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Impact of groundwater markets in 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. It increased costs of groundwater irrigation and caused welfare losses. At the same time informal groundwater markets are slowly emerging and are believed to improve water distribution and to increase water use efficiency in the irrigation sector. These claims are evaluated in this study. For this purpose data was collected from a sample containing three different groups of water users: water sellers, water buyers and a control group of non-traders. First the socio-economic characteristics of these groups are compared. Then the efficiency of water use of the three groups is studied using Data Envelopment Analysis. The results indicate that groundwater markets provide resource poor farmers access to irrigation water, giving them the opportunity to raise their productivity. Water buyers are furthermore shown to be most efficient in their water use, while water sellers are also shown to be more efficient than the control group. The differences in efficiency between the groups are statistically significant. The demonstrated potential of groundwater markets to improve the efficiency of water use and to increase equity in resource access should be taken into account by the Indian government when deciding on their attitude towards the emerging groundwater markets.

1. Introduction

Evidence from numerous countries shows that irrigation can contribute significantly to household food supply as well as to income and employment generation (Hussain and Hanjra, 2004; Smith, 2004). Historically, staple food production has been dependent on irrigation and irrigated production is estimated to account for 60% of worldwide agricultural output (Meinzen-Dick and Rosegrant, 2001). This also holds for India, where 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 premature failure of wells, decline in groundwater yield and lowering water tables are apparent (Chandrakanth et al., 2004; Diwakara and Chandrakanth, 2007; Nagaraj et al., 2005; Mukherji and Shah, 2005; Shah et al., 2008). In spite of improvements in groundwater extraction and water use technologies, the situation is expected to further worsen due to population growth and the increase in effective demand for groundwater by intensive agricultural production. Within this context, this paper examines whether groundwater markets have the potential to contribute to improved water use efficiency. In practise, informal groundwater markets have been gradually expanding in the study area. The groundwater markets ensure that surplus pumping capacity is being used, which increases economic benefits for the tube well owners. The markets furthermore allow farmers, who are unable to make the necessary investments in tube wells, to meet their irrigation water demand, offering them the opportunity to benefit from improved agricultural productivity (Shiferaw et al., 2008). In this way they appear to be beneficial for society (Kolavalli and Chicoine, 1989; Saleth, 1998, 2004). Groundwater markets in India are mostly informal and usually emerged from farmers' initiatives. They are enforced through users' cooperation and water rights in these markets often are not explicitly defined (Zekri and Easter, 2007).

Most studies on established water markets focus on the economic benefits (Brooks and Harris, 2008; Nieuwoudt and Armitage, 2004; Zekri and Easter, 2005) or on the functioning of

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the markets themselves (Bjornlund, 2003, 2006; Brennan, 2006; Chong and Sunding, 2006; Murphy et al., 2009). In addition, there are also many studies using simulation results to predict the economic potential of the introduction of water markets (Berger et al., 2007; Gomez-Limon and Martinez, 2006; Pujol et al., 2006). In this paper however we are specifically interested in the effect of water markets on water use efficiency. Data envelopment analysis (DEA) is used to calculate the sub-vector efficiencies of water use[1] for farmers belonging to three groups: a control group, water sellers and water buyers. The control group consists of farmers who own a well but do not engage in the water market. Our hypothesis is that because of the role played by water markets, water sellers and buyers will use water more efficiently and will operate closer to the efficiency frontier than the control group. The DEA methodology was recently also applied to calculate water use efficiency by Speelman et al. (2008) for smallholders in South Africa, by Frija et al. (2009) for greenhouses in Tunisia and by Lilienfeld and Asmild (2007) for irrigators in Kansas (USA). These studies however did not focus on the effect of water markets. Our paper furthermore also investigates the claim that groundwater markets in the study area increase water access for resource poor farmers.

The remainder of the paper is organized in three sections: section two describes the DEA methodology for estimation of water use efficiencies, section three presents the results and discussion and section four provides conclusions and policy implications.

