Allocative Inefficiency and Tenure Arrangements in Irrigated Agriculture in Pakistan

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1. Introduction

Irrigated water is a major input in agricultural production in many countries around the world. Pakistan is home to one of the largest and most complex irrigation infrastructure systems in the world, consisting of 25 million hectares of irrigated agriculture, 56,000 kilometres of main canals, tubewells in excess of 600 thousand, and with nearly 100 million people depending on 107,000 water courses fed by 44 canal systems (Hussain, 2004; Briscoe and Qamar, 2006). Ineffective water-management policies in the past have affected water availability and soil quality. The Government of Pakistan Planning Commission's report *Pakistan: Framework for Economic Growth 2011* lists water availability as a major constraint on the agricultural sector and stresses the urgent need to conserve irrigation water. Moreover, institutional constraints affect the degree and efficiency of utilization of water in Pakistan's agricultural sector (Briscoe and Qamar, 2006). Tenure arrangements in Pakistan are one form of institutional constraint that could lead farmers to misallocate inputs. Differences in incentives across tenure systems may explain an important part of Pakistan's water-management issues (Dinar et al. 2004).

Pakistan has a vibrant agricultural sector spread across its four provinces with wheat, cotton, rice, and sugarcane constituting the bulk of agricultural production. Pakistani agriculture is characterized by a diversity of tenure arrangements that reflect the risks and constraints that farmers face. Agricultural tenure falls under three basic categories: owner-cultivators, fixed-rent tenants, and sharecroppers. According to *Government of Pakistan Statistics Division (2003)*, owner-cultivators operate

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approximately two thirds of the total cultivable land. Since Pakistan's independence in 1947, state and market-assisted land reforms as well as other economic forces have led to a decline in sharecropping and a rise in owner-cultivated land (Cheema and Nasir, 2010). The incentives for efficient allocation of resources under each form of tenure differ, and consequently production and input-use decisions vary across tenure as well.

Pakistan's economic growth strategy, as laid out in the report *Pakistan: Framework for Economic Growth 2011,* emphasizes irrigation water reform as one of its goals to enhance agricultural productivity. Past studies have identified over-watering as a major problem in Pakistan's agricultural sector (Hussain et al. 2000; World Bank, 2006). These studies show that agricultural yields in Pakistan decline with surface water use and that low surface water charges increase the incentive for farmers to over-utilize surface water.

However, a comparison of agricultural yields with surface water availability alone may be misleading because agricultural yields also depend on a host of other farm-specific factors such as utilization of groundwater, other agricultural inputs, soil quality, weather conditions, and technical knowledge of farmers. Quantification of the effect of irrigation water on agricultural yields in Pakistan requires a more systematic approach with simultaneous considerations of surface and groundwater sources.

Most farmers in Pakistan supplement surface water with groundwater, and the share of groundwater in irrigation has increased significantly in the last two decades (Qureshi et al., 2004). Yet the degree of utilization of both sources of irrigation depends on many factors. Since most tubewell pumps utilized to extract groundwater in Pakistan are diesel-operated, the price of groundwater in Pakistan varies with the price of diesel and is relatively high (Shah et al., 2009). The degree of utilization of groundwater and surface water also depends on access to capital, which is influenced by tenure and the overall institutional environment of farms. To help achieve the goals of Pakistan's economic growth strategy, a comprehensive analysis is needed to identify the factors that influence the efficiency of utilization of irrigation water in Pakistan and to formulate policies that could lead to a more optimal allocation of irrigation water.

Given the differences in incentives across tenure systems, one way of examining Pakistan's water-management problem in relation to institutional constraints is through the allocative efficiency of irrigation water within each tenure system. Allocative efficiency reveals the degree of over or under-utilization of inputs given their prices. It measures the ability of a firm to use inputs in optimal proportions, given their prices and the existing production technology (Coelli et al., 2005). Technical efficiency, in contrast, reflects the ability of a firm to produce the maximum output from a given level of inputs.

Studies on Pakistani agriculture (Battese et al., 1996; Ali et al., 1994) have generally focused on overall technical and allocative efficiency of farms and have not compared input-specific allocative inefficiencies across tenure systems. Failure to account for input-specific allocative inefficiency might lead to biased estimates if the inputs are correlated with the error term (Kumbhakar and Lovell, 2000). Estimation of input-specific allocative inefficiency explains the degree of utilization of each input. Quantifying the differences in input-use across tenure systems could help policymakers target input-conservation policies towards farmers under specific tenure arrangements.

In this paper we estimate the allocative inefficiency of groundwater in Pakistani agriculture and compare it across tenure systems, using a panel dataset of rural households. We use a stochastic approach based on a system of equations to estimate both the technical efficiency of farms and the allocative efficiency of groundwater use. The allocation of surface irrigation water in Pakistan is fixed per unit of land, so its allocative inefficiency cannot be estimated. Therefore, we will treat surface water as a fixed factor and focus mainly on groundwater. The analysis sheds light on the utilization of irrigation water across tenure systems and other farm specific characteristics. It also provides a basis for a possible redesign of water policy. The results in this paper constitute the empirical basis for future policy work that we will focus on in the second part of this research project.

This paper is organized as follows: Section 2 reviews various approaches used in the literature to measure allocative inefficiency. Section 3 develops a model of allocative inefficiency and presents the estimation strategy. In section 4, the data from two waves of the Pakistan Rural Household Survey[4] are discussed and descriptive statistics on agriculture and water across the 4 provinces—Punjab, Sindh, KP and Baluchistan—are

[4] We would like to thank the Pakistan Institute of Development Economics (PIDE) for assistance in obtaining the two waves of the Pakistan Rural Household Survey that are used in this study.

compared. Section 5 explains the creation of the panel dataset for Punjab and Sindh, and the construction of the variables used to estimate allocative inefficiency. Section 6 discusses the estimation results. Section 7 concludes and addresses some of the policy implications of the findings.

2. Review of Stochastic Frontier Approaches

2.1 The Econometric Approach to Examining Efficiency

Productivity and efficiency analysis can be conducted using non-parametric and parametric approaches. The non-parametric approach includes Data Envelopment Analysis (DEA) that uses linear programming techniques to confine observed data within the smallest possible convex set. The advantage of DEA is that a functional form for the production function does not need to be specified *a priori*. The disadvantage is that all deviations from the frontier are considered a result of technical inefficiency and thus it leaves no scope for measurement and random error. The parametric approach includes econometric methods to estimate production, cost, and profit functions. Assumptions must be made about the functional form, but the approach can accommodate measurement and random error. This approach is often preferable for analysing efficiency in agriculture because unobserved random factors affect agricultural production and farm-level data usually contain considerable measurement error.

