Performance of Groundwater Markets in Pakistan

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Irrigation provides crucial water for agricultural production on over 80 percent of the gross cropped area in Pakistan. Most of this irrigation comes through public canal systems, but groundwater has become a crucial input, both as a sole source of irrigation and as a supplement to surface irrigation in canal irrigation commands. However, ownership of private tubewells is concentrated among large farmers: 70 percent of all tubewells are owned by farmers with over 12.5 acres and half are owned by farmers with over 25 acres, which seems "to point toward an adverse effect of private tubewells on income distribution within agriculture" [World Bank (1984), p. 35]. Institutional arrangements are needed to spread access to groundwater to other farmers, to increase agricultural productivity and improve equity in the use of irrigation water resources without overcapitalisation of agriculture.

Water markets provide one of the most promising institutional mechanisms for increasing access to irrigation from private groundwater, for providing vertical drainage, and for increasing the efficiency of water use in irrigation systems see Rosegrant and Binswanger (1992). While such markets are not formalised or officially recognised, the sale of water from private tubewells is a growing form of private irrigation development.[1] This paper examines the nature and operation of markets for groundwater in Pakistan. It deals with the extent of water market development, who participates, and the effect of purchased irrigation on the productivity of irrigated agriculture. It concludes with policy issues for improving the performance of water markets.

[1]Sale and purchase of public canal water supplies, though legally prohibited under the Canal and Drainage Act, is another type of private water market transaction which takes place. These are, however, much less common than sales of tubewell water.

BACKGROUND

Public tubewells provided the predominant source of groundwater from the mid-1950s to 1980 in Pakistan. Rising operation and maintenance expenses for public tubewells, in conjunction with the poor performance of public tubewells in terms of timeliness and reliability of irrigation supplies, led the government to devolve responsibility for groundwater irrigation development from the public to the private sector during the 1980s [WAPDA (1982)]. As the public tubewells are closed, expansion of groundwater use in the private sector becomes critical, both to increase agricultural productivity and to provide vertical drainage to control waterlogging.

There is increasing interest throughout much of South Asia in water markets as a means of expanding access to and use of groundwater for irrigation. The potential advantages to be derived from development of groundwater markets lie in improving utilisation of tubewell capacity, increasing access to irrigation water supplies (especially among farmers with small or fragmented holdings), and lowering water tables in areas of waterlogging. By providing water to other farmers, tubewell owners generally use a higher proportion of their well capacity than would otherwise be used on their own holdings. The availability of hired tubewell services reduces the need for other farmers to install their own wells [Chambers, Saxena and Shah (1989)]. Since water markets limit overinvestment in tubewells and increase the use of installed pumping capacity, they can improve the economic efficiency of private tubewell irrigation. Water markets can improve equity of access to water by making it possible for those without wells to use groundwater for irrigation. The opportunity to sell groundwater can make it profitable for farmers to invest in wells even if their own holdings are too small to use the full pumping capacity see Shankar (1992).

The following sections of this paper use empirical data to examine the performance of water markets in rural Pakistan, with particular emphasis on equity of access to irrigation and impact on production. Data for the analysis are drawn from household surveys on various aspects of rural poverty conducted by IFPRI in Faisalabad, Attock, Dir, and Badin Districts during 1991-1992. While the latter three districts were selected to represent the poorest infrastructure development in Punjab, NWFP and Sindh provinces, Faisalabad was included to represent a leading agricultural district for details, see Alderman and Garcia (1991).

WHO PARTICIPATES IN WATER MARKETS?

Water markets are reported in all provinces in Pakistan, but are most active in Punjab, where the greatest groundwater development has taken place. A relatively high proportion of well-owners in NWFP are also involved in water markets: according to NESPAK (1991) data, 25 percent of sample well-owners

reported selling water in NWFP, compared to 22 percent in Punjab, 3.5 percent in Sindh, and 2.5 percent in Balochistan.[1]

In the IFPRI study, groundwater markets were found only in Faisalabad District of Punjab and Dir District of NWFP. Attock District of Punjab is a *barani* (rainfed) area, and no Attock farmers in our sample owned or used tubewells. The study villages in Badin District of Sindh are largely underlain by saline groundwater aquifers, which pose a serious constraint to groundwater irrigation and water markets. Only one sample farmer from Badin in Sindh owns a tubewell, but does not sell water from it; none reported buying groundwater.

