Explaining investments in irrigation wells under increasing groundwater scarcity: panel data analysis for 6 Indian villages

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ABSTRACT

While groundwater irrigation in India has made a substantial contribution in terms of raising agricultural productivity and farm incomes for poor and marginal farmers, excessive extraction has led to depletion of scarce groundwater resources in many parts of the country. The basic incentive structures that induce overexploitation of groundwater in this context are related to a lack of clearly defined and secure property rights that encourage cooperation. Lack of assurance about the actions of others, and lack of adequate legal and institutional arrangements to regulate users has lead to an open access solution, characterized by over-pumping and depletion of the resource. In this study we use time series data (2001-2005) collected in the framework of the ICRISAT Village Level Studies to capture farmers' decisions to invest in wells. The dataset, which contains information on 367 rural households of 6 villages in the states Andhra Pradesh and Maharashtra, allowed us to use a double hurdle model to determine not only the factors that affect the decision to make investments in wells but also the intensity of the investment. Results show that factors playing a role in these decisions are the land size, whether the irrigated land is owned by the irrigator, the perception on the existing water access, the households financial asset status (indebtedness, savings) and the past investments in wells. Understanding of these decisions can help policy makers to design the policies which are necessary to ensure the sustainability of the groundwater irrigation sector in India.

KEY WORDS: *Groundwater irrigation; Well investments; Double-Hurdle model; India .*

INTRODUCTION

In India a real groundwater pumping revolution took place in the past 40 years. The land area irrigated by private wells rose from 20% in the 1980s to 60% in 2007 (Kajisa *et al.*, 2007, Kulkarni and Shankar, 2009).This boom can also be observed in the number of wells, which in 2005 was already estimated at 20 million with a yearly increase of about one million during the last years (Mukherji & Shah, 2005 and Scott & Shah, 2004). The rapid expansion in groundwater irrigation has been largely through the individual investment of millions of farmers scattered throughout the countryside (Mukherji, 2007). The success can be explained by the favourable government policies, promoting well development through the facilitation of access to credit and by energy subsidies, even to the extent of free electricity (IWMI, 2007). The rationale for these policies was that the evolution of groundwater development schemes could be an effective poverty eradication tool in situations where other sources of water were inadequate. Irrigation could not only increase the cropping intensity and productivity of crops, by the timely access to water that it provides, it indirectly also increases the demand for agricultural labourers and thus the wage rates. Furthermore the increased affordability of food grains due to the higher wages helps the rural poor to cross the poverty barriers (Narayanamooorthy, 2007). The positive impacts of groundwater use in terms of enhancing productivity and eradicating poverty were analyzed by many authors e.g. Bhattarai & Narayanamoorthy (2003), Saleth *et al.* (2003) and Manjunatha *et al.*, 2011.

Currently however, the agricultural use of groundwater has turned into a matter of concern for policy makers and planners because effects of overdraft like premature failure of wells, decline in groundwater yield and lowering water tables are becoming more and more apparent (Chandrakanth *et al.*, 2004; Diwakara & Chandrakanth, 2007; Nagaraj *et al.*, 2005; Mukherji & Shah, 2005; Shah *et al.*, 2008). These manifestations of the unsustainable character of the groundwater development also raise concern among policy makers and stakeholders regarding the viability of farm incomes. In addition it triggers interest of researchers regarding the decisions of individual farmers to invest in wells.

By drilling a new well, farmers expect to improve their access to groundwater. However, in situations of overdraft, this expectation might not be fulfilled due to cumulative interference of irrigation wells. The question therefore is why farmers often myopically keep on investing in additional or deeper wells, falsely continuing to associate access to groundwater with the depth of a well and why they keep investing (Varghese *et al.*, 2013a; Palanisami *et al.*, 2008.).

According to Maréchal (2009) this might be related to what is called, the escalation of commitment. This is a phenomenon where people justify the decision of increased investment, based on the cumulative prior investment, despite new evidence suggesting that the earlier decision was probably wrong. In economics and business management, this is known as the sunk cost fallacy: increasing the resources available to an unsuccessful venture in the hope of recovering past losses. Such behaviour is also reported by Phillips *et al.* (1991). Vadivelu (2009) on the other hand relates these decisions of farmers to a lack of information. He describes that decisions made by individuals are based on the limited understanding and information that they have and their cognitive ability in rationally processing the available information. In the case of investments in wells decisions seem to be more related to random guesses then that they are based on a scientific assessment of the probability of success to find groundwater with the attempt (Vadivelu, 2009). The invisible nature of the resource and the difficulty faced by farmers to perceive the impact of their own use on the dynamics of groundwater is also mentioned by Moench (2007) to explain why groundwater is in particular prone to this type of over-extraction. This is one of the first studies which tries to capture the well investment behaviour using time series data.