The econometric analysis of efficiency begins with the estimation of a frontier based on the theoretical aspects of production, cost, and/or profit functions. The frontier, therefore, reflects either the maximum attainable output given a set of inputs (production frontier), the minimum cost of producing output given the prices of inputs (cost frontier) or the maximum profit that can be attained given output and input prices (profit frontier). In all cases, technology and fixed factors are also taken as given. The frontier represents an ideal in the sense that no agent can exceed it. In this context, the measurement of inefficiency is the estimation of the difference between observations and the best practice frontier (Greene, 2008).

The econometric models of frontier analysis can be either deterministic or stochastic. In the former case, deviations from the frontier are considered solely the result of inefficiency. Stochastic frontier analysis considers deviations from the frontier to be a consequence of inefficiency and random factors outside the control of the agents. It incorporates measurement error and other statistical noise and allows for the estimation of more precise estimates of inefficiency.

Generally, stochastic models include a deterministic component, a non-negative random variable for inefficiency, and a symmetric random error term to capture statistical noise. Observed outputs tend to lie below the deterministic part, and they can only lie above if the noise effect dominates the inefficiency effect.[5]

Production, cost, or profit frontiers can be estimated either as a single equation or as a system of equations. In the single equation estimation, inputs and outputs (if a profit frontier) are treated as exogenous. However, inputs and outputs are a function of their relative prices and treating them as exogenous biases the parameters of the estimated frontier. A system of equations method allows the simultaneous estimation of the production, profit, or cost frontier and input demand and output supply equations. The input demand and output supply equations are derived by imposing a specific behavioural assumption on the producers.

A stochastic profit frontier applies to situations where the behavioural objective of producers is to maximize profits. Profit-maximizing producers face exogenous input and output prices and their input and output functions are determined endogenously. Stochastic profit frontier analysis can be divided into the primal and dual approaches. In the primal approach, a stochastic production function is used and the output supply and input demand functions are determined through the first-order conditions of profit maximization. This system of equations is then estimated. In the dual approach, a profit function is stated and Hotelling's lemma is applied to derive the input and output share equations. Parameters are estimated using this system of equations. Allocative inefficiency in this context is measured as the extent to which the first-order conditions of profit maximization fail to hold.[6]

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[5] See Coelli et al. (2005).

[6] Allocative inefficiency in the profit frontier approach can be different from allocative inefficiency in the cost frontier approach. The difference lies in the first-order conditions of the two objectives. In the cost approach, allocative inefficiency is given by the departure of the marginal rate of substitution (between two inputs) from the ratio of the input prices. In the profit approach, allocative inefficiency represents the departure of the marginal product (of an input) from its normalized price (ratio of input and output prices).

2.2 Applications of Stochastic Frontier Analysis

Stochastic frontier analysis has been used extensively to examine the efficiency of firms in a variety of settings. Below we review some recent applications of stochastic frontier analysis in agriculture.

Liu and Myers (2009) estimate a stochastic production frontier for maize growers in Kenya under different functional forms. They also incorporate exogenous factors that affect technical efficiency in their production function. Their results show that the magnitude of efficiency estimates and the effect of exogenous factors on efficiency differ across specifications. However, the efficiency ranking remains largely constant across all specifications. Exogenous household characteristics account for only 10 percent of the variation in efficiency. They find that education, non-farm income, and farm-size increase technical efficiency while female-headed households, distance from a bus stop (used as a proxy for transactions costs), and owned-land (versus rented) decrease it.

Revoredo-Giha et al. (2009) use panel data on 358 Scottish farms to examine cost efficiency in a stochastic cost frontier framework. They find a wide variation in the cost efficiency levels within and between different farm-type groups. Also, farms that have been heavily supported by subsidies demonstrate the greatest variation in cost efficiency. They also regress cost efficiency against exogenous farm-level factors and find that their effect on cost efficiency differs across types of farms.

Abdulai and Tietje (2007) use panel data on 149 farms in northern Germany to estimate several stochastic production frontiers (under different specifications) and technical efficiency while accounting for farm-level heterogeneity. They show that a random-effects model produces biased estimates while the fixed-effects model can be considered consistent and a benchmark for comparison with other models. Also, time-invariant models underestimate efficiency while time-variant models were not sensitive to firm-specific heterogeneity.

Idiong (2007) estimates a stochastic production frontier to analyse the technical efficiency of small-scale rice producers in Nigeria. The author obtains a mean efficiency score off 77 percent suggesting that farmers can improve technical efficiency by 23 percent. The author also regresses the efficiency estimates on exogenous farm-level factors and finds that education, membership in a cooperative association, and access to credit greatly improve efficiency.

Chen et al. (2009) also estimate a stochastic production frontier for Chinese farms across four regions. They find that the four production frontiers have statistically different structures and that the marginal products of the inputs differ across regions as well (including overuse of labor), implying that the allocation of inputs did not meet an efficiency standard across regions. They also suggest that using machinery and eliminating land fragmentation could increase technical efficiency. Moreover, institutional changes could improve the efficiency of Chinese agriculture by drawing down labor in the sector.

Rahman (2003) examines the profit efficiency (technical and allocative) of 380 rice farms in Bangladesh using cross-sectional data. He also incorporates the exogenous factors influencing profit efficiency directly in the profit function, which offers more precise and consistent estimates of the parameters than a two-step procedure. He finds that on average farmers can increase profits by 30 percent by improving technical and allocative efficiency. Furthermore, education, experience of growing rice, soil fertility, and agricultural extension have a positive effect on efficiency while tenure status (rented land versus owner operated), lack of infrastructure, and percentage of non-farm income adversely impact efficiency.

Magalhães et al. (2011) analyse the sources of technical and allocative inefficiency in a cross-sectional sample of 308 beneficiaries of a market assisted land reform program in Brazil (known as Cédula da Terra). They estimate a stochastic production function and incorporate the sources of inefficiency directly into the production function. They find that the beneficiaries rely mainly on the intensive use of labour and land, while other variable inputs were not significant determinants of production. This occurs owing to the credit restrictions on this group, which cannot make the necessary investments that would modify the production structure. Producers who had access to better technical assistance had lower technical and allocative inefficiency. Moreover, education (through its effect on technical assistance and allowing better access to credit) plays a vital role in decreasing inefficiency. The authors conclude that access to land itself does not increase efficiency and productivity because farmers still face many other constraints.

