CAN GROUNDWATER MARKETS PROMOTE EFFICIENCY IN AGRICULTURAL PRODUCTION?

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ABSTRACT

In the hard rock areas of India overdraft of groundwater is resulting in negative externalities such as reduction in water table and well failures. This has increased the costs of groundwater irrigation resulting in inefficiency and welfare losses. Informal groundwater markets are slowly emerging with the potential of improving water distribution and mitigating scarcity. This study aims to demonstrate how groundwater markets can improve efficiency in agricultural production. The technique applied is to quantify input use efficiency or, more specifically, to relate economic surpluses to inputs applied, using Data Envelopment Analysis (DEA). The efficiency was estimated for three groups of famers: (i) a control group: farmers are not selling or buying groundwater, (ii) a water seller group: farmers are selling groundwater and (iii) a water buyer group: farmers are buying groundwater. The results indicate that, water buyers are more efficient followed by sellers and the control group, in particular, in using inputs in general and water specifically. Hence, groundwater markets promote efficiency among those participating in water markets. Differences in efficiencies between the groups are shown to be significant using a Kruskal-Wallis test. The information provided by this study can be used by policy makers to determine their attitude towards the emerging groundwater markets.

Keywords: Data envelopment analysis, Externalities, Groundwater markets, efficiency, India

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1. INTRODUCTION

Water is a vital resource for irrigation, which is crucial for food and livelihood security. Historically, stable food production, also in India, has been dependent on irrigation, with irrigated agriculture contributing 60% to global agricultural output (Meinzen-Dick and Rosegrant, 2001). In India, the green revolution, which was mostly responsible for countering the past food deficits, has largely been successful due to groundwater irrigation. However, effects of overdraft such as increasing failure of wells and declining water tables nowadays constrain agriculture in hard rock areas of India, which constitute 60% of India's groundwater irrigated area (Chandrakanth, et al., 2004; Nagaraj et al., 2005). This situation is exacerbated by population growth and the attached increase in water demand intensive agriculture production.

In the light of this backdrop, the present study examines whether groundwater markets have the potential to contribute to efficiency in input use, particularly if groundwater gets a price by putting a charge on water. Water markets have been gradually expanding due to the increasing water scarcity and currently they span over 15% of the irrigated area in India (Saleth, 2004). In practice, groundwater markets have been gradually expanding in many study areas due to increased water scarcity and in addition to increasing irrigation costs because of the frequent incidence of well failures. Groundwater markets ensure that a surplus pumping capacity is being used more properly, thereby increasing economic benefits for the tube well owner. This furthermore allows farmers, which are unable to make the necessary investments in wells, to meet their irrigation water demand and offers them the opportunity to benefit from improved agricultural productivity (Shiferaw et al., 2008). In such way markets appear to be beneficial for society (Kolavalli and Chicoine, 1989; Saleth, 1998, 2004, 2008). The groundwater markets in India are mostly informal and usually emerged from farmers' initiatives. They are enforced through user's cooperation and water rights in these markets; often they are not explicitly defined (Zekri and Easter, 2007).

Most studies on established water markets focus on the financial benefits (Brooks and Harris, 2008; Zekri and Easter, 2005) or on the implementation of these markets themselves (Howe and Wiener, 2006; Bjornlund, 2006; Bjornlund, 2003). In this paper we are particularly concerned with the effect of groundwater market on input use, particularly water use rates. The paper uses Data Envelopment Analysis (DEA), a non-parametric mathematical programming approach, to measure the efficiency in input use of farmers belonging to three groups: a control group, group of water sellers and water buyers (Coelli, 1996; Cooper et al., 2007). The hypothesis is that because of the role played by water markets, water sellers and water buyers will use inputs, particularly water, more efficiently and they will operate closer to the efficiency frontier than the control group. DEA has recently also been used to calculate water use efficiency for smallholders in South Africa and by Lilienfeld by Speelman et al. (2008) and Asmild (2007) for irrigators in Kansas (USA); but the focus of those papers was not on the effect of water markets on efficiency, rather of input use. The remainder of the paper is organized in three sections: section two describes the methodology for estimation of efficiencies using DEA, section three presents' results and a discussion and a final section offers conclusions and implications.