METHODS

Econometric Model

In cases where the dependent variable takes only positive values and a large proportion of zeroes (which is typically the case for investment data), ordinary least squares (OLS) econometric techniques are biased.

In principle, the decisions whether to invest in wells, and how much to invest (intensity of investment), can be made jointly or separately. In the case that the two decisions were made jointly and that they were affected by the same set of factors, then a Tobit model would be appropriate for analyzing the factors affecting the joint decision (Greene, 2000). However, neither straightforward binary nor censored data models may help in a case where factors affecting each decision are different (Moffatt, 2005). So where the decision whether to invest in wells and the decision about how much are not jointly made, it is more suitable to apply a “double-hurdle” model, in which a probit regression on adoption is followed by a truncated regression on the non-zero observations (Cragg, 1971, Worku and Mekonnen 2012).

Actually the double-hurdle model is a parametric generalization of the Tobit model (Martínez-Espiñeira, 2006) that introduces an additional hurdle which must be passed for positive observations to be observed. As the name “double-hurdle” suggests, farm households must scale two hurdles in order to invest in wells. Some farmers do not invest, and hence fall at the first hurdle, and others pass the first hurdle. The first decision or hurdle for farm households in our setting is whether they will make any investment in wells at all, while their second decision is the intensity of investment, conditional on their first decision.

In the double-hurdle model, both hurdles have equations associated with them, incorporating the effects of farmer characteristics and circumstances. Explanatory variables may appear in both equations or in either of them, and a variable appearing in both equations may have opposite effects in each of them. The double-hurdle model contains two equations - the investment equation and the intensity of investment equation:

$$\begin{gathered} d_i^* = z_i^{'}\alpha + \varepsilon_i \\ y_i^{**} = x_i^{'}\beta + \mu_i \\ \begin{pmatrix}\varepsilon_i \\ \mu_i\end{pmatrix} \sim N\left[\begin{pmatrix}0 \\ 0\end{pmatrix}, \begin{pmatrix}1 & 0 \\ 0 & \sigma^2\end{pmatrix}\right] \end{gathered} \tag{1}$$

where d^* is a latent investment variable that takes the value 1 if the household invests in wells, and 0 otherwise; z is a vector of explanatory variables; and α is a vector of parameters. y represents intensity of investment and x is a vector of explanatory variables, and β is a vector of parameters.

The first hurdle is represented by:

$$\begin{gathered} d=1 \text{ if } d^* > 0 \\ d=0 \text{ if } d^* \leq 0 \end{gathered} \tag{2}$$

The second hurdle is given by:

$$y_i^* = max\,(y_i^{**}, 0) \tag{3}$$

Finally the observed variable y_i is given by:

$$y_i = d_i y_i^* \tag{4}$$

A panel data specification of the above described double-hurdle model was estimated using the econometric software Limdep (version 9).

Data Set

The data collection was conducted by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), near Hyderabad. The core data are based on surveys in six villages across India’s semi-arid tropics, more specifically in the states Andhra Pradesh and Maharashtra. A general description of these 6 villages is found in Table 1 (Rao *et al*., 2011).

The entire village level dataset from ICRISAT follows 447 rural households between 2000 and 2005. The selection of the households is considered representative for the 6 villages. A census was taken in these six villages in 2001 and all the households were classified into labor and cultivator groups. Labor households were defined as those that cultivate less than 0.2 ha and receive most of their income from daily labor. Cultivator households were those operating more than 0.2 ha. This group was further classified into small farmers, medium farmers and large farmers on the basis of their operational farm size. In total the dataset contains 112 labourers households (25%), 182 small scale farmers (41%), 105 medium scale farmers (23%) and 49 large scale farmers (11%).

From 2002/2003 onwards the six villages were visited yearly creating a comprehensive panel dataset on a large number of households from different socioeconomic and agro-ecological environments. The information collected include: details of the sample households’ assets and endowments including land, livestock, farm implements, irrigation equipment, farm building, consumer durables, etc; cultivation details covering input and output data for each crop or crop mixtures on a subplot basis; utilization of family labor; details of bullock utilization and its economics; and wage employment. Data on investments in soil conservation practices and digging wells and bore wells, etc..