Dinar et al. (2007) use a non-neutral stochastic production function to evaluate the impact of agricultural extension services on the performance of a sample of farms in Crete, Greece.[7] Their approach allows them to examine agricultural extension through its role as an input in production (direct effect) and as a parameter affecting technical efficiency (indirect effect). Their results show that for a one percent increase in extension visits the increase in output through the direct effect dominates the increase through the indirect effect. Therefore, the effect of extension services would be underestimated in a model that incorporates the effect solely through the efficiency parameter. The authors conclude that extension services should be viewed as a specific type of input in production and its provision and timing should be adapted according to the socio-demographic characteristics of individual farmers.

Alene and Hassan (2006) estimate stochastic production and cost functions for traditional and hybrid maize producers in eastern Ethiopia. They decompose efficiency into its technical and allocative components while accounting for scale effects. Their results show that conventional decomposition approaches (without accounting for scale effects) overestimate the efficiency measures under increasing returns to scale and underestimate the measures under decreasing returns to scale. Under the conventional approach, traditional maize production comes out to be significantly inefficient compared to hybrid maize production. When accounting for scale effects the results reveal that hybrid maize production has greater technical and allocative inefficiency.

The studies reviewed above suggest that technical efficiency varies with household characteristics and the impact of these characteristics differs across regions. Moreover, many of the studies do not account for allocative efficiency in an econometrically consistent manner and have not explored the sources of allocative inefficiency. Using the theory of profit maximization we include both technical and allocative efficiency in our model and compare them across a set of farm-specific factors.

[7] In a non-neutral stochastic frontier, the exogenous factors influencing efficiency can be interacted with the inputs. Hence, shifts in the frontier can occur through the impact of inefficiency on input-use.

3. Modelling Allocative Inefficiency in a Profit Maximization Framework

We assume that farmers maximize profit defined over aggregate output and multiple inputs. Technical inefficiency is treated as a producer specific fixed-effect and allocative inefficiency as a producer and input-specific fixed-effect.[8] Since the two period panel dataset used to estimate the model only spans three years, we find it reasonable to treat technical inefficiency and allocative inefficiency as fixed-effects. Treating inefficiency as time-invariant allows us to estimate the model without making strong distributional assumptions about the inefficiency terms. One drawback of this approach is that the technical inefficiency term will subsume any unobserved time-invariant heterogeneity (Greene, 2008). Nonetheless, avoiding strong distributional assumptions about the inefficiency terms is an attractive feature of the model.

We follow Kumbhakar and Lovell (2000) and Kumbhakar and Wang (2006) in deriving a primal profit system. The stochastic production function for a single aggregate output is given by:

$$y_{it} = f(x_{it}, z_{it}) \exp\{v_{it} - u_i\} \qquad i = 1, \ldots, I \qquad (1)$$

where i and t refer to producers and time, x_{it} is a vector of variable inputs, z_{it} is a vector of quasi-fixed inputs, v_{it} is statistical noise, and u_i is output-oriented and time-invariant technical inefficiency (the percentage loss in output due to technical inefficiency).

The first-order conditions for profit maximization imply:[9]

$$f_n \exp\{v_{it} - u_i\} = \frac{w_{nit}}{p_{it}} \exp\{-\xi_{ni}\} \qquad n = 1, \ldots, N \qquad (2)$$

where p_{it} is the output price and w_{nit} is the price of the nth input, and ξ_{ni} is defined as time-invariant allocative inefficiency. Allocative inefficiency is defined as the extent to which the first-order condition of profit maximization for the jth input fails to hold.

We employ a translog production function, which after dropping the producer subscript i is given by:

[8] This implies that both technical inefficiency and allocative inefficiency are invariant across time.

[9] $Max[py - w'x]\ st. y = f(x) \exp\{v - u\}$

$lny_t =$
$\beta_0 + \sum_n \beta_n lnx_{nt} + \sum_q \gamma_q lnz_{qt} + \frac{1}{2}[\sum_n \sum_k \beta_{nk} lnx_{nt} lnx_{kt}] + \frac{1}{2}\left[\sum_q \sum_r \gamma_{qrt} lnz_{qt} lnz_{rt}\right] +$
$\sum_n \sum_q \delta_{nq} lnx_{nt} lnz_{qt} + v_t - u$ (3)

Using equations (2) and (3) we derive the input demand equations in (4). Since the production function is translog the input demand equations in (4) are not in closed form.

$$lnx_{nt} = lny_{t|v=0} - ln\frac{w_{nt}}{p_t} + \ln\left[\beta_n + \sum_k \beta_{nk} lnx_{kt} + \sum_q \delta_{nq} lnz_{qt}\right] + \xi_n \qquad (4)$$

We eliminate the time invariant terms β_0, u, and ξ_n by first differencing equations (3) and (4). After adding a stochastic noise term to each of the input demand equations the system of equations can be estimated using Iterated Nonlinear Seemingly Unrelated Regressions (INLSUR).

After estimating the parameters, the intercept β_0 can be calculated using the following normalization:

$$\widehat{\beta_0} = \max(\bar{e})$$

where the $\bar{e}$ is the temporal mean of the residuals of equation (3).

After calculating $\widehat{\beta_0}$, we follow Kumbhakar and Lovell (2000) in calculating technical and allocative inefficiency by means of:

$$\hat{u} = \widehat{\beta_0} - \bar{e}$$

$$\widehat{\xi_n} = \overline{lnx_{nt}} - \overline{lny_{t|v=0}} + \overline{ln\frac{w_{nt}}{p_t}} - \overline{\ln\left[\beta_n + \sum_k \beta_{nk} lnx_{kt} + \sum_q \delta_{nq} lnz_{qt}\right]}$$

where a bar over a term represents its temporal mean.

4. Data Sources and Descriptive Statistics of Variables in the PRHS Surveys

This section begins with a discussion of the two data sources that are used in the analysis—Pakistan Rural Household Survey I (PRHS-I) and Pakistan Rural Household Survey II (PRHS-II). Section 4.2 then presents a broad array of descriptive statistics on land holdings, tenancy, and irrigation water sources in Pakistan.

4.1 The PRHS-I and PRHS-II Surveys

PRHS-I is a nationally representative survey that includes data from 2,600 households in 143 villages across the four provinces of the country (Punjab, Sindh, Khyber Pakhtunkhwa (KP) and Balochistan). About 50 percent of the households in PRHS-I owned or operated farmland. PRHS-II followed a sample of 1,800 households from 94 villages, some of which also were included in PRHS-I. However, the PRHS-II households were sampled only from the Punjab and Sindh provinces. About 60 percent of the households in PRHS-II owned or operated farmland.