2. Methodology

2.1. Measures of efficiency

Studies on efficiency differentials among farms often use simple measures, such as yield per ha or output per m^3, which are easy to calculate and understand. However, such measures tell very little about the reasons for observed differences among farms and might be misleading. Output per m^3 of water, for example, does not take into account the possible differences in non-water inputs among farms, such as labour or fertilizers (Coelli et al., 2002). We therefore propose to use a systems approach, in which the relationship between all inputs and outputs is taken into account, to calculate more consistent measures of efficiency (Speelman et al., 2008). This way of evaluating efficiency began with the seminal work of Farrell (1957) who introduced the concept of technical efficiency. According to this concept, the technical efficiency of a firm can be evaluated by comparing the inputs it uses and the outputs it produces with those of other firms in a given group. In general technical efficiency measures can take two forms: (i) input-oriented, considering the potential of firms to reduce input use for producing a given level of output and (ii) output-oriented, considering the potential to increase outputs with a given level of input use (Coelli, 1996; Coelli et al., 2005). The present study on groundwater markets uses the input-oriented approach because we are specifically interested in how efficient water is used as an input in agricultural production. To this end we calculate the sub-vector efficiency of water use. Sub-vector efficiency measures look at the possible reduction in a subset of inputs, holding all other inputs and outputs constant (Färe et al., 1994; Frija et al., 2009; Lilienfeld and Asmild, 2007; Oude Lansink et al., 2002; Speelman et al., 2008). The measured sub-vector efficiency of water use thus indicates how much a farmer could reduce his water use, while still producing the same output level and not changing the use of other inputs (Lilienfeld and Asmild, 2007).

2.2. The DEA model to measure sub-vector efficiency

The methodology used for measuring the sub-vector efficiencies in this study is Data Envelopment Analysis (DEA). DEA provides a straightforward approach for calculating the efficiency gap between the actions of individual producers and best practises, inferred from observations of the inputs used and the outputs generated by efficient firms. The method was introduced by Charnes et al. (1978). It is a deterministic approach to measure efficiency, non-parametric in nature. In contrast with the Stochastic Frontier Approach, no assumptions regarding the functional form of the production function or the distribution of the error term are needed (Alsharif et al., 2008; Banker, 1993; Coelli, 1996; Cooper et al., 2007; Färe and Grosskopf, 1995; Subhash, 2004). A disadvantage of DEA is that it is sensitive to measurement errors. However, because DEA enables to easily calculate sub-vector efficiencies for water use (see for example Frija et al. (2009), Speelman et al. (2008) and Lilienfeld and Asmild (2007)), we opt to use this methodology for our study.

DEA involves the use of linear programming to construct a piecewise linear frontier over the data. Efficiency measures are then calculated relative to this frontier (Coelli et al., 2005). Using the notion of sub-vector efficiency proposed by Färe et al. (1994), the technical sub-vector efficiency for the variable input k (θ^k) is determined for each farm i by solving following programming problem (Eq. (1)). Note that this linear programming problem must be solved once for each farm in the sample, yielding a value θ^k for each farm.

$$\mathrm{Min}_{\theta^k,\lambda}\theta^k \tag{1}$$

Subject to:

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

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

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

$$N1'\lambda = 1$$

$$\lambda \geq 0$$

The model is presented here for a case where there is data on L inputs and M outputs for N farms. For the i-th farm, input and output data could be represented by column vectors x_i^L and y_i^M, respectively. A L by N input matrix, X^L, and a M by N output matrix, Y^M, represent the input and output data for all N farms in the sample. The terms x_i^{L-k} and X^{L-k} in the third constraint refer to x_i^L and X^L with the exclusion of the input k, whereas x_i^k and X^k in the second constraint represent the use of input k by the i-th farm and by all N farms respectively. $N1$ finally is an N by1 vector of ones. Looking at Eq. (1) it can be seen why this methodology is called data envelopment analysis. The second constraint and third constraint define a lower limit for the inputs and the first constraint an upper limit for the outputs of the i-th farm. Within these limits θ^k is minimized. The set of solutions to all farms forms an upper bound that envelops all observations.

The obtained sub-vector efficiency score θ^k, can have a value between 0 and 1, where a value of 1 indicates that the observation is a best performer located on the production frontier and has no

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[1] In this paper the sub-vector efficiencies for water use are used as a measure of water use efficiency. In determining the efficiency of water use or the potential to save water, this multidimensional measure takes into account the differences in non-water inputs among farms. The concept is explained in Section 2.1.