2. METHODOLOGY

2.1 Data collection and sampling technique

The data collection for the present study was undertaken in one of the taluks of the Eastern Dry Zone (EDZ) of Karnataka, which lies on the Peninsular of India. This region provides agricultural products, such as fruits, vegetables, but also flowers, for the mega city of Bangalore, farmers are comparatively rich, and the region is characterised by groundwater market activities. A simple random sampling procedure was adopted to select 90 sample respondents comprising the following categories: (i) Control group**:** this subsample includes 30 farmers who own tube wells and who use the water for irrigation, but are not involved in either selling or buying of groundwater for irrigation. (ii) Group of Water Sellers**:** This subsample includes 30 farmers who own tube wells and who do not only use part of their water for irrigation of the land, but also sell part of the groundwater to neighboring farmers. They receive a rent for water which is let out in terms of crop shares, labour or cash (Kajisa and Sakurai, 2005; Deepak et al, 2005). And (iii) the group of Water Buyers: This subsample includes 30 farmers who buy irrigation water from neighbours. It must be noted, however, that some buyers may also own wells. But, these wells are not yielding sufficient groundwater for their irrigation activities. The survey data elicited from the respondents pertains to the year 2007-2008.

Using structured and pre-tested questionnaires detailed information was elicited from the respondents. Following aspects were covered: (i) general information about the farm family, including family size , education level of the household head, size of the land holdings etc.; (ii) information regarding sources of irrigation, details of wells, investment on wells, crop wise particularities of well command, costs and returns of crops grown and (iii) information regarding existence of water markets and their types, functioning and pricing systems prevailing, particulars of water purchases and sales, reasons for buying and selling of water.

2.2 Measures of Efficiency

Efficiency in production is achieved when the farmers' output is produced at best productivity and in 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). According to him efficiency consists of two components: (i) technical efficiency, which gives the capacity of the firm to achieve highest output with a given level of inputs and (ii) allocative efficiency, which reveals the capacity of the firm to apply all inputs in optimal quantities at given prices. Then, a combination of technical and allocative efficiency presents a measure of economic or cost efficiency (Coelli, 1996). Measuring efficiency can furthermore take two forms: (i) input-oriented in which the capacity of a firms to reduce input use for producing is given at a level of output and assessed and (ii) output-oriented in which the capacity of a firms to increase output with a given level of inputs is assessed (Coelli, 1996; Johansson, 2005). Our analysis on groundwater markets considers the input oriented approach for finding efficiency levels across different groups of sampled farmers. It indicates how much farmer should reduce use of inputs in general and groundwater in particular in order to operate at the efficient level (Lilienfeld and Asmild, 2007).

2.3 The use of Data Envelopment Analysis (DEA) to measure efficiencies

The performance of a farm can be appraised on the measures of efficiency and this has led to the formulation of DEA. Efficiency analysis can be carried out using deterministic and stochastic approaches. The deterministic approach called Data Envelopment Analysis (DEA), is non-parametric in nature and applies mathematical programming to measure efficiency; also it is not imposing restrictions on the data set (Coelli, 1996; Cooper et al., 2007). DEA was introduced by Charnes et al. (1978) extending the past work of Farrell's (1957) (see: Lilienfeld and Asmild, 2007). In contrast, the Stochastic Frontier Approach (SFA), which is parametric in nature, applies random production and cost or profit functions to measure efficiency (Coelli, 1996; Andreu and Grunnewald, 2006). Both methods estimate a firm's relative position to the efficiency frontier (Johansson, 2005). DEA was criticized in the past because of its inability to account for errors and to test for significance of the efficiency measures. As a response Banker (1993) and Fare and Grosskopf (1995) revealed a number of statistical tests which have made DEA a powerful tool for analyzing efficiencies. SFA has drawbacks on the grounds of a priori assumption of functional forms and distribution of, for example, the one sided error term (Forsund, Lovell, and Schmidt, 1980). It can, however, account for measurement errors and for random disturbances, for example, due to climate factors, fate etc. (Coelli, 1996; Lilienfeld and Asmild, 2007). In the current analysis, DEA is used for calculating the efficiencies of farmers because of the flexibility in operation and because of the estimation possibilities (Speelman et al., 2008).