The surveys aimed at collecting data from rural households to allow an analysis of Pakistan's rural economy. Households in PRHS-I were surveyed from September 2001 to January 2002. Agricultural households were asked information about their agricultural activities in the 2000 kharif (autumn harvest) and 2001 rabi (spring harvest) seasons. Households in PRHS-II were surveyed from August 2004 to October 2004, and agricultural households provided information on the 2003 kharif and 2004 rabi seasons. The two datasets contain plot-level information on agricultural production, tenure and irrigation water availability as well as household-level socioeconomic data. Although some households are observed over time, the plots are not uniquely identified across the surveys.

Panel estimation of the allocative inefficiency of groundwater was restricted to farms in Punjab and Sindh because these were the only two provinces included in both waves of the PRHS survey. Therefore, for the descriptive statistics across the PRHS waves we divided the PRHS-I observations into PRHS-I(a) that includes only observations from Punjab and Sindh, and PRHS-I(b) that includes only observations from KP and Balochistan. The following sections provide a descriptive analysis of variables pertaining to the PRHS-I, PRHS-I(a), PRHS-I(b), and PRHS-II samples.

4.2 Descriptive Statistics of the 2 PRHS Surveys

4.2.1 Agrarian Structure

This section provides a description of the agrarian structure at the level of households and plots across provinces, seasons, tenure statuses and PRHS waves.

Landholdings[10]

According to the Pakistan Agriculture Census 2000, the average farm size of a total of 6,620,054 private farms was 60.8 kanals,[11] and the average cultivated area was 49.6 kanals. The average farm size of a total of 4,933,952 private farms in Punjab and Sindh was 62.4 kanals, or slightly larger than the national average.

The average landholding in the PRHS-I and PRHS-I(a) samples is somewhat larger than the averages in the 2000 census.[12] Half of the landholdings in both samples have an area of 32 kanals or less (Table 1). The average and median landholdings in Punjab and Sindh across time are very similar, which suggests that landholdings in these provinces have not changed much in the period between the two surveys. The average landholding in KP and Balochistan is much larger than the average landholding in Punjab and Sindh because the sample includes a small number of very large farms in Balochistan. However, the median landholding in KP and Balochistan is 8 kanals smaller than the median landholding in Punjab and Sindh.

Table 1: Landholdings Statistics (Kanals) of the PRHS survey

	PRHS-I	PRHS-I(a)	PRHS-I(b)	PRHS-II
Mean Farm Size	85.6	76.5	103.4	76.8
Median Farm Size	32	32	24	32
Standard Deviation	303.3	129.0	491.0	136.8
Number of households	1383	919	464	814

Note: PRHS-I(a) includes only observation from Punjab and Sindh, and PRHS-I(b) includes only observations from KP and Baluchistan.

[10] PRHS refers to landholdings as agricultural landholdings. Farm size is defined as the sum of the areas of all the plots cultivated by a farmer. We use landholdings and farm size interchangeably.
[11] 8 kanals equals 1 acre or 0.405 hectares.
[12] "Landholding" is used here to refer solely to land owned. Other forms of tenure will be discussed below.

Table 2 presents the size distribution of landholdings across six farm size classes. As can be seen from the table, the distribution of landholdings in Punjab and Sindh has not changed much over time (PRHS-I(a) and PRHS-II). There is a more significant difference between the distributions of landholdings in these two provinces compared to the other provinces. While the data in Table 1 indicated that the average farm size was larger in KP and Balochistan (PRHS-II(b)) than in Punjab and Sindh (PRHS-I(a)), Table 2 shows that this does not reflect a distribution that is skewed toward larger farms. The reverse is true. PRHS-I(b) shows that KP and Balochistan actually have a higher share of farms up to 25 kanals (56% compared to only 41% in Punjab and Sindh. Again, there are a few very large farms in the PRHS-I(b) that artificially inflate the average.

Table 2: Share of Landholding by Size Class (%)

Size group (Kanals)	PRHS-I	PRHS-I(a)	PRHS-I(b)	PRHS-II
1-10	21	19	26	19
10-25	24	22	28	23
25-50	22	23	19	21
50-150	21	24	16	24
150-500	10	10	9	11
>500	2	2	2	1
Number of Households	1383	919	464	814

Table 3 presents additional information on the size distribution of landholdings. It shows farm sizes at selected percentiles of the distribution. The results lend further support to the view that the size distributions have not changed much over time in Punjab and Sindh (PRHS-I(a) and PRHS-II). Up to the 75th percentile they are nearly identical, while large farms at and above the 90th percentile of the distribution have increased somewhat in size. Farms tend to be smaller in KP and Balochistan (PRHS-I(b)) with the exception of the very top end of the distribution.

Table 3: Farm Size at Selected Percentiles (Kanals)

Percentile (%)	PRHS-I	PRHS-I(a)	PRHS-I(b)	PRHS-II
10	6	7	4.75	7
25	12	16	10	16
50	32	32	24	32
75	76	80	60	80
90	168	192	160	200
95	304	310	280	320
100	8000	1376	8000	1880

Table 4 reports the distribution of households that own one or more plots. At least 50 percent of households that owned land in all samples owned just one plot. In Punjab and Sindh, the share of households that owned a single plot increased by eight percentage points relative to the first period (58% vs. 66%). The share of households that owned two plots or more was higher in KP and Balochistan than in Punjab and Sindh.

Table 4: Number of Plots Owned (%)

Number of Plots	PRHS-I	PRHS-I(a)	PRHS-I(b)	PRHS-II
1	55	58	50	66
2	21	22	18	19
3	12	10	16	11
4	7	6	10	2
>5	5	4	6	1
Number of Households	1307	871	436	811

Plot size

Table 5 reports descriptive statistics on plot size. The average and median plot sizes were about half of the average and median landholdings. In light of the fact that 55 percent of landowners had a single plot in the first survey year (Table 4, PRHS-I), we conclude that the average and median size of plots owned by households with multiple parcels was also quite small.