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potential to reduce use of input k without reducing the output level or increasing the use of other inputs. A value of θ^k smaller than 1, however, indicates inefficiency, i.e., the excess use of input k, meaning that saving of input k can be achieved. In our case we are specifically interested in the efficiency of water use and therefore the input for which we calculate sub-vector efficiencies is water.

It is furthermore important to mention that constraint 4 is a convexity constraint, which specifies the Variable Returns to Scale specification (VRS). Without this convexity constraint, the DEA model would describe a Constant Returns to Scale (CRS) situation, implying that production scale does not affect efficiency. However in the case of agriculture, increased amounts of inputs usually do not proportionally increase the amount of outputs. Therefore the VRS option might be more suitable for our problem. The VRS specification permits for the calculation of technical efficiency devoid of scale efficiency effects (Coelli, 1996; Coelli et al., 2005). Comparison of results using CRS and VRS specification gives insight in the scale efficiency.

The concept of sub-vector efficiency and the difference with overall technical efficiency is graphically illustrated in Fig. 1. The problem takes the farm B and then seeks to contract the use of input water as much as possible, while holding for example fertilizer use and output constant and remaining within the feasible input set. The inner-boundary is a piecewise linear isoquant determined by the frontier data points (the efficient farms in the sample are M1 and M2). The projected point is a linear combination of the observed data points, with the constraints in Eq. (1) ensuring that the projected point cannot lie outside the feasible set. The contraction projects point B to B′ and the sub-vector efficiency θ^k is given by the ratio of distances 0′B′/0′B. For overall technical efficiency, the contraction would be radial and the projected point would be B^0

After calculation of the water use sub-vector efficiency for all respondents it was tested if average scores differed among the three groups. The statistical significance of the difference in sub-vector efficiency among the three groups in the sample is tested using the non-parametric Kruskal–Wallis test. Subsequently Mann–Whitney U-tests are used to compare results two by two. Non-parametric tests are required here because the efficiency scores are effectively censored between zero and one (Oude-Lansink and Bezlepkin, 2003).

2.3. Data collection and analysis

The present study was undertaken in one of the taluks[2] of the Eastern Dry Zone (EDZ) of Karnataka, which lies in southern Peninsular India. The EDZ of Karnataka is a semi arid region, with high evaporation. The region provides agricultural products for the city of Bangalore. Farmers in Karnataka mainly use electric pumps for the extraction of groundwater. Electricity for agricultural use is nearly 100% subsidised. While there are no legal restrictions on water extractions, by limiting supply of electricity to 7–9 h per day, farmers nevertheless face a practical limit. Nonetheless, there is over-extraction of groundwater, causing declining water tables and well failures, which in turn induced farmers to engage in appropriative competition[3] (Grossman and Mendoza, 2003). The region is also characterised by intensive groundwater market activities. The markets emerged in the region because of the deep groundwater table, which causes high initial investments for tube wells and because of the high risk of well failure. Both the number of buyers that the owners of wells can expect and the number of sellers that those demanding water can turn to is physically limited (Kajisa and Sakurai, 2000, 2005). The result is that there often is a one seller-one buyer relationship. In such a situation, which is close to a 'bilateral monopoly', bilateral bargaining between the seller and buyer determines the price paid for water. Kajisa and Sakurai (2000) demonstrated that this market structure mostly works in favour of the buyers. The situation in the study area therefore clearly differs from the one in Gujarat described by Shah (1993), where there were few sellers and many buyers and where sellers enjoyed monopoly power.