DEA considers a piece wise linear convex hull, which was used by various researchers across the world for estimation of the frontier. Efficiency is estimated relative to this frontier and any deviation from the frontier is considered as inefficiency (Johansson, 2005; Coelli, 1996). The method became most popular after the work of Charnes, Cooper and Rhodes (1978). They proposed an input-oriented model with an assumption of Constant Returns to Scale (CRS). The CRS assumption is applicable when all the farmers are operating at optimal scale. Consider there are K inputs and M output on each of N farmers or DMUs. Where, Y is K×N matrix of outputs and X is K×N matrix of input representing the data of all farmers. The technical efficiency of the farmers under CRS can then be expressed in envelopment form, which is easier to solve than multiplier and ratio form, as follows (Coelli, 1996; Speelman et al., 2008):

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

Subject to:

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

$\theta x_i - X\lambda \geq 0$,

$N1'\lambda = 1$,

$\lambda \geq 0$

Where θ is a scalar which represents the i-th farmer technical efficiency relative to the other farmers in the sample, x_i and y_i represent input and output of the i-th farmer and Yλ and Xλ are efficient projections on the frontier. The value of θ gives the efficiency score of the i-th farmer. If a farmer's efficiency score is one, then he is considered as fully technically efficient. A value less then one indicates that input use can be reduced proportionally without any reduction in the output (Coelli, 1996; Johansson, 2005). In general, farmers may not operate at the optimal scale because of imperfect competition, constraints on finance etc. In such as situation, Banker, Charnes and Cooper (1984) proposed extension of CRS model to reckon Variable Returns to Scale (VRS) situations. The VRS will permit for the calculation of technical efficiency devoid of scale efficiency effects. The VRS mathematical programming problem can be derived by adding convexity constraint (N1 'λ) to CRS equation. Where N1 is an N×1 vector of one's. The VRS approach forms a convex hull of intersecting planes which envelope the data points more tightly than the CRS conical hull. It thus provides technical efficiency scores, which are higher than or equal to those obtained using the CRS model. Again the minimization problem below has to be solved for each farmer (Coelli, 1996; Johansson, 2005; Baris and Nilgun, 2007).

In order to obtain economic/cost efficiency the following model is used:

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

Subject to:

$-y_i + Y\lambda \geq 0$

$\theta x^* - X\lambda \geq 0$

$N1'\lambda = 1$

$\lambda \geq 0$

Where θ is expressed as $W_i^{'}\ X_i^{*}$ and W_i is the vector of input prices for the i-th farmer and X_i^{*} is the cost minimizing vector of input quantities for the i-th farmer, given the input prices W_i and output levels y_i. The cost or economic efficiency (EE) is the ratio of minimum cost to observed cost for the i-th farmer and is calculated as follows:

$$EE = {W'_i X_i^*}\big/{W'_i X_i^*}$$

The allocative efficiency estimates the i-th farmer relative ability to allocate the inputs in the cost minimizing mode with the given amount of technology (Coelli, 1996). The allocative efficiency is calculated as follows:

$$AE = {EE}\big/{TE}$$

In our study the efficiency measures, explained above, are calculated considering water, labour, manure and fertilizers as inputs and gross returns as output. In a second step the statistical significance of the differences in technical, allocative and cost efficiency among the three sample groups is tested using a non-parametric Kruskal -Wallis test. This type of test is required since the efficiency scores are situated between 0 and 1. Statistical significance of differences is assessed at 1, 5 and 10 % level (Oude Lansink and Bezlepkin, 2003).

3. RESULTS AND DISCUSSION

3.1 Farm characteristics of water sellers, water buyers and control group

In India the size of landholdings is one of the important factors for determining the economic status of the farmers. Considering landholdings of the farmers selling groundwater, 83% of them are large farmers (owning more than 5ha). From the farmers buying groundwater, 61% are small and marginal farmers (landholdings up to 2.5ha). This shows that groundwater sale for irrigation is dominated by large farmers, while small and marginal farmers are the predominant buyers of groundwater for agriculture. It should however be noted that small and marginal farmers also participate in groundwater sales. The above findings are similar to the results of Fujita and Hossain (1995) in Bangladesh and Meinzen-Dick (1997) in Punjab province of Pakistan and to those of Deepak et al. (2005) and Purushottam and Sharma (2006) in India. The latter also reported a skewed distribution of land and water ownership. According to them, well owners are mostly resource rich farmers who are involved in selling water and small farmers act as buyers because they are often unable to do the large investments needed to construct a well.

The cropping pattern of the farmers is a function of the availability of irrigation during different seasons of the year. Tomato, potato, carrot and mulberry (host plant of silk worms, a perennial crop) are the major irrigated crops in all categories of sample farmers. As typical crop mulberry requires less water, the share of the land cultivated with mulberry is however different for water sellers and buyers. Among sellers it constitutes 4.1% while for buyers this is 17.8%.