Table 5: Plot Size in the PRHS Samples (Kanals)

	PRHS-I	PRHS-I(a)	PRHS-I(b)	PRHS-II
Mean Plot Size	41.9	40.1	45.4	40.4
Median Plot Size	18	24	8	24
Standard Deviation	178.8	64.4	297.4	66.2
Number of Plots	3519	2357	1162	1917

The plot level data across provinces is consistent with the information on landholdings. The mean plot size is lower and the median higher in Punjab and Sindh (PRHS-I(a)) relative to the other two provinces (PRHS-I(b)), yet over time the mean and median plot sizes are virtually unchanged in Punjab and Sindh. This suggests that structural changes in either owned or operated farm sizes are unlikely to be causing changes in the efficiency of water-use that are studied with the panel dataset in this paper.

Tenancy

Since independence Pakistan has seen a rise in owner-cultivation and a steady decline in tenant farming, especially sharecropping (Cheema and Nasir, 2010). The datasets distinguish between leased-in and leased-out plots. Table 6 shows the share of plots under owner-cultivation and the share of plots leased-out under fixed-rent tenancy and under sharecropping. By excluding farmers with no land of their own who only lease-in (discussed below), the focus here is on what owners do with the land that they own. We report the shares by season in order to investigate potentially important differences.

Results in Table 6 show that the majority of the plots were owner-cultivated in both the kharif and rabi seasons. Based on PRHS-I, owner-cultivated plots accounted for 68 percent of the total in the kharif season and 71 percent in the rabi season. The share of plots leased-out to sharecroppers was more than double the share of plots leased-out to fixed-rent tenants in both seasons according to PHRS-I, although there were important differences across provinces. Sharecropping was much more common in KP and Balochistan, accounting for roughly one third of all plots in both seasons. Owner cultivation represented around 75 percent of all plots in Punjab and Sindh. This share remained relatively constant over time, rising by 1.4 percentage points in the kharif season and falling by 0.8 percentage points in the rabi season. Leasing out to fixed rate tenants declined between one and two percentage points in these two provinces, while sharecropping increased by a similar magnitude.

Table 6: Share of Plots by Tenure Classification (Owner-Cultivated and Leased-Out Plots)

	PRHS-I	PRHS-I(a)	PRHS-I(b)	PRHS-II
Kharif				
Owner-Cultivated	67.8	73.9	53.4	75.3
Leased-Out to Fixed-Rent Tenants	10.0	9.3	11.7	7.6
Leased-Out to Sharecroppers	22.2	16.8	34.9	17.2
Number of Plots	1749	1228	521	1213
Rabi				
Owner-Cultivated	70.6	76.0	59.2	75.2
Leased-Out to Fixed-Rent Tenants	8.3	9.1	6.6	7.7
Leased-Out to Sharecroppers	21.1	14.9	34.2	17.1
Number of Plots	1817	1229	588	1210

Table 7 reports shares using leased-in plots. The focus is no longer solely on owners and what they do with their land. We now examine the status of all plots in the dataset that are farmed, including plots of landless households who only lease-in as well as plots of owners who also might choose to lease-in.

Results in Table 7 show that the number of leased-in plots in the PHRS samples is greater than the number of leased-out plots (Table 6).[13] Thus, the share of owner-cultivated plots falls by about 10 percentage points in PRHS-I, even though they remain the majority. The drop in the share of owner-cultivated plots—from around 69 percent when leased-out plots are used to around 59 percent when leased-in plots are used—is largely compensated by an increase in the share of sharecropped plots. These now account for over 30 percent of the plots. The share of fixed-rent plots does not change significantly.

[13] This is a reflection of the particular samples being used. In a census of plots, the number of leased-in plots should equal the number of leased-out plots.

Table 7: Share of Plots by Tenure Classification (Owner-Cultivated and Leased-In Plots)

	PRHS-I	PRHS-I(a)	PRHS-I(b)	PRHS-II
Kharif				
Owner-Cultivated	57.7	57.1	59.7	59.5
Leased-In by Fixed-rent Tenants	9.3	8.5	11.8	10.8
Leased-In by Sharecroppers	33.1	34.4	28.5	29.7
Number of Plots	2057	1591	466	1583
Rabi				
Owner-Cultivated	60	59.2	62.1	60.2
Leased-In by Fixed-Rent Tenants	9.5	9.4	9.6	10.8
Leased-In by Sharecroppers	30.5	31.4	28.2	29.0
Number of Plots	2138	1578	560	1563

The differences *across regions* that were observed in Table 6 are much less significant in Table 7. When the focus was on how owners use their land, Table 6 showed that—relative to KP and Balochistan—a much higher share of owners cultivated the land themselves in Punjab and Sindh (around 75 percent compared to less than 59 percent), and that there was a lower share of sharecroppers (around 15 percent compared to 34 percent). When the focus shifts to how plots are used, Table 7 shows similar shares of owner-cultivation (around 59 percent) and sharecropping (between 28 and 34 percent) across regions. Thus, overall land-use patterns are in fact much more similar across regions than suggested by Table 6.

Table 7 also shows that owner-cultivation of plots is slightly more common in the rabi season, rising by about one to two percentage points depending upon the survey. When attention is restricted to the Punjab and Sindh regions, a decline in the importance of sharecropping is observed over time. Sharecropped plots fall between 2 and 5 percentage points, depending on the season, to under 30 percent of cultivated plots. This is consistent with the long term national trend.

Seasonal Variation in Tenancy of Plots

To observe changes in tenure status of plots across seasons we created crosstabs of tenure in kharif with tenure in rabi for both leased-out plots (Table 8) and leased-in plots (Table

9).[14] When the focus is on owners, Table 8 shows that almost all plots under a specific tenancy in kharif remained under that tenancy in rabi. Irrespective of the survey or region, over 99.2 percent of owner-cultivated plots in kharif remained owner-cultivated in rabi. Similarly, at least 97.4 percent of fixed rent plots remained that way over seasons, and at least 98.2 percent of sharecropped plots did not change status. A similar conclusion is reached when the focus is on plots leased-in (Table 9). Over 99 percent of plots do not change tenure status across seasons in all provinces and in both rounds of the survey.

[14] In PRHS-I owner-cultivated and leased-out plots are part of the owner questionnaire, and leased-in plots are part of the tenant questionnaire. So in Table 8 the crosstab contains owner-cultivated plots along with leased-out plots while Table 9 has only leased-in plots.

