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Arif Watto

Amin Mugera

DOES THE RISK OF GROUNDWATER DEPLETION DRIVE TUBE-WELL TECHNOLOGY ADOPTION: A CASE OF PAKISTAN

MUHAMMAD ARIF WATTO (1), AMIN W. MUGERA
(1): School of Agricultural and Resource Economics, the University of Western Australia M089, 35 Stirling Highway, Crawley WA 6009 Australia
(2): The UWA Institute of Agriculture and School of Agricultural and Resource Economics, the University of Western Australia M089, 35 Stirling Highway, Crawley WA 6009 Australia.
(3): The University of Agriculture, Faisalabad 38400, Pakistan.

We employ a moment-based approach to empirically analyze farmer's decisions to adopt tube-well technology under the risk of groundwater depletion and associated production uncertainties from the Indus Basin of Pakistan. We use a cross-sectional farm level data from 200 farming households comprising of 100 adopters and 100 non-adopters. The results indicate that risk plays an important role in the farmer's adoption decisions. We find that the higher the expected profit the greater the probability of adoption. Similarly, with increasing variance of profit the probability of adopting a tube-well increases significantly. We further find that farmers generally do not consider downside profit risk when making adoption decisions and that the extreme events could decreases adoption significantly.

INTRODUCTION

Pakistan is the 3rd largest groundwater consumer accounting for approximately 9% of the global groundwater withdrawals Giordano [1]. With 5.2 million hectares area equipped for groundwater irrigation, Pakistan irrigates 4.6% of the global groundwater-fed cropland Siebert et al. [2]. A sharp increase in groundwater use in Pakistan has manifested as a kind of "silent revolution" after the 1960s' Green Revolution. The continued expansion of irrigated area and the introduction of high yielding crop varieties during the Green Revolution increased irrigation water demands by about three times Ahmad et al. [3]; Rodel et al. [4]. With the continued increasing demands, irrigation water supplies were being rendered through groundwater abstractions. In 1960 groundwater contribution was 8% to the total irrigation water supplies at the farm gate, but 25 years later in 1985 this share had gone up to 40% Byrelle and Siddiq [5]. In subsequent years, the diminishing supplies of surface water further increased reliance on groundwater even by more than 50% for irrigation purposes. In recent years, groundwater dependence has increased up to 70% in many canal water deficient areas Qureshi et al. [6]; Strosser and Rieu [7]. Nevertheless, renewable groundwater resources are not sufficient enough to meet the unimpededly outpacing irrigation water demands. As a result, groundwater resources are depleting in large areas in Pakistan Kijne [8]; Khan et al. [9]; Qureshi et al. [10].

Presently, Pakistan is amongst those countries where groundwater withdrawals are far higher than the replenishments Wada et al. [11]; Khan et al. [12].

In Pakistan, groundwater abstractions were started to control waterlogging through large scale tube-well development in high water table areas and to encourage agricultural production in areas with limited canal water supplies. Later, higher yields and greater economic returns Meinzen-Dick [13] encouraged farmers to adopt tube-well technology and transition to water intensive crops Muhammad [14, [15]; Falcon and Gotsch [16]; Nulty [17].

The objective of this paper is to analyze farmer's decisions to adopt tube-well technology under depleting groundwater resources and associated production uncertainties. We use a flexible representation of uncertainty by using moments of the profit distribution as determinants of farmer's decision regarding the adoption of tube-well technology Antle [18]; Antle and Goodger [19]; Koundouri et al. [20]; Antle [21].

THEORETICAL FRAMEWORK

We employ an expected utility maximization framework following Koundouri et al. [20] to represent adoption decisions under depleting groundwater resources. We conjecture that farm household j is risk averse and uses a vector of conventional inputs $\mathbf{x}_j$ together with applied irrigation water x_{jw} to produce a single output q and profit π_j through a technology described by a well-behaved (i.e., continuous and twice differentiable) production function $f(\cdot)$. Let p_j denote output price and $\mathbf{r}_j$ the corresponding vector of input prices for the household j. This risk is represented by a random variable ε_j, whose distribution $G(\cdot)$ is exogenous to the farmer's decisions. This is the only source of risk we consider as p_j and $\mathbf{r}_j$ are assumed to be non-random (i.e., farmers are assumed to be price takers in both output and input markets).