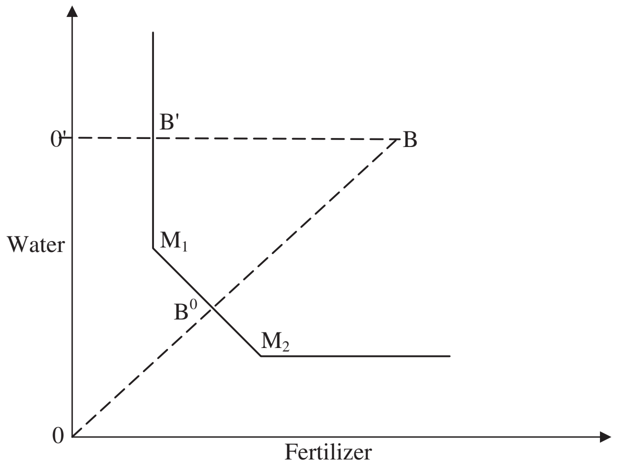

Fig. 1. Deriving the sub-vector efficiency of farm B for the case of two inputs (water and fertilizer) and one output (profit). Source: Adopted from Oude Lansink et al. (2002).

The selected taluk, Malur taluk, has the highest groundwater market activity in the region. It is furthermore classified as a dark zone[4] and there is no potential for further development of irrigation in the area. Finally, the recharge potential of the water table in the area is extremely low because the hard rock area lacks primary porosity (Nagaraj et al., 1999).

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 ten villages was selected randomly out of the 306 villages in Malur taluk. Three groups of farmers were identified: (i) water sellers: these farmers own tube wells and use part of the groundwater 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, cash or labour (Kajisa and Sakurai, 2005). When payment is in terms of crop share, typically one third of the value of gross returns realized by using the purchased water is paid to the water sellers; (ii) water buyers: these farmers buy water for agriculture from neighbours. They themselves may also own tube wells, but these do not yield sufficient water to meet their demand; (iii) control group: these farmers own tube wells and use the water of the wells for irrigation, but they are not involved in either selling or buying of groundwater for irrigation. For each group about three farmers from each of the ten sample villages were randomly chosen. Consequently the sample contains 90 respondents in total

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[2] A taluk is an administrative division in India.

[3] Appropriative competition refers to the situation where resource scarcity induces individuals to extract more of a resource, thus leading to a faster rate of resource exhaustion.

[4] According to Department of Mines and Geology, Government of Karnataka, an area is considered as a dark zone if water extraction exceeds more than 85 percent of recharge. These zones are characterized by over exploitation and restricted institutional finance for installation of tube wells (Nagaraj et al., 1999; Saleth, 1996).

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and 30 respondents in each group. This sample size satisfies the rule for conducting DEA proposed by Banker et al. (1989). He proposed that the sample size should be greater than three times the sum of the number of inputs and outputs, which in our case is 21. Detailed information was elicited from the respondents involved in water transactions and from the control farmers, using structured and pre-tested questionnaires, covering the following aspects:(i) general information about the farm family, including size of the family, education level of the household head and size of the landholdings (ii) information regarding the sources of irrigation water, details regarding the wells used, the investment in wells, the cropping pattern and the cost 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.

3. Results and discussion

3.1. Comparing the groups in terms of farm characteristics

Size of the landholding is one of the important factors determining the economic status of the farmers. The farmers selling groundwater are generally larger, with an average farm size of 3.2 ha, than those buying groundwater who on average have 1.5 ha. Landholdings of control farmers are in between. Furthermore the irrigated area is also higher for water sellers and the control group of non-traders than for buyers, probably because of the easier access to groundwater. These results confirm the finding by Purushottam and Sharma (2006) that groundwater sale for agriculture is dominated by large farmers, while buyers are mostly poorer farmers, who cannot afford the investment in irrigation infrastructure and who without the markets would not have access to irrigation (Shah et al., 2008). In this sense the informal water markets in India differ from the markets observed in for instance Australia, where water is moving from smaller to larger farmers (Bjornlund, 2006; Brooks and Harris, 2008). Hadjigeorgalis (2008) reports that it is typical for groundwater markets to find that buyers are smaller farmers with limited resources, limited access to technology, and poor access to credit or liquidity.

Tomato, potato, carrot and mulberry (host plant of silk worms) are the major irrigated crops for all categories of farmers in the study area. The share of land cultivated with mulberries is however different among the groups. Among sellers it constitutes 4.1%, for the control group 11.8%, while for buyers this is 17.8%. There are two main reasons for this difference in cropping pattern (i) water sellers have easier access to water and therefore they do not have to opt for mulberries, which require less water than the other crops (ii) the fact that the mulberries, with the stable prices, provide a lower, but more stable income all year round makes it an attractive crop for poorer farmers.