Table 8: Change in Tenure Classification Over Seasons (Share of Owner-Cultivated and Leased-Out Plots)

PRHS-I

Tenure in Kharif (2000)	Tenure in Rabi 2001		
	Owner-Cultivated	Leased-Out to Fixed-Rent Tenants	Leased-Out to Sharecroppers
Owner-Cultivated	99.3	0.7	1.2
Leased-Out to Fixed-Rent Tenants	0.1	98	0.6
Leased-Out to Sharecroppers	0.6	1.4	98.3
Total	100	100	100

Based on 1041 owner-cultivated, 147 fixed-rent, and 346 sharecropped plots

PRHS-I(a)

Tenure in Kharif (2000)	Tenure in Rabi 2001		
	Owner-Cultivated	Leased-Out to Fixed-Rent Tenants	Leased-Out to Sharecroppers
Owner-Cultivated	99.4	0.9	1.8
Leased-Out to Fixed-rent Tenants	0.1	98.2	0.0
Leased-Out to Sharecroppers	0.5	0.9	98.2
Total	100	100	100

Based on 783 owner-cultivated, 109 fixed-rent, and 171 sharecropped plots

PRHS-I(b)

Tenure in Kharif (2000)	Tenure in Rabi 2001		
	Owner-Cultivated	Leased-Out to Fixed-Rent Tenants	Leased-Out to Sharecroppers
Owner-Cultivated	99.2	0.0	0.6
Leased-Out to Fixed-Rent Tenants	0.0	97.4	1.1
Leased-Out to Sharecroppers	0.8	2.6	98.3
Total	100	100	100

Based on 258 owner-cultivated, 38 fixed-rent, and 175 sharecropped plots

PRHS-II

Tenure in Kharif (2003)	Tenure in Rabi 2004		
	Owner-Cultivated	Leased-Out to Fixed-Rent Tenants	Leased-Out to Sharecroppers
Owner-Cultivated	100.0	2.2	1.5
Leased-Out to Fixed-Rent Tenants	0.0	97.9	0.0
Leased-Out to Sharecroppers	0.0	0.0	98.5
Total	100	100	100

Based on 908 owner-cultivated, 93 fixed-rent, and 204 sharecropped plots

Table 9: Change in Tenure Classification over Season (Share of Leased-In Plots)

PRHS-I

Tenure in Kharif (2000)	Tenure in Rabi 2001	
	Leased-In by Fixed-Rent Tenants	Leased-In by Sharecroppers
Leased-In by Fixed-Rent Tenants	99.4	0.2
Leased-In by Sharecroppers	0.6	99.8
Total	100	100

Based on 180 fixed-rent and 569 sharecropped plots

PRHS-I(a)

Tenure in Kharif (2000)	Tenure in Rabi 2001	
	Leased-In by Fixed-Rent Tenants	Leased-In by Sharecroppers
Leased-In by Fixed-Rent Tenants	99.2	0.2
Leased-In by Sharecroppers	0.8	99.8
Total	100	100

Based on 130 fixed-rent and 445 sharecropped plots

PRHS-I(b)

Tenure in Kharif (2000)	Tenure in Rabi 2001	
	Leased-In by Fixed-Rent Tenants	Leased-In by Sharecroppers
Leased-In by Fixed-Rent Tenants	100.0	0.0
Leased-In by Sharecroppers	0.0	100.0
Total	100	100

Based on 50 fixed-rent and 124 sharecropped plots

PRHS-II

Tenure in Kharif (2003)	Tenure in Rabi 2004	
	Leased-In by Fixed-Rent Tenants	Leased-In by Sharecroppers
Leased-In by Fixed-Rent Tenants	100.0	0.0
Leased-In by Sharecroppers	0.0	100.0
Total	100	100

Based on 160 fixed-rent and 433 sharecropped plots

<u>Area and Farm Size by Tenure Status</u>

The above description shows that owner-cultivation is the predominant form of tenancy in terms of the share of plots farmed in Pakistan. The same conclusion is reached when area shares are analyzed. Table 10, which is based on owner-cultivated and leased-in plots, shows that the share of total area under owner-cultivation is almost double the share under sharecropping. The area under fixed-rent tenancy is less than 11 percent of total area.

Table 10: Share of Area Operated by Tenure (%)

	PRHS-I	PRHS-I(a)	PRHS-I(b)	PRHS-II
Owner-cultivated	58.8	57.8	64.1	66
Fixed-rent	10.1	10.9	5.6	10
Sharecropped	31.1	31.2	30.3	24
Total	100	100	100	100

In Punjab and Sindh (PRHS-I(a)) the share of area under owner-cultivation is 6 percentage points lower than in KP and Balochistan (PRHS-I(b)), but fixed-rent area is 5 percentage points higher. The area under sharecropping is about the same in PRHS-I(a) and PRHS-I(b). In the second period in Punjab and Sindh the area under owner-cultivation increases while the area under sharecropping falls.

The fact that the area under owner-cultivation exceeds that under fixed-rent tenancy and sharecropping reflects the combination of the number of farms in each form of tenure and average farm size. We now examine farm size. Table 11 reports descriptive statistics on plot size by tenure for both leased-out and leased-in plots. From the point of view of what owners did with their land, PRHS-I shows that plots leased-out to sharecroppers were larger (in terms of their mean and median) than owner-cultivated or fixed-rent plots. When leased-in plots were considered, a somewhat different picture emerged. Sharecroppers still had the largest median plot size, but fixed-rent tenants had the largest mean size.

Table 11: Plot Size by Tenure Status (Kanals)

PRHS-I	Mean	Median	Standard Deviation	Number of Plots
Owner-cultivated	31.2	16.0	55.0	1434
Leased-out to Fixed-rent Tenants	25.9	12.0	44.0	182
Leased-out to Sharecroppers	48.0	20.0	104.9	432
Leased-in by Fixed-rent tenants	36.1	16.0	56.3	215
Leased-in by Sharecroppers	31.1	24.0	32.1	765
PRHS-I(a)	**Mean**	**Median**	**Standard Deviation**	**Number of Plots**
Owner-cultivated	35.0	18.0	59.9	1064
Leased-out to Fixed-rent Tenants	36.7	18.0	51.2	119
Leased-out to Sharecropper	71.2	40	126.1	221
Leased-in by Fixed-rent tenants	45.1	24.1	62.7	156
Leased-in by Sharecroppers	34.0	24.0	26.4	598
PRHS-I(b)	**Mean**	**Median**	**Standard Deviation**	**Number of Plots**
Owner-cultivated	20.1	8.0	35.1	370
Leased-out to Fixed-rent Tenants	5.5	4.0	5.2	63
Leased-out to Sharecropper	23.7	8.0	68.8	211
Leased-in by Fixed-rent tenants	12.3	6.0	19.8	59
Leased-in by Sharecroppers	20.8	8.0	45.9	167
PRHS-II	**Mean**	**Median**	**Standard Deviation**	**Number of Plots**
Owner-cultivated	34.3	20	47.6	915
Leased-out to Fixed-rent Tenants	49.5	16.9	83.2	94
Leased-out to Sharecroppers	55.3	40.0	65.3	214
Leased-in by Fixed-rent tenants	43.9	24.0	115.8	180
Leased-in by Sharecroppers	31.0	24.0	25.6	490

Table 11 shows that the average and median plot sizes in Punjab and Sindh were considerably higher under each tenancy than in KP and Balochistan. The average and median plot areas for owner-cultivated and fixed-rent plots (leased-out) in Punjab and Sindh were similar and less than half that of sharecropped plots (leased-out). In KP and Balochistan, however, the average and median plot areas of owner-cultivated and sharecropped plots were similar while the average and median areas of fixed-rent plots were quite small.