In contrary to Koundouri et al. [20], in this study we deal with the adoption of tube-well technology which does not necessarily increase efficiency of irrigation water as sprinkler and drip irrigation do but tube-well ownership ensures more promising irrigation water supplies and hence overcoming production uncertainties . Allowing for risk- aversion, the farmer's problem is to maximize the expected utility of profit such as:

$$\max_{\mathbf{x}_j, x_{jw}} E[U(\pi)] = \max_{\mathbf{x}_j, x_{jw}} \int \{U[p_j f(\varepsilon_j, \mathbf{x}_j, x_{jw}) - r_{jw} x_{jw} - \mathbf{r}_j \mathbf{x}_j]\} dG(\varepsilon) \tag{1}$$

where $U(\cdot)$ is the *von Neumann-Morgenstern* utility function. Assuming that p_j and r_{jw} are non-random, the first order condition for groundwater irrigation water input can be rewritten as follows:

$$E[r_{jw} U'] = E\left\{p_j \frac{\partial f(\varepsilon_j, x_{jw}, \mathbf{x}_j)}{\partial x_{jw}} U'\right\} \Leftrightarrow \tag{2a}$$

$$\frac{r_{jw}}{p_j} = E\left\{p_j \frac{\partial f(\varepsilon_j, x_{jw}, \mathbf{x}_j)}{\partial x_{jw}} U'\right\} + \left\{\frac{\text{cov}[U'; \partial f(\varepsilon_j, x_{jw}, \mathbf{x}_j) / \partial x_{jw}}{E[U']}\right\} \tag{2b}$$

where $U' = \partial U(\pi) / \partial \pi$. In the case of a risk-neutral farmer, the first term in the right hand side of the relation (2b), i.e., the ratio of input price to output price (r_{jw} / p_j) is equal to the expected marginal product of irrigation water. However, for a risk-averse farmer the second term in the right hand side of the relation (2b) is different from zero and measures deviations from risk-neutrality case. More precisely, this term is proportional and opposite in sign to the marginal risk premium with respect to the irrigation water input Koundouri et al. [20].

Let us now incorporate into the above general model, the farmer's decision whether or not to adopt tube-well technology. This decision can be modelled using a binary choice model, where farmers can choose to adopt (A=1) or not (A=0) to adopt. Suppose the farmer is fully aware of the use and future costs and benefits of tube-well technology at the time of adoption, adopting the new technology implies a fixed cost $(I^1 > 0 \text{ and } I^0 = 0)$ and might change the marginal cost of water $\left(r_{jw}^1 \neq r_{jw}^0\right)$. Denote $\mathbf{x}_j^1\left(\mathbf{x}_j^0\right)$ as the optimal input use by adopters and non-adopters. A farmer will decide to install a tube-well if the expected utility with adoption $E\left[U\left(\pi^1\right)\right]$ is greater than the expected utility without adoption $E\left[U\left(\pi^0\right)\right]$

$$E\left[U\left(\pi^1\right)\right]-E\left[U\left(\pi^0\right)\right]>0 \quad (3)$$

Empirical Estimation Procedure

In order to avoid specifying a functional form for the probability function of profit $\pi(\cdot)$, the distribution of risk $G(\cdot)$, and farmer's risk preferences i.e., utility function $U(\cdot)$, we use a moment based approach which allows a flexible representation of risk Antle [18]; Koundouri et al. [20]; Antle [21]. In the first step, profit is regressed on the farm level input variables to have an estimate of the "*mean*" effect. The model takes the following general form:

$$\pi_j = f\left(x_{jw}, \mathbf{x}_j, \mathbf{z}_j; \boldsymbol{\beta}\right)+u_j \quad (4)$$