The module on well investments recorded information about the number of attempts made by households to bore a new well or deepen an existing well, the depth (in feet) of each such attempt, the number of successful attempts, the number of wells presently in use and the total amount spent on each attempt.

In our model we study investments in irrigation wells (either deepening of existing wells or construction of new wells). Because we assume that such investments are conditional on involvement in agricultural production we have excluded those households from our sample which in the period considered did not report any landownership, nor leased-in land. We retain a sample of 367 households.

Table 1. Characteristics of the sample sites

Districts	**Mahbubnagar**	**Sholapur**	**Akola**
Villages	Aurepalle, Dokur	Shirapur, Kalman	Kanzara, Kinkheda
Mean rainfall	630mm	630mm	890mm
Soil type	Alfisols (low water retention capacity)	Vertisols (high water retention capacity)	Inceptisols (medium water retention capacity)
Major crops	Cotton, sorghum, paddy, pigeonpea, groundnut	Sorghum, pigeonpea, pulses, sunflower, vegetables	Cotton, soybean, sorghum, pigenonpea, wheat
Number of households (2001)	Aurepalle: 649 Dokur: 515	Shirapur: 580 Kalman: 624	Kanzara: 338 Kinkheda: 170
Sample size	Aurepalle: 100 Dokur: 80	Shirapur: 88 Kalman: 94	Kanzara: 52 Kinkheda: 32

RESULTS

First some farm characteristics of the respondents will be described. Over the years the respondents cultivate about 5.5 acres on average of which about 2.5 acres is irrigated. There is a slight decreasing trend in the irrigated area. Irrigation is primarily used for paddy rice, cotton, sugar cane and vegetable crops. When considering the financial liabilities and assets of the households there is a large variation. About 70% of the households have an outstanding loan. Purpose of these loans is diverse: farm inputs, marriage, education or investments. On average the households are indebted for around 26000 Rs (36000 Rs if zeros are excluded). In the study period the indebtedness grew considerably. On the other hand the share of households having savings increased from 30% to 56%. Mainly initiatives of self-help groups and chit funds are responsible for this increase. For many households the amount saved therefore is rather modest. On average the amount saved was around 9000 Rs. In a similar study by Hadrich *et al.* (2012) on machine investments in the US it was found that financial characteristics played an important role in the investment decision.

In Table 2 the characteristics of the investments in wells are presented. First it can be observed that over time the number of farmers using irrigation has decreased, from 227 in 2001 to 200 in 2004. For the first year in the dataset information was collected on the investments in wells between 1985 and 2001. From 2002 onwards data are annual. Between 1985 and 2001, 180 farmers made some investments in wells (either drilling one or more new wells or deepening existing wells). On average these investments summed up to 28605 Rs per farmer. When looking at the annual investments between 2002 and 2004 one can see that these clearly have increased. Also for the average depth of wells a trend is found. While wells in the period 1985-2001 were one average 189 ft, average depth after 2002 was more than 250 ft. Finally it is interesting to consider the number of attempts to drill or deepen a well and the rate of success of these attempts. Aggregating attempts between 1985 and 2001 irrigators investing in wells on average did 2,34 attempts to improve their water access and they were successful in 64% of these. In the period between 2002 and 2004 it seems that farmers have increased their efforts , but are less successful.

Overall the above description confirms the picture of a growing water scarcity: farmers are forced to drill deeper wells, increasing the investment costs. Moreover the effect of the investments in terms of increased water availability seems to be less and less certain, resulting in a higher share infructuous attempts (Varghese *et al.*, 2013).

A factor which might influence the investments in wells is the farmers perception on the rainfall and on water availability in wells. For the years 2001, 2003 and 2004 there is not much variation in these perceptions. A tremendous majority of the farmers (more than 90%) indicates that rainfall quantity was below what could be expected in a normal year. An even higher percentage of farmers (more then 95%) states that water availability in wells was lower than normal in the particular year. In 2002 there was more variation. With about 20 % of the respondents indicating that it was a good year in terms of rainfall and water availability in wells.