When leased-in plots were considered, in Punjab and Sindh fixed-rent plots had the same median area as sharecropped plots, which was higher than the area of owner-cultivated plots. In KP and Balochistan the average and median areas under each tenancy were still lower than in Punjab and Sindh. The median areas of owner-cultivated and sharecropped plots in KP and Balochistan were the same and 2 kanals higher than the median area of fixed-rent plots.

Over time in Punjab and Sindh the median area of sharecropped plots (leased-out) remained the same while the median area of owner-cultivated plots increased by 2 kanals and the median area of fixed-rent plots (leased-out) decreased by about 1 kanal. There was little change in the median area of sharecropped and fixed-rent plots over time when leased-in plots were considered.

4.2.2 Irrigation Water Availability

In this section we examine the irrigation water supply characteristics of the plots in the PRHS samples. This allows us to see whether we have a large enough sample of irrigated plots in order to conduct a thorough analysis of water-use inefficiency, and to describe their main characteristics. The analysis includes both leased-out and leased-in plots.

<u>Canal Irrigation</u>

In the PRHS datasets households are asked whether their plots receive canal irrigation in both kharif and rabi, in one season only, or whether their plots do not receive canal irrigation. Table 12 presents the distribution of plots with respect to canal irrigation.

Table 12: Share of Plots that Receive Canal Irrigation (%)

Canal Irrigation	PRHS-I	PRHS-I(a)	PRHS-I(b)	PRHS-II
Kharif Only	16.1	24.0	0.1	33.2
Rabi Only	1.1	1.6	0.0	0.1
Kharif and Rabi	33.2	41.7	15.7	39.4
No Canal Irrigation	49.7	32.8	84.2	27.3
Number of Plots	3507	2355	1152	1917

In Punjab and Sindh (PRHS-I(a)) the most common situations was for plots to receive canal irrigation in both karif and rabi (41.7%). In the second period (PRHS-II) the share of plots that received canal irrigation in both seasons fell slightly, but so did the share of plots that did not receive canal irrigation at all. The share of plots that received canal irrigation in kharif only rose by 9 percentage points in the second period compared to the first. The overwhelming majority (84%) of plots in KP and Balochistan did not receive canal irrigation. Thus, for a study of allocative efficiency of irrigation water, it makes sense to restrict the study (as we do) to Punjab and Sindh.

The PRHS datasets do not distinguish between plots that did not have access to canal water and plots that might have had access to canal water but were not irrigated with it. To get a better understanding of plots with access to canal water Table 13 reports the location of the plots on a watercourse.

Table 13: Share of Plots by Location on Watercourse (%)

Location	PRHS-I	PRHS-I(a)	PRHS-I(b)	PRHS-II
Head	17.0	17.1	16.2	23.0
Middle	39.2	37.7	52.6	33.8
Tail	43.8	45.2	31.2	43.1
Number of Plots	1742	1569	173	1393

In Punjab and Sindh (PRHS-I(a)), nearly 45 percent of the plots were located at the tail of the watercourse. Over the two PRHS waves the share of plots located at the tail decreased slightly and the share of plots located at the head increased. It is not clear if this reflects an improvement in the irrigation system or is a reflection of a change in the sample. The majority of the plots in KP and Balochistan were located at the middle of the watercourse.

Not shown in Table 13 is the fact that 1765 plots (50%) in PRHS-I, 786 plots (33%) in PRHS-I(a), 979 plots (85%) in PRHS-I(b), and 524 plots (27%) in PRHS-II did not lie on a watercourse. These plots most likely rely on groundwater irrigation, which we will address later.

Location on the watercourse does not necessarily guarantee access to canal water. To examine the relationship between canal irrigation and the location of plots on the watercourse we cross-tabulate the two variables in Table 14.

Table 14: Location on Watercourse of Plots that Receive Canal Irrigation (%)

PRHS-I

Canal Irrigation	Location on Watercourse: Head	Middle	Tail	Total
Kharif Only	4.1	11.2	16.5	31.8
Rabi Only	0.2	0.6	1.3	2.1
Kharif and Rabi	12.5	26.4	25.7	64.6
No Canal Irrigation	0.1	1.0	0.4	1.6
Total	16.9	39.2	43.8	100

Based on 1741 plots[15]

PRHS-I(a)

Canal Irrigation	Location on Watercourse: Head	Middle	Tail	Total
Kharif Only	4.5	12.4	18.3	35.3
Rabi Only	0.3	0.7	1.4	2.4
Kharif and Rabi	12.2	24.2	25.2	61.6
No Canal Irrigation	0.1	0.4	0.3	0.8
Total	17.03	37.8	45.2	100

Based on 1568 plots

PRHS-I(b)

Canal Irrigation	Location on Watercourse: Head	Middle	Tail	Total
Kharif Only	0.0	0.0	0.0	0.0
Rabi Only	0.0	0.0	0.0	0.0
Kharif and Rabi	15.6	45.7	30.1	91.3
No Canal Irrigation	0.6	6.9	1.2	8.7
Total	16.2	52.6	31.2	100

Based on 173 plots

PRHS-II

Canal Irrigation	Location on Watercourse: Head	Middle	Tail	Total
Kharif Only	9.1	13.7	22.9	45.7
Rabi Only	0.1	0.1	0.0	0.1
Kharif and Rabi	13.9	20.0	20.2	54.2
No Canal Irrigation	0.0	0.0	0.0	0.0
Total	23.0	33.8	43.1	100

Based on 1393 plots

In PRHS-I only 1.6 percent of plots located on the watercourse did not receive canal irrigation. In Punjab and Sindh the share of plots located on the watercourse that did not receive canal irrigation dropped from 0.8 percent to 0 percent overtime. Thus, in

[15] One plot observation from Punjab and Sindh drops out because of missing data on canal irrigation.

these provinces location on the watercourse did guarantee access to canal irrigation. There were, in contrast, 9 percent of plots in KP and Balochistan that lie on the watercourse that did not receive canal irrigation. Not shown in Table 14 is that almost all plots that are not located on the watercourse did not receive canal irrigation.