where π_j is the value of crop production i.e. profit of a household (*j*) with $j=1,....,N$ denoting individual farms in the sample, $\mathbf{x}_j$ is the vector of inputs, $\mathbf{z}_j$ is the vector of extra shifters including farmer's characteristics, u_j is the usual identically independently distributed error term which captures unobserved variations in crop production and production shocks while $\boldsymbol{\beta}$ is the vector of parameters to be estimated. The Ordinary Least Squares (OLS) estimation of equation (4) gives consistent estimates of the parameter vector $\boldsymbol{\beta}$. Then the j^{th} central moment of profit ($j=2,...,m$) is defined as:

$$\mu_j(\cdot)=E\left\{[\pi(\cdot)-\mu_1]^j\right\} \quad (5)$$

where μ_1 represents the mean or first moment of profit. The estimated errors from the mean effect regression, $\hat{u}_j = \pi_j - f\left(x_{jw}, \mathbf{x}_j, \mathbf{z}_j; \hat{\boldsymbol{\beta}}\right)$, are estimates of the first moment of the profit distribution. The estimated errors $\hat{u}_j$ are then squared and regressed on the same set of explanatory variables:

$$\hat{u}_j^2 = g(x_{jw}, \mathbf{x}_j, \mathbf{z}_j; \boldsymbol{\delta})+\tilde{u}_j \quad (6)$$

The Ordinary Least Square estimates (OLS) of equation (6) provides consistent estimates of the parameter $\boldsymbol{\delta}$. The predicted values $\hat{\hat{u}}_j^2$ from equation (6) are consistent estimates of the second central moment i.e., variance of the profit distribution Antle [21]. We estimate the third and fourth moment of profit distribution by raising estimated errors from the mean regression model to the power of three and four. The four estimated moments are then incorporated into a

discrete model of technology adoption along with farmer's structural demographic characteristics.
Farmers will only choose to adopt tube-well technology if:

$$Y_j^* \equiv E\left[U\left(\pi^1\right)\right] - E\left[U\left(\pi^0\right)\right] - VI > 0 \quad (7)$$

where Y_j^* is an unobservable random index for each farmer that defines their propensity to adopt a tube-well technology. For purpose of estimation, we denote the indirect utility (per year) of farmer j if he is a non-adopter as:

$$Y_{0j} = \mathbf{z}'_{0j}\boldsymbol{\alpha}_0 + \mathbf{m}'_{0j}\boldsymbol{\alpha}_0^m + v_{0j}, \quad (8)$$

and that of an adopter as:

$$Y_{1j} = \mathbf{z}'_{1j}\boldsymbol{\alpha}_1 + \mathbf{m}'_{1j}\boldsymbol{\alpha}_1^m + v_{1j}, \quad (9)$$

where $\mathbf{z}'_j$ is a vector of regressors including all structural and demographic characteristics, $\mathbf{m}'_j$ is the vector of four profit moments that introduce uncertainty into the model, $\boldsymbol{\alpha}$ is a vector of parameters to be estimated and v_j is the error term. From (8) and (9), the probability of farmer i adopting tube-well technology can be given by the following model:

$$\Pr[Y_j = 1] = \Pr[Y_{0j} < Y_{1j}], = \Pr[v_j < \mathbf{z}'_j\boldsymbol{\alpha} + \mathbf{m}'_j\boldsymbol{\alpha}^\mathbf{m}], = \Phi\,[\mathbf{z}'_j\boldsymbol{\alpha} + \mathbf{m}'_j\boldsymbol{\alpha}^\mathbf{m}] \quad (10)$$

where $v_j = v_{0j} - v_{1j}, z_j = z_{0j} - z_{1j}, m_j = m_{0j} - m_{1j}, \alpha = \alpha_1 - \alpha_0$ and $\alpha^m = \alpha_1^m - \alpha_0^m$

The binary choice model in (10) is estimated using a probit model, assuming that v_j is $N(0,\sigma^2)$ and that $\Phi(\cdot)$ is the cumulative of the normal distribution.

Study Districts Data Descriptions

The data used in this study was collected using a detailed survey from the two districts, *Lodhran* from cotton-wheat region and *Jhang* from the mixed-cropping region of the Punjab province, Pakistan. Both cropping regions have arid to semi-arid continental subtropical climate with long hot summers and cool winters.