Half of the sample farmers in Faisalabad District purchase tubewell water, which is twice the number that own tubewells. Although all the sample villages in Faisalabad District fall within the command area of public canal irrigation systems, the watercourses in Jaranwala village receive almost no surface water. Thus many of the farmers in Jaranwala have invested in wells, often jointly with other farmers, giving it a significantly higher proportion of well owners (75 percent) than other villages. In Dir District, where groundwater irrigation is less prevalent, 9 percent of all sample farmers purchase water, approximately the same number that own tubewells. Only five of eleven study villages in Dir had any groundwater use among sample farmers, and water markets were reported in four of these villages.

What are the characteristics of tubewell owners and water purchasers? Table 1 presents a logistic regression (logit) model to examine tubewell ownership among sample farmers in Faisalabad and Dir Districts. The logit technique allows us to examine the effect of a number of variables on the underlying probability of a dichotomous dependent variable, such as the probability of owning a tubewell. In this model, land ownership, age of head of household, whether a household has a member who has worked or is working abroad, and dummy variables for Jaranwala village and Dir District (areas with less access to canal irrigation) are hypothesised to influence the probability of owning a tubewell. Other indicators of wealth or household income are not included because it is likely that tubewell ownership has contributed to wealth or income, rather than the reverse. Similarly, factors such as cropping pattern, which influence demand for tubewell water, are not included because no indicator is available for farmers' desired cropping pattern, and availability of tubewell water has a stronger influence on cropping pattern than actual cropping pattern has on availability of tubewell water.

Results of this model indicate that land ownership has a strong positive effect on well ownership, indicating that households owning more land are more likely to own wells . The age of head of household has a significant positive effect on well ownership, perhaps because farmers invest in tubewells as the household becomes established. Households with a member currently working abroad or returned from abroad are also significantly more likely to own wells. This seems to indicate that

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[1]Provincial figures reported in the NESPAK (1991) final report are a simple average of percentage selling across all districts. The percentages reported here are a weighted average of percentage selling, with the number of tubewells in each district as the weights.

remittances are a source of financing for tubewell investment. The dummy variable for Jaranwala village has a large and significant coefficient. As noted above, the lack of alternative canal irrigation supplies has pushed these farmers to purchase tubewells, and joint investment has enabled even small farmers in this village to own at least a partial share of a well. The pattern of well ownership in Dir District, however, is not significantly different from that of Faisalabad District. This model correctly predicts the well ownership status of 90 percent of all cases.

Table 1

Results of Logistic Regression Model for Tubewell Ownership

Independent Variables	Units	Coefficient	T Ratio	Wald Statistic
Size of Land Ownership	Acres	.122**	4.03	16.24
Age of Head of Household	Years	.051**	2.34	5.48
Relative Abroad	Dummy	1.668**	2.15	4.63
Jaranwala Village	Dummy	4.458**	5.41	29.32
Dir District	Dummy	.036	.05	.00
Constant		−6.829**	−4.35	18.90

Model Chi-Square   =   66.9** with 5 Degrees of Freedom
Number of Observations   = 182.
Tubewell Ownership Correctly Predicted = 89.6 percent of Cases.

Source: IFPRI survey data, 1991-92.
        *Significant at 10 percent probability level.
        **Significant at 5 percent probability level.

Although small holding size is not an insurmountable obstacle to well ownership (as demonstrated by a high proportion of joint well owners with small holdings in Jaranwala village), it is a constraint to widespread tubewell ownership. In the survey on water markets, over 60 percent of groundwater purchasers cited the expense of purchasing a tubewell as the reason why they did not have their own wells, but 25 percent cited a lack of land ownership or too small a holding size as the reason for not investing in a well. Groundwater quality problems also prevent farmers from installing their own wells. Water markets meet a need for water among those who have too little land, cannot afford tubewells, or find the investment not worthwhile, and those who have problems with the groundwater quality on their own land.