Table 1 gives an overview of the input and output variables used in the DEA model. The average water use of water sellers and control farmers is respectively 64% and 29% higher than the use 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 would be logical 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. To be able to distinguish such relationship, a multidimensional measure such as the DEA sub-vector efficiency is needed. Comparison of the sub-vector efficiency scores for the different groups can reveal if the water use efficiency between the groups really differs.

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

	Farmer category		
Variables: mean (std dev)	Control group[a]	Water sellers	Water buyers
Water (m^3)	8613.8 (4471.4)	11008.8 (4759.2)	6722.5(4862.0)
Irrigated area (ha)	0.81 (0.16)	0.97 (0.24)	0.53 (0.20)
Labour (mandays)	253.4 (133.1)	345.2 (160.1)	193.3 (128.4)
Machine power (hours)	12.3 (7.7)	18.3 (10.2)	9.4 (7.2)
Manure (tonnes)	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[b])	138,602 (80,850)	196,975 (92,748)	100,300 (66,054)

[a] The control group concerns farmers who own a well but who are not engaging in trade.

[b] INR is Indian National Currency (One Euro is equivalent to approximately INR.65).

It can be seen in Table 1 that also 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 the control farmers.

Both the findings related to input use and those regarding landholdings confirm that water buyers are resource poor farmers, who probably lack the financial means to make the large investments necessary to install a well. Consequently they depend on markets for their access to water. Studies by Mukherji and Shah (2005), Polak and Yoder (2006) and Shah et al. (2008) also showed that the existence of groundwater markets offers these resource poor farmers access to increased agricultural productivity through irrigation. In this way the type of groundwater markets, based on private tube well development, which emerged in India has a different effect from the water markets in many other countries. In most cases where water markets were installed to trade existing surface water rights, negative distributional effects were found (Zekri and Easter, 2007). This was for instance reported for Chile, where there was an accumulation of resources by the most powerful social-economic groups (Bauer, 2004; Romano and Leporti, 2002).

3.2. Efficiency of groundwater use

The sub-vector efficiencies for water use (WUE) found in this study indicate that there is considerable scope to reduce water use. On average they are situated around 0.72 using the CRS specification and around 0.77 using the VRS specification of the DEA model. Using a DEA approach, a similar low average WUE was also found by Speelman et al. (2008) among smallholder irrigators in South Africa and by Lilienfeld and Asmild (2007) for irrigated agriculture

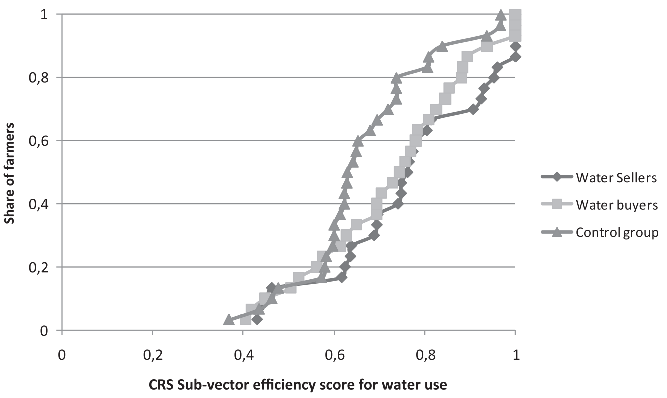

Fig. 2. Cumulative distribution of water sub-vector efficiency scores under CRS specification.