Table 1: Summary Statistics of the Variables

	Adopters		**Non-adopters**	
Variable	Mean	Std. Dev.	Mean	Std. Dev.
Economic Data				
Farm production (in Kgs)	8473	6199	4598	3811
Farm size (in Acres)	10.05	6.78	5.47	4.33
Seed quantity (in Kgs)	88.75	65.94	48.56	42.27
Labour (in Hours)	3396.75	2522.904	1814.45	1549.29
Fertilizer (in Kgs)	2300.88	1866.25	1231.02	1226.89
Chemical input (in Rs.)	48233.71	38549.41	26005.80	24357.05
Machinery cost (in Rs.)	39027.802	25896.19	22303.19	18785.18
Irrigation water (in m^3)	24074.09	17842.71	12143.78	10084.01
Total cost (in Rs.)	354028.27	255971.51	210269.63	178565.02
Total revenue (in Rs.)	750789.72	556826.59	395989.01	333305.16
Profit (in Rs.)	396761.46	324392.72	185719.38	175871.68

Mean annual rainfall is also very low with 360mm in the mixed-cropping zone and 120mm in the cotton wheat-zone. Both the districts are characterized by deep water tables which require high tube-well installation costs. At the time of the survey, variation in the bore depth was observed to be between 60meters and 99meters in Lodhran while between 33meters and 57meters in Jhang district. The survey provides detailed farm level information about production patterns, input use, and output produced, gross revenues, structural characteristics and the number of farms that adopted tube-well technology and that did not. Table 1 compares the selected economic variables used in estimation while Table 2 presents information on the socio-economic characteristics of the farms surveyed.

Table 2: Summary Statistics of the Variables used in Probability Model

	Adopters		Non-adopters	
Variable	Mean	Std. Dev.	Mean	Std. Dev.
Farm Characteristics				
Farmers Age (years)	43.32	9.31	44.73	8.66
Land Tenureship (1=*owners,* 0=*tenants*)	0.99	0.10	0.65	0.48
Off-farm income in *Rs*.	91,220	2,20,090	50,236	84,489
Farm's debts in *Rs*.	32,000	68,854	41,333	60,207
% of farm income spent on irrigation water in *Rs*.	23.33	16.47797	26.6802	13.67277
Farmers Education (years of schooling)	5.87	4.47	3.67	3.62
Extension Services (1=*yes,* 0=*no*)	0.51	0.50	0.09	0.29
Access to information sources (*0=No, 1=Yes*)	0.52	0.502	0.131	0.339

RESULTS AND DISCUSSION

Estimation results of the two-stage instrumental bootstrapped probit model are presented in Table 3. The statistical significance of the mean, variance and kurtosis suggest that decision makers are not risk-neutral. The moments of profit distribution are assumed to be exogenous to farmer's adoption decisions, their signs in the probit model indicate that farmers who are more risk averse are more likely to install a tube-well. Statistical estimates of the proportion of farm income spent on irrigation indicate that farmers who spent a lower proportion of farm income on irrigation are more likely to adopt tube-well. Since the proportion of farm income spent on irrigation is derived from total farm income and total irrigation costs, different farms may differ in their productivity even at the same irrigation costs. In case of fixed irrigation cost, the farm with higher profitability could be spending less proportion of its income on irrigation and *vice versa*. Off-farm income is often considered exogenous as it creates opportunities for additional financial incentives which help to overcome shocks as a result of an outlier activity. Similar to this common hypothesis, we conjecture that farmers who have more off-farm business generating activities are more likely to bear unexpected farming outcomes and ensure a consistent income and hence are better-off in adopting a tube-well.

Majority of the farmer's own characteristics are highly significant in the choice of adopting tube-well technology. Statistically significant association between tube-well adoption and land tenureship suggest that land owners are more likely to adopt a tube-well than tenants or non-land holders. Because tube-well installation requires heavy investment and is not a portable type of technology, tenants put lower value on adopting a tube-well. Moreover, the presence of water markets where tenants have the option to buy water does not make it necessary to have their own tube-well. As far as extension services and access to different sources of information is concerned, positive statistical significant impact of extension services to tube-well adoption may have two different interpretations. First, it indicates that there exists a positive value on waiting for better information before deciding to adopt. Second, it may be because adopters (as we see in the case of adoption of tube-well technology) are one step ahead in seeking contact with extension staff and different other sources of information e.g., radio, television and newspaper in comparison to non-adopters.