A logistic regression model, similar to that for tubewell ownership, has been calculated to predict who purchased tubewell water during *rabi* and *kharif* of 1991-92 [c.f. Saleth (1991)]. Because remittances have less impact on water purchases than on investment in tubewells, the variable for relatives abroad is omitted from this model, but a variable for season is added to see if there is a significant

difference between *rabi* and *kharif*.[2] Table 2 shows that, whereas size of land ownership and age of household head have a strong positive effect on tubewell ownership, these variables have a significant negative effect on water purchases. Thus younger households with less land are most likely to purchase groundwater. Farmers in Dir are significantly less likely to purchase groundwater than those in Faisalabad, in part because of the lower availability of tubewells and higher rainfall in Dir. Farmers in Jaranwala are also significantly less likely to purchase water, because a higher proportion of farmers in that village own at least a share of a tubewell.[3] Because alternative sources of irrigation are not available, farmers seek to assure themselves of access to groundwater by investing in wells rather than depending on groundwater purchases. The season does not have a significant effect on water purchases: 30 percent of farmers reported purchasing irrigation in *kharif*, compared to 25 percent in *rabi*.

Table 2

Results of Logistic Regression Model for Tubewell Water Purchase

Independent Variables	Units	Coefficient	T Ratio	Wald Statistic
Size of Land Ownership	Acres	−.039**	−2.28	5.22
Age of Head of Household	Years	−.031**	−3.30	10.87
Season	Dummy	−.355	−1.24	1.54
Jaranwala Village	Dummy	−1.398**	−3.38	11.46
Dir District	Dummy	−3.262**	−8.15	66.50
Constant		2.250**	3.98	15.82

Model Chi-Square = 118.4** with 5 Degrees of Freedom
Number of Observations = 352.
Water Purchasing Correctly Predicted = 81.0 percent of Cases.

Source: IFPRI survey data, 1991-92.
  **Significant at 5 percent probability level.
  *Significant at 10 percent probability level.

Land ownership and age are indicators of overall status of farm households. It is not surprising that higher-status households are more likely to own wells, and lower-status households are more likely to rely on tubewell water purchases. However, not only low-status households purchase water: 7 of 28 tubewell owners

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[2]Ownership of a tubewell was included in an alternative specification of the model, and found to have no significant effect on water purchases. It was omitted from the final model because of multicollinearity with area of land owned.

[3]Tubewell ownership was not included in the model because of the high multicollinearity between land ownership and tubewell ownership. Similarly, operational holding size was not included because it is highly correlated with land ownership. An alternative specification of the model, with operational holding instead of ownership, did not show a significant effect of holding size on water purchases.

in the IFPRI sample also purchase water. Water purchases may provide a backup when a farmer's own well is not functioning, or may be used to irrigate land that cannot be served by a farmer's well. In several cases farmers preferred buying water to operating their own wells because purchased water from electric-powered wells was cheaper than using their own tractor-powered tubewells.

Results of the first model are consistent with findings by Chambers, Saxena and Shah (1989) and Chaudhry (1990) that private well ownership tends to be concentrated among larger or wealthier farmers because of their ability to mobilise the necessary resources, including personal finances, credit, and government connections for electricity supplies. The second model supports the idea that water markets improve equity of groundwater use by making water available to small landowners or tenants and younger households–those farmers who are least likely to own tubewells.

AGRICULTURAL PRODUCTIVITY UNDER WATER MARKETS

What effect does purchased tubewell water have on agricultural production? Previous studies have shown clear productivity gains to farmers purchasing groundwater over those using only public canal or public tubewell supplies, but the gains were much less than those obtained by tubewell owners. The wheat and cotton yield increases of tubewell water purchasers (compared to those with canal water only) were half as great as the yield increases for tubewell owners in Freeman, Lowdermilk and Early's (1978) study. For rice the gap was less: the water purchasers obtained 78 percent of the yield increases of tubewell owners.[4] A study of private tubewells by WAPDA (1980), cited in World Bank (1984) found that overall cropping intensity and the proportion of area under water-consumptive crops was higher for tubewell owners than for water purchasers. There was also a yield gap between water purchasers and tubewell owners for sugarcane, rice, wheat, and vegetables.