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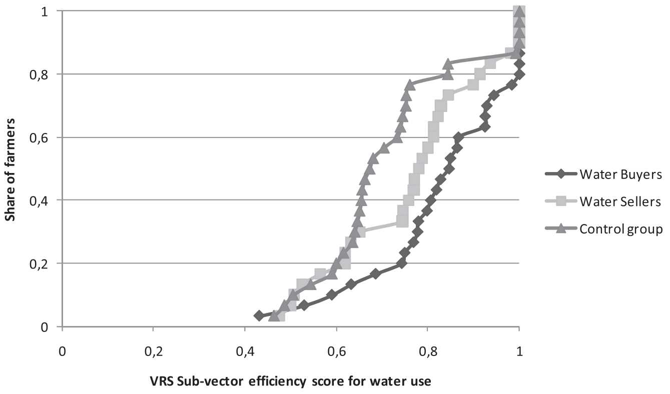

Fig. 3. Cumulative distribution of water sub-vector efficiency scores under VRS specification.

in Western Kansas, USA. The occurrence of low average WUE implies that there is substantial excess water use. Lilienfeld and Asmild (2007) furthermore reported that significant differences in WUE existed among farmers. In order to overcome such differences, less efficient farms have to adjust their farming practises in order to move to the efficiency frontier.

When comparing WUE among the different groups in our study, the average WUE 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 Figs. 2 and 3, which depict the cumulative distribution function of the sub-vector efficiency scores. The small difference between CRS and VRS scores indicates that scale effects are rather limited. Given that even the larger farmers in the sample have landholdings below 5 ha, this is quite logical.

In a second step, Kruskal–Wallis tests are used to see if the observed difference in WUE among the different groups in this study is statistically significant. The test shows that both the CRS sub-vector efficiencies for water use and the VRS sub-vector efficiencies for water use are significantly different respectively at 5% and 1% level. Pairwise comparisons with Mann–Whitney *U*-tests reveal that under both specifications (CRS and VRS) water buyers differ significantly (1% significance level) from the control group in terms of their WUE. Water buyers thus have significantly higher WUE than the control group. It appears that the fact that these farmers are paying more than the extraction cost for water induces them to use it more efficiently. The DEA analysis furthermore also showed that although water sellers use more water than the control group (Table 1), they use it more efficiently. Pairwise comparisons reveal that this difference is significant (10% level) under both specifications (CRS and VRS). The possibility to sell the saved and surplus water is an economic incentive for the water sellers to use water more efficiently. In this way this is a perfect case of how markets promote efficiency in the use of resources, which is consistent with findings of Bjornlund (2007). Finally the results of the Mann–Whitney *U* test for the difference in WUE between water sellers and water buyers are mixed. The VRS sub-vector efficiencies for water use are significantly different at 10% level, while the difference in the CRS scores was not significant.

4. Conclusions

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 (Bjornlund, 2007; Bruns and Meinzen-Dick, 2005; Gillit et al., 2005; Nieuwoudt and Armitage, 2004; Zekri and Easter, 2007). This effect would be apparent in increased water use efficiency. Moreover in the case of groundwater markets in India an additional advantage of water markets is that they offer poor farmers, who do not have the financial means to invest in their own well, the opportunity to achieve higher agricultural productivity by buying irrigation water. In this way water markets could contribute to equity. For our study area this study confirms both benefits of groundwater markets.

First the descriptive analysis showed that the group of water buyers consists of resource poor farmers who without water markets would not be able to practise irrigation. Secondly significant higher water use efficiencies were found among water sellers and water buyers compared to the 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 water more efficiently. The difference between water sellers and the control group originates from the economic incentive, which the water sellers have by being able to sell surplus water. It should be noticed however that because of the lack of quantity restrictions on water extraction, the water markets will probably not decrease the extracted quantity and therefore have no effect on the sustainability of the water extraction pattern. On the other hand, the limitations in power supply will also prevent extractions to be increased.

The findings in our study are important to guide government policy towards groundwater markets. Firstly given the potential of the markets to improve WUE, government should facilitate groundwater markets by developing a legal framework and strengthening the property rights to water. This would increase the efficiency of the market, lowering insecurity among market participants. Secondly by offering resource poor farmers access to irrigation water, groundwater markets have a pro poor effect which should be fostered.

Given the current over-extraction of groundwater incentives should however also be given to increase irrigation efficiency in order to prevent further degradation. Shah et al. (2008) already reported the negative effect on the poor of a decrease in groundwater market activity in the state of Gujarat in India due to excessive water scarcity. Policies encouraging the use of water saving irrigation technologies could avoid this scenario in other areas. Other options to ensure sustainability of the groundwater extraction are to limit extraction by installing a system of volumetric licences or by using economic instruments.

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