3.2 Descriptive statistics on inputs and output used in DEA

Water sellers and control farmers average water use is respectively 64% and 29% higher than that of water buyers. Water sellers and control farmers consume more water than water buyers because they have their own water source, which provides them an easier access to water. Moreover as stated above, they also irrigate larger areas. Furthermore it should be noted that water buyers, who are the only ones who pay more than the extraction costs for water, use water more economically than the other groups.

Table 1: Descriptive statistics on inputs and output used in DEA model

Variables: mean(stddev)	Farmer Category		
	Control group	**Water sellers**	**Water buyers**
Water (m^3)	8613.81 (4471.37)	11008.83 (4759.18)	6722.48 (4861.97)
Labour (mandays)	253.4 (133.1)	345.2 (160.1)	193.3 (128.4)
Manure (tonnes)	22.6 (15.9)	31.1 (15.7)	15.8 (12.1)
Fertilizers (kgs)	1060 (690)	1500 (765)	750 (630)
Gross Returns (INR)	138602 (80850)	196975 (92748)	100300 (66054)

In using other inputs such as labour, manure and fertilizers, again water sellers have the highest average usage, followed by the control group. It is important to consider that water sellers are mostly large farmers, who have ability to invest and take risk for maximizing returns from farming and selling groundwater as well as water buyers are mostly small farmers, who lack capital to invest and take less risk for maximizing production. Thus, sellers are risk takers and buyers are risk averse in nature (Deepak et al., 2005; Nagaraj et al., 2005; Shah, 1993; Kajisa and Sakurai, 1999).

3.2 Cost minimizing inputs

If the cost minimizing input vector for the different sample groups (table 2) is compared with the actual levels, it can be seen that all groups have the potential to reduce the input use; this is important in order to start operating on the efficiency frontier. However, water sellers have the largest scope to reduce input use in general and water and labour use in particular, followed by the control group. Water buyers apparently only have a modest potential for reduction of input use.

Table 2: Cost minimizing inputs (quantities) under CRS and VRS assumptions

Variables: mean(stddev)	Farmer category					
	Control group		Water sellers		Water buyers	
	CRS	VRS	CRS	VRS	CRS	VRS
Water (m^3)	5048.02 (2945.02)	13348.32 (2919.24)	7266.24 (3377.68)	7437.90 (3044.64)	3667.55 (2390.90)	4295.60 (1984.88)
Labour (mandays)	110.07 (63.19)	289.41 (102.23)	159.19 (74.43)	203.89 (121.38)	79.78 (51.59)	92.71 (58.77)
Manure (tonnes)	27.69 (16.26)	73.37 (16.07)	38.81 (19.15)	34.05 (14.86)	19.98 (13.35)	18.19 (12.96)
Fertilizers (kgs)	1385 (812.5)	3668.5 (763.5)	1942 (955)	1737 (799.5)	999.5 (667)	887 (675)

3.3 Technical, allocative and cost efficiency of farms

Water buyers have the highest average technical efficiency compared with water sellers and the control group whereas sellers have the highest average allocative and cost efficiencies. Although the number of the farms with total technical efficiency is greater, the number reduces with allocative and cost efficiency. Table 3 makes clear that farmers in all the groups over-use inputs leading to allocative and cost inefficiency. The intensity of inefficiency is higher among control farmers compared to water sellers and water buyers. This could be an indication of the importance of groundwater markets in promoting efficiency in input use. The results of the DEA can be used to convert inefficient farms to operate on the efficiency frontier.