The difference in yields could be due, in part, to tubewell water purchasers using lower applications of irrigation water and complementary inputs such as ferti-lizer than tubewell owners. This explanation does not seem satisfactory, however, because the WAPDA study showed that tubewell water purchasers used more inputs and had higher yields than non-users for almost all crops. Renfro (1982) found that tubewell water purchasers' cash and labour inputs were virtually as high as those of tubewell owners, but water purchases were more similar to farmers with canal water than to tubewell owners in terms of cropping intensity, proportion of area under water-consumptive crops, and gross income per acre. He concludes that, in

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[4]A WAPDA (1990) study also assesses the productivity impact of purchased water. But the yield differential are based on farmers' assessments of what their yields would be with and without privately purchased water, and are thus not as reliable as comparisons of actual yields of farmers who do and do not purchase water.

comparison with water purchasers, "Obviously actual sampled tubewell owners can exert more control over water supplies with favourable impacts on productivity" [Renfro (1982, 1983)].

The impact of different sources of irrigation on plot-level 1991-92 wheat yields among IFPRI sample farmers is estimated in Table 3. Seeding rate, total fertilizer applications (defined as kilograms of elemental Nitrogen and Phosphorous per acre), total labour inputs, soil characteristics of pH, potassium, phosphorous, and salinity are included in the model along with the number of irrigation applications from own tubewells, purchased groundwater, and canal water.[5] Soil pH has been transformed to degree of alkalinity, a variable computed by subtracting 7 from to the original pH value.[6] Salinity is represented by a dummy variable indicating if measured electrical conductivity levels are greater than or equal to 4 mmhos/cm, the average threshold level for crop tolerance of salinity.

The seeding rate, amount of nitrogen and phosphorous fertilizer,[7] and labour have significant positive effects on wheat yields, as do the level of potassium in the soil and degree of soil alkalinity. Higher pH values influence yields because slightly alkaline soils (those with a pH above 7.0) are characterised by greater nitrogen, phosphorous, and potassium availability. The coefficients for other soil characteristics–phosphorous content and salinity–are not significant. The lack of a significant effect of electrical conductivity on wheat yields is important because in areas of tubewell irrigation, secondary soil salinity induced by large amounts of groundwater use is a serious concern [Murray and Vander (1992)]. Present levels of salinity do not appear problematic, but higher levels may reduce productivity.

After controlling for fertilizer input and soil fertility, all three types of irrigation inputs had a significant positive effect on wheat yields. But the magnitude of the coefficients indicates that each irrigation application from own tubewells has the highest impact on yield, followed by purchased groundwater and canal applications. The number of applications is an imperfect indicator of irrigation because it does not control for the volume of water used per application, nor for timing of applications. The volume of water per application is usually lower for tubewell than for canal applications, and therefore would not explain the higher productivity of groundwater irrigation. However, the productivity of irrigated agriculture is not determined solely by the amount of irrigation water supplied. Timeliness and reliability of water supplies are also critical. Timing waterings to meet crop evapotranspirative demand has a direct impact on yield, while the

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[5]Alternative functional forms, such as Cobb-Douglas and semi-log, were tested, but did not fit the data as well as linear regression. The large number of cases with values of 0 for one or more of the independent variables, notably the irrigation inputs, may account for the poor fit of log-transformed functional forms.

[6]Original pH on sample plots ranges from 7.0 (neutral) to 8.5 (somewhat alkaline).

[7]A single variable for the sum of nitrogen and phosphorous fertilizer is used because the levels of these two inputs are multicollinar. If N and P are included as separate variables in the model, both have significant coefficients of approximately the same magnitude as the total fertilizer coefficient (4.4) in the final model.

confidence farmers have in their water supply can affect their crop choice, level of fertilizer use, labour, and other inputs. Farmers have relatively little control over timing under *warabandi* rotations of canal systems. Tubewell water can be adjusted to the crop needs and growing cycle, and therefore have a greater impact on production.