Table 3: Estimation of the Results for the Probability of Adopting a Tube-well

Household and farm characteristics	Estimate	Bootstrapped Std. Error	t-Ratio
Age	0.008	0.011	(0.73)
Land tenure status (*0=Tenants, 1=Owners*)	2.298***	0.395	(5.83)
% of farm income spent on irrigation	-0.681***	0.213	(-3.20)
Off-farm income Rs.	0.904***	0.190	(4.76)
Farm debts in *Rs*.	-0.015	0.061	(-0.24)
Education (years of schooling)	0.007	0.028	(0.23)
Extension services (*0=No, 1=Yes*)	1.253***	0.246	(5.10)
Access to diff. sources of information (*0=No, 1=Yes*)	1.015***	0.213	(4.76)
Profit moments			
First moment	0.485*	0.278	(1.74)
Second moment	7.858***	1.746	(4.50)
Third moment	0.634	1.017	(0.62)
Fourth moment	-2.683***	0.846	(-3.17)
Constant	-3.617***	0.676	(-5.35)
Valid chi^2	97.79		
McFadden's R^2	0.518		

Note: *, **, *** indicate significant at 10%, 5% and 1% respectively. Number of bootstraps=2000

The role of risk in farmer's decision is highlighted through the significance of the sample moments of profit distribution. The first and the second moment, which approximate mean profit and profit variance, are highly significant while fourth moment (kurtosis) is marginally significant. The third moment, i.e. skewness is not statistically significant. The results indicate that the higher the expected profit the greater the probability that a farmer decides to adopt a tube-well technology. Similarly, in case of variance, we see that with increasing variance the probability of adopting tube-well increases significantly. More generally, the higher is the variance of profit (and greater the probability of facing extreme profit values), the greater is the probability to adopt tube-well. Based on these results we can infer that: 1) since tube-well installation requires heavy investment, farmers need to reduce production risks in order to get consistent profits; 2) under uncertain water supplies for irrigation, farmers generally tend to install tube-well as a source of reliable irrigation supplies in order to hedge against crop failures. Finally, statistical non-significance of the third moment indicates that farmers are not taking downside yield risk into account when they decide to adopt a technology whereas highly significant fourth moment may possibly be interpreted that as a result of extreme events, farmer's adoption decreases significantly.

CONCLUSIONS

We conclude that the sample moments of the profit distribution are exogenous to farmer's adoption decisions. Estimates show that the higher the expected profit the greater the probability that a farmer decides to adopt a tube-well technology. We also find that with increasing variance of profit the probability of adopting tube-well increases significantly. These results imply that the farmers adopt tube-well technology in pursuit of reliable irrigation supplies and to hedge against production risks associated with uncertain irrigation supplies in the form of crop failures. Conversely, as a result of production risks due to crop failures farmers may face profit uncertainties. Hence, due to low or inconsistent profits farmers may not have sufficient means to invest in tub-well technology. Farmers can only adopt tube-well technology as mean to risk management when their expected profit is not affected by the risk. Second, under risk-averse scenarios incremental values generated by the use of variable inputs remain lower than the incremental costs which may lead to an inefficient resource allocation inference. Since tube-wells serve only to increase access to irrigation water but do not improve irrigation efficiency as sprinkler or drip irrigation technologies do, multi-dimensional policies are required under technology adoption and resource conservation objectives. Besides taking risk into consideration while contemplating economic instruments (e.g., subsidies, long-term loans or provision of adoption related information) in order to give incentives for tube-well adoption (as it has been a major policy theme in Pakistan), there should be a relevant cost-benefit analysis of groundwater resource management both in terms of short-term gains (i.e. farm profits) and long-term future benefits i.e. sustainable groundwater management.

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