Table 3: Number of farms in the efficiency categories under CRS and VRS

Efficiency measure and classes	Farmer Category					
	Control group		Water sellers		Water buyers	
Technical Efficiency	**CRS**	**VRS**	**CRS**	**VRS**	**CRS**	**VRS**
<60%	0	0	0	0	0	0
60-69%	2	1	1	0	0	0
70 -79%	12	9	8	9	6	3
80-89%	12	13	13	12	12	14
90-99%	4	2	5	5	7	5
100%	0	5	3	4	5	8
Average score	0.81	0.85	0.84	0.86	0.88	0.90
Allocative Efficiency	**CRS**	**VRS**	**CRS**	**VRS**	**CRS**	**VRS**
<60%	0	0	0	0	2	2
60-69%	3	2	0	0	2	1
70 -79%	3	4	4	2	8	5
80-89%	11	12	9	15	13	14
90-99%	13	11	15	10	5	7
100%	0	1	2	3	0	1
Average score	0.86	0.86	0.90	0.90	0.80	0.83
Economic Efficiency	**CRS**	**VRS**	**CRS**	**VRS**	**CRS**	**VRS**
<60%	3	0	0	0	2	2
60-69%	11	11	10	8	13	6
70 -79%	13	14	10	9	13	14
80-89%	2	3	7	10	2	4
90-99%	1	1	1	0	0	3
100%	0	1	2	3	0	1
Average score	0.70	0.73	0.76	0.78	0.69	0.75

This is apparent from a study conducted in Australia which assessed the efficiency of irrigation schemes. The finding is that 3.72% of the irrigation schemes were technically inefficient and 63.89% of the schemes had average efficiency score less than 50%. This led to measures which have reduced costs by AU$ 17 million, thereby covering the maintenance expenditure for 43 major irrigation schemes in Australia in 1998 and 1999 (Gang and Felmingham, 2004).

3.4 Testing the significance of the differences in efficiency measures

The results of the Kruskal-Wallis tests (table 4) showed that technical and allocative efficiency is significantly different among water sellers, water buyers and control farmers, either at the critical 1%, 5% or 10% level, both under CRS and VRS assumptions. The economic efficiency under CRS differs significantly between the groups at the critical value of 10%, while under VRS there is not significant difference among the groups for this measure.

Table 4: Kruskal-Wallis tests for differences in efficiency measures

Efficiency measure	**Hypothesis**	**CRS**		**VRS**	
		χ^2 value	**P-value**	**χ^2 value**	**P-value**
Technical Efficiency	$H_0: \theta_t^1 = \theta_t^2 = \theta_t^3$; $H_1: \theta_t^1 \neq \theta_t^2 \neq \theta_t^3$	5.887	0.0527	5.306	0.0704
Allocative Efficiency	$H_0: \theta_a^1 = \theta_a^2 = \theta_a^3$; $H_1: \theta_a^1 \neq \theta_a^2 \neq \theta_a^3$	17.569	0.0002	8.313	0.0157
Economic Efficiency	$H_0: \theta_e^1 = \theta_e^2 = \theta_e^3$; $H_1: \theta_e^1 \neq \theta_e^2 \neq \theta_e^3$	4.772	0.092	3.278	0.194

Note: 1= control farmers, 2= water sellers and 3=water buyers;
θ_t = Technical efficiency, θ_a= Allocative efficiency and θ_e= Economic efficiency

4. CONCLUSIONS AND IMPLICATIONS

Water markets are gaining popularity over the years, due to the increasing water scarcity. This is the case in many parts of the world and particularly also in India. Water markets have been advocated to improve resource management, leading to more efficient water use and allocation within and between sectors. Markets are also more flexible than command-and-control instruments in allocating water to higher-value users in a manner acceptable to all parties, and therefore they can promote economic growth and diminish social tension (Easter et al., 1999; Kemper, 2001; Kemper et al., 2003). In many countries governments are trying various options to achieve more sustainable management of groundwater. It has been found that water marketing can be an instrument for improving productivity and income distribution (Fujita and Hossain, 1995; Meinzen-Dick, 1997).

The DEA analysis in this study showed that farmers in all groups can reduce input use while maintaining the same level of output. The reduction potential of input use is nevertheless higher with water sellers and control farmers than with water buyers. Water buyers have a higher average technical efficiency than the other two groups, while water sellers have a higher allocative and cost efficiency. The observation that water buyers are more efficient in using groundwater compared to water sellers and the control group can be explained by the fact of paying a price for water which exceeds extraction costs. When comparing water sellers and the control group, water sellers are more efficient in using their resources than control farmers. Hence, groundwater markets appear to promote efficiency among those participating in water markets. The differences between water sellers and control group originate from the economic incentive, which water sellers have because they are able to sell surplus water.

These findings provide crucial information for the policy makers on input use, irrigation methods and cropping pattern for improving efficiency in agricultural production and to mitigate water scarcity problems. Based on the results the Indian government should facilitate groundwater markets by developing a legal framework for them and furthermore there should be a form of regulation from the government on quantity of water extraction by the individual farmers, since unregulated water market activities might promote overexploitation (Easter et al., 1999).

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