector efficiency scores is needed to assess if the water use efficiency between the groups really differs.

Table 1: Descriptive statistics on gross returns and inputs used in the DEA model

Variables: mean (std dev)	Farmer category		
	Control group	Water sellers	Water buyers
Water (Acre-inches)	83.8 (43.5)	107.1 (46.3)	65.4 (47.3)
Labour (mandays)	253.4 (133.1)	345.2 (160.1)	193.3 (128.4)
Machine power (h)	12.3 (7.7)	18.3 (10.2)	9.4 (7.2)
Manure (cartloads)	22.6 (15.9)	31.1 (15.7)	15.8 (12.1)
Fertilizers (50 kg bags)	21.2 (13.8)	30.0 (15.3)	15.0 (12.6)
Gross returns (INR ¹)	138,602 (80,850)	196,975 (92,748)	100,300 (66,054)

In terms of the use of the other inputs (labour, machines for land operations, manure and fertilizers) the water sellers have the highest mean usage followed by control farmers. This seems to confirm that water buyers usually are resource poor farmers. The existence of water markets offers them access to increased agricultural productivity through irrigation. Furthermore, because sellers are mostly larger farmers, they have the ability to invest and take risk to maximize returns from farming and selling groundwater. The

¹ INR is Indian National Currency (One Euro is equivalent to around INR.60)

buyers on the other hand lack the financial means to invest and they take less risk to maximize production. Thus, sellers are more risk takers and buyers are more risk averse in nature.

3.2 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 also apparent from table 2 where the farmers are divided into different efficiency classes and from figure 1 and 2, which depict the cumulative distribution of the efficiency scores.

Table 2: Distribution of water use efficiency scores over different farmer groups

Efficiency classes	Farm category					
	Control group (# farmers)		Water sellers (# farmers)		Water buyers (# farmers)	
	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 Kansas of USA. The latter found that over-pumping in the Ogallala aquifer has led to expansion of irrigated agriculture and they found significant differences in farming maintained under different groundwater regimes. In order to overcome such differences, less efficient farms have to

adjust their farming practices in order to move to the efficiency frontier. Lilienfeld and Asmild (2007) propose that a market mechanism could possibly help to bridge the efficiency gap.

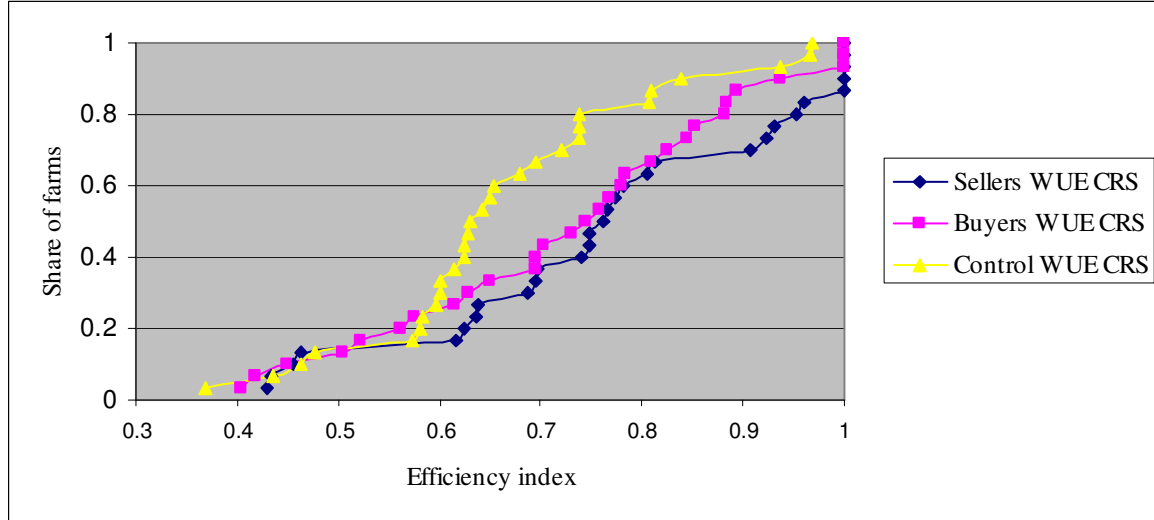


Figure 1: Cumulative efficiency distribution for water subvector efficiency under CRS specification

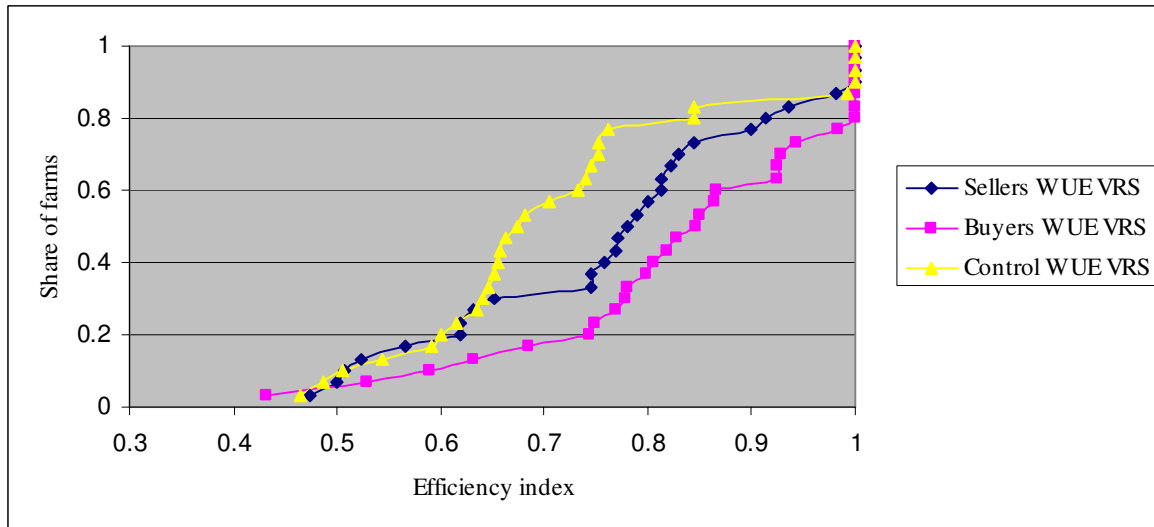


Figure 2: Cumulative efficiency distribution for water sub vector efficiency under VRS specification

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 3. 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 3: 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 summary, 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.

First descriptive analysis showed that the group of water buyers consists of resource poor farmers who without water markets would not be able to practice irrigation. Secondly significant higher water use efficiencies were found among water sellers and water buyers compared to a control group. The difference between water buyers and the control group can be explained by the fact that the first have to pay for water, which encourages

them to use it efficiently. The difference between water sellers and the control group originates from the economic incentive the water sellers have by offering them the opportunity to sell part of the water they pump.

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