This model, which focuses on fertilizer, soil fertility, and irrigation, does not include all influences on productivity, such as weather, variety, labour, human and physical capital, and even water quality. Furthermore, there are selection processes underlying farmers' decisions to invest in tubewells and to purchase tubewell water and factors which affect whether farmers have access to canal water, which could be included in the model. However, the results show that irrigation, and especially tubewell irrigation, has a strong impact on yields. At the same time, they point to a productivity gap between the effect of own tubewell water, over which farmers have considerable control, and purchased tubewell water, over which farmers have less control.

Table 3

Effect of Irrigation Applications on Plot-level Wheat Yields in Faisalabad and Dir Districts

Independent Variables	Coefficient	Standard Error	T Statistic	Variable Mean
Seeding Rate (kg/acre)	3.60**	1.82	1.98	40.93
Fertilizer (N + P kg/acre)	4.67**	.73	6.09	47.12
Labour (person-days/acre)	1.89*	1.12	1.68	27.86
Degree of Alkalinity (adjusted pH)	253.54**	69.20	3.66	0.62[a]
Soil Potassium (ppm/acre)	1.25**	.38	3.32	128.14
Soil Phosphorous (ppm/acre)	−4.50	4.82	−.93	10.07
Soil Salinity Dummy	−44.61	68.99	−.65	.13[b]
Canal Irrigations	31.14**	9.00	3.46	2.53
Purchased Tubewell Irrigations	44.58**	16.66	2.68	.62
Own Tubewell Irrigations	48.31**	18.45	2.62	.50
Constant	−63.16	112.20	−.56	

Adjusted R Square   = 0.31** with 10 Degrees of Freedom
Number of Observations   = 263.

Source: IFPRI survey data, 1990-1992.
        [a]Degree of alkalinity = soil pH − 7.0.
        [b]Variable equals 1 if electrical conductivity ≥ 4 mmhos/cm, 0 otherwise.
      **Significant at 5 percent probability level.
        *Significant at 10 percent probability level.

POLICY MEASURES FOR WATER
MARKET DEVELOPMENT

Water markets are largely autonomous, indigenous institutions which function—and are likely to continue functioning—without a great deal of official intervention. What type of attention, then (if any), should the government and other agencies pay to water markets?

First, understanding the role water markets play in mediating access to and control over groundwater resources can assist programmes for tubewell development to serve a larger number of farmers. Neither public tubewells nor ownership of tubewells by all farmers is required to ensure widespread use of groundwater in areas where water markets operate, but a higher density of tubewells can foster the development of competitive water markets in areas of plentiful groundwater supply [Chambers, Saxena and Shah (1989)]. Water markets can be especially beneficial in expanding conjunctive use of groundwater within the command of canal irrigation systems.

As noted above, large farmers are most likely to own tubewells, while small farmers are more likely to depend on water purchases, and have to face lower reliability of access to groundwater. But larger farmers are also likely to use more of their tubewell water on their own land. Farmers with smaller holdings are more likely to sell water, because they have surplus capacity beyond what is needed to irrigate their holdings. Tubewell owners with less land may also rely more on water sales to recoup their investment in the well and pumpset, and hence be more concerned with providing reliable irrigation services to others. Thus, targeting farmers with smaller holdings for tubewell purchase is likely to increase the activity and reliability of water markets.

Many of the efforts to encourage private tubewell development have focused on drilling wells and purchasing pumping equipment. The contribution of lined channels and pipes to the development of groundwater irrigation in general, and water markets in particular, has been largely overlooked. Lining delivery channels to reduce water losses extends the effective command area of tubewells. In the IFPRI sample, the average distance from tubewell to purchasers' plot was 600 meters in Faisalabad and 180 meters in Dir, but distances of 1 to 3 kilometers were possible using lined watercourses. The watercourse rehabilitation and lining done under the On Farm Water Management Project can, therefore, not only contribute to canal irrigation performance, but also provide infrastructure to assist the development of water markets.