The results of the Double-Hurdle model are presented in Table 3. The results demonstrate that the decision to invest in wells and the decision about how much to invest appear to be explained by different processes. Past investments have a positive and significant impact on the decision whether to invest or not. This is in line with Maréchal (2009) or Varghese *et al.* (2013) who attributed the well investment behaviour to a sunk cost fallacy. Perception about the rainfall quantity also significantly influenced the choice to invest. The probability to invest appears to be lower after a

Table 2. Description of the well investments

	2001	**2002**	**2003**	**2004**
Farmers operating irrigated land	227	221	199	200
Farmers investing in Wells	180[a]	24	34	13
Invested amount in Rs (*st. dev.*)	28605 (*29937*) [b]	20458 (*14747*)	26230 (*22334*)	28115 (*23503*)
Average depth of wells in ft (*st. dev.*)*	189 (*77*)[c]	203 (*79*)	275 (*180*)	260 (*159*)
Average number of attempts (*st. dev.*)*	2.34 (*1.99*)[d]	1.39 (*0.72*)	1.66 (*1.15*)	1.46 (*0.88*)
% succesfull attempts*	64 [e]	62	49	57

[a] Have invested in the period 1985-2001; [b] Average sum of investments over period 1985-2001; [c] Average depth of wells constructed between 1985-2001; [d] Average number of attempts over period 1985-2001; [e] Success rate over period 1985-2001.

year in which rainfall quantity is perceived as below average. Finally the decision to invest is dependent on the district. In Sholapur farmers are less likely to invest in wells. The other explanatory variables included in the first hurdle part of Table 3 are not significant.

The second hurdle considers the intensity of investment. If farmers do not own the land they are irrigating they tend to spend less on wells. In contrast to the first hurdle the quantity of past investments does not significantly influence the amount currently invested. It is furthermore found that if water availability in the wells was good in the past year that this lowers the spending. The effect of the district again shows that both decisions are different. In the second hurdle model it is observed that farmers in Sholapur invest higher amounts. Probably aquifer conditions in this district force farmers to drill deeper (more costly) wells while this knowledge might make them more hesitating to make this decision in the first place. Against expectations and in contrast with the results of Hadrich et al (2012) we did not observe a significant effect of the households financial status. Possibly other financial characteristics like cash flow might have an effect.

Table 3. Results of the double hurdle model

First Hurdle	Probit model	
	Coefficients	**St errors**
Ownership-dummy	0.142	0.250
Past investments	0.576×10^{-5} **	0.294×10^{-5}
Change in irrigated area	-0.011	0.029
Irrigated area	0.017	0.029
Total farm size	-0.019	0.016
Indebtedness	0.189×10^{-5}	0.147×10^{-5}
Savings	-0.614×10^{-6}	0.291×10^{-5}
Rainfall trend dummy	-1.503 **	0.608
Water availability dummy	0.046	0.648
District Mahabubnagar	-0.567	0.389
District Sholapur	-0.630*	0.362
Rho	0.35***	
Pseudo R square	0.6	
Second Hurdle	**Truncated Model**	
	Coefficients	**St-errors**
Ownership-dummy	42664.6*	22932.5
Past investments	-0.0	0.4
Change in irrigated area	26.7	21.1
Irrigated area	492.7	2198.9
Total farm size	95.9	1329.2
Indebtedness	-0.2	0.2
Savings	0.0	0.3
Rainfall trend dummy	31.5	60.3
Water availability dummy	-59.8*	35.8
District Mahabubnagar	519.3	1102.9
District Sholapur	36801.1**	15322.4
Sigma	50930.5297***	

* significant at 10%; ** significant at 5 %.

CONCLUSION

While groundwater irrigation in India has made a substantial contribution in terms of raising agricultural productivity and farm incomes for poor and marginal farmers, excessive extraction has led to depletion of scarce groundwater resources in many parts of the country.

In this study we use time series data (2001-2005) collected in the framework of the ICRISAT Village Level Studies to understand farmers' decisions to invest in wells. The dataset contains information on 367 rural households of 6 villages in the states Andhra Pradesh and Maharashtra. Using a double-hurdle model we showed that the factors affecting the decision to invest in wells and those affecting the intensity of investment are different. We evaluated the effects of the land size, the ownership status of the irrigated land, the perception on the existing water access, the households financial asset status (indebtedness, savings) and the past investments in wells. We found that past investments have a positive effect on the decision to invest. This confirms the decision as an "escalation of commitment", as was suggested by Maréchal (2009) or Varghese *et al.* (2013a). Further it was observed that the intensity of investment increases under scarcity conditions. This is in line with the findings of Varghese *et al.* (2013b) who observe appropriative competition for groundwater in Karnataka, India. They link this behaviour to the uncertainty created at one hand by the nature of the groundwater resource, but also by the lack of clearly defined and secure property rights over groundwater. Our study makes clear that adequate legal and institutional arrangements are necessary to regulate users. Licensing of wells, a reform of the property rights and making people aware of the non-viability of their investments seem indispensable measures to ensure sustainability.

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