The status of households—particularly defined in terms of land ownership and age of head of household—has an important effect on access to irrigation. Private water markets expand access to groundwater for irrigation, especially for tenants and farmers with small farms. Thus water markets are, on the whole, a positive influence on equity of irrigation use.

Results from this and other studies indicate that use of groundwater, especially in conjunction with canal irrigation, increases productivity more than irrigation from public canals alone. But there is also evidence that those who depend on purchased groundwater do not receive as much of this benefit as those who own tubewells. Further investigation is needed into the sources of this gap, and ways of improving the productivity of water purchasers–who are also likely to be landless tenants or small farmers.

Much of the empirical work on water markets to date has been in relatively favourable conditions: fresh groundwater areas, often within the command area of canal systems which recharge the aquifer. The extent to which water markets operate in areas with groundwater problems–either salinity or shortages–merits further investigation. The incentive and managerial problems of getting farmers to pump and purchase groundwater where it is so saline that it has to be mixed with canal flows are considerable, and may require continued state intervention through public tubewells. Where waterlogging (but not salinity) is a problem, developing water markets can help to control rising water tables. In areas where groundwater is in scarce supply, water markets may encourage overexploitation of the resource, and thus need to be kept in check. If tubewell owners reserve first use of groundwater to meet their own crop needs before selling water to others, groundwater scarcity is likely to exacerbate problems of unreliability for water purchasers. Research is needed on how water markets work in these less favourable environments, and to identify policy interventions that are appropriate under each set of circumstances.

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Comments on
"Performance of Groundwater Markets in Pakistan"

In the paper presented by Dr Ruth on the performance of groundwater markets in Pakistan, an attempt has been made to analyse the current status of water markets in the country as a consequence of the rapid expansion in the installation of tubewells. The data included in the paper has been drawn from the household survey conducted by the International Food Policy Research Institute (IFPRI). This data are confined to the district of Dir in N.W.F.P. which has been taken as a rainfed area and the district of Faisalabad representing irrigated agriculture in the Punjab.

The analysis of this data brings out useful information about the development of water markets in Pakistan. However, these results have very limited application in the country as a whole because the areas so selected do not represent either a typical irrigated area or a typical rainfed area of Pakistan. For example, out of the total of 215000 tubewells in the Punjab, only 8025 are in the district of Faisalabad with the largest population being in other districts of the province. Also the sub-soil water at most of the places is saline in this district and therefore, its direct use for crop production is limited. Moreover, the sample size which is based on a few households is too small to depict a correct and representative picture.

In estimating the participation of tubewell owners, it has been mentioned that while tubewell water sellers were only 5 percent, the number of water buyers was as high as 55 percent. The reason for this situation has not been mentioned. This may have been closely linked with the cropping intensity and the types of crops grown in the tubewell irrigated areas. If these variables were included in the analysis, the results would have presented a more realistic picture and also explained the reason of this situation.

The district of Dir was taken to represent the rainfed area of the province of N.W.F.P. But this again does not represent a typical rainfed area of the province. Firstly, Dir is a tribal area where the socio-political environment is different as compared with the rainfed areas of the settled districts. Moreover, in Dir, the landownership rights in most cases, still remain unsettled. The total number of tubewells in this district being only 24, which is too small to be of any consequence for the type of economic analysis that is envisaged.

In determining the impact of water markets it has been concluded that all types of irrigation has a positive effect on improving productivity but the application of water from own tubewells had the biggest effect on increasing production. This observation needs further clarification as under normal conditions one would expect better results from canal water irrigation because of its silt contents which provides extra fertility to the soil which tubewell water does not contain.

For improving the reliability of water markets it has been suggested that small farmers be encouraged to install tubewells. Such a step would be a major contribution to the development of water markets. It is to be clarified in this connection that the Government of Pakistan is already providing substantial support by way of subsidy for the installation of tubewells etc. Therefore, it would have been useful to indicate specifically what additional facilities are needed to be provided to farmers to encourage the installations of tubewell.

The proposed policy measures on which action has already being undertaken subject to the availability of resources include the lining of water courses, provision of electricity etc. However, the lining of channels although technically sound is difficult to implement on a large scale because of the heavy cost involved, which an average farmer cannot afford.

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