Since most plots located on the watercourse received canal irrigation we can conclude that location on the watercourse mostly guarantees access to canal water. However, as expected, location on the watercourse influences the probability of access to irrigation. In Punjab and Sindh in both periods, for example, plots located at the head were almost 30 percent more likely to have irrigation in both seasons relative to plots at the tail. The advantage relative to plots in the middle of the course declined from 11% to 2 percent over the two PRHS waves. Of relevance to our study of allocative efficiency, the above analysis shows that plots located on the watercourse would be either fully or partially canal irrigated.

Close to one third of the plots in Punjab and Sindh in the two periods were neither on the watercourse nor received canal irrigation. These plots might have been supplied with groundwater.

Groundwater Availability

In the PRHS datasets groundwater availability on plots is differentiated by quality of groundwater. Table 15 reports the share of plots that had different qualities of groundwater and the share of plots that did not have groundwater irrigation.

Table 15: Share of Plots with Groundwater Irrigation (%)

Groundwater Irrigation	PRHS-I	PRHS-I(a)	PRHS-I(b)	PRHS-II
Good Quality Groundwater	34.1	40.0	21.6	37.2
Medium Quality Groundwater	8.9	11.0	4.7	8.7
Poor Quality Groundwater	5.9	8.6	0.0	3.4
No Tubewell Irrigation	51.1	40.4	73.8	50.8
Number of Plots	3328	2256	1072	1917

With the exception of PRHS-I(a), the majority of the plots in the other samples did not use groundwater irrigation. In Punjab and Sindh the share of plots that did not use groundwater irrigation increased from 40.4 to 50.8 percent over time. In KP and Balochistan (PRHS-I(b)) almost two thirds of plots do not use groundwater irrigation. In all samples, groundwater irrigated plots generally received good quality water. Plots that did not use groundwater irrigation might rely on canal water irrigation instead. We examine this possibility in the subsequent tables.

Groundwater use might depend on the location of plots on the watercourse. In Table 16 we provide cross-tabs of groundwater availability and the location of plots on the watercourse.

Table 16: Location on Watercourse of Plots that Use Groundwater Irrigation (%)

PRHS-I

Groundwater Irrigation	Location on Watercourse: Head	Middle	Tail	Total
Good Quality Groundwater	4.8	12.6	16.3	33.7
Medium Quality Groundwater	1.4	5.1	6.2	12.7
Poor Quality Groundwater	1.4	5.0	4.3	10.7
No Tubewell Irrigation	9.4	16.6	16.9	42.9
Total	17.1	39.2	43.7	100

Based on 1733 plots

PRHS-I(a)

Groundwater Irrigation	Location on Watercourse: Head	Middle	Tail	Total
Good Quality Groundwater	5.3	13.9	17.7	36.9
Medium Quality Groundwater	1.60	5.4	6.9	13.9
Poor Quality Groundwater	1.60	5.5	4.8	11.9
No Tubewell Irrigation	8.7	12.9	15.8	37.3
Total	17.2	37.7	45.1	100

Based on 1560 plots

PRHS-I(b)

Groundwater Irrigation	Location on Watercourse: Head	Middle	Tail	Total
Good Quality Groundwater	0.0	0.6	4.1	4.6
Medium Quality Groundwater	0.0	2.31	0.0	2.3
Poor Quality Groundwater	0.0	0.0	0.0	0.0
No Tubewell Irrigation	16.2	49.7	27.2	93.1
Total	16.2	52.6	31.2	100

Based on 173 plots

PRHS-II

Groundwater Irrigation	Location on Watercourse: Head	Middle	Tail	Total
Good Quality Groundwater	6.6	11.8	14.3	32.7
Medium Quality Groundwater	2.3	4.1	2.5	8.9
Poor Quality Groundwater	0.7	1.1	2.2	4.0
No Tubewell Irrigation	13.5	16.9	24.1	54.5
Total	23.0	33.8	43.1	100

Based on 1393 plots

Plots that were located at the head of the watercourse, and thus had better access to canal irrigation, were less likely to utilize groundwater irrigation. Interestingly, they were also less likely to have good quality groundwater irrigation. In the baseline data for the Punjab and Sindh, for example, plots with no tubewell irrigations falls 50 percent at the head to 35 percent at the tail of the watercourse. In the same provinces, plots with good quality groundwater irrigation rises from 31 percent at the head to 39 percent at the tail. The differences in both use and quality became less pronounced over time. Relative to these provinces, groundwater irrigation was much less common in KP and Balochistan for plots located on a watercourse. Over 87 percent of these plots did not use groundwater irrigation.

We mentioned previously that households with plots that receive canal water might choose not to use groundwater, and those that don't have access to canal irrigation would be more likely to use groundwater. Therefore, we now provide cross-tabs on canal water availability with groundwater use in Table 17. Unlike in Table 16, the data now include plots that are not located on a watercourse.

17: Share of Plots that Use Canal and Groundwater Irrigation (%)

PRHS-I

	Groundwater Irrigation				
Canal Irrigation	Good Quality Groundwater	Medium Quality Groundwater	Poor Quality Groundwater	No Tubewell Irrigation	Total
Kharif Only	9.7	1.8	2.4	2.9	16.9
Rabi Only	0.3	0.2	0.3	0.4	1.1
Kharif and Rabi	7.5	4.9	3.0	19.6	34.9
No Canal Irrigation	16.6	2.1	0.2	28.2	47.2
Total	34.1	9.0	5.9	51.1	100

Based on 3317 plots

PRHS-I(a)

	Groundwater Irrigation				
Canal Irrigation	Good Quality Groundwater	Medium Quality Groundwater	Poor Quality Groundwater	No Tubewell Irrigation	Total
Kharif Only	14.3	2.7	3.5	4.3	24.8
Rabi Only	0.4	0.2	0.4	0.6	1.6
Kharif and Rabi	10.6	6.9	4.4	21.3	43.2
No Canal Irrigation	14.7	1.2	0.4	14.2	30.4
Total	40.0	11.0	8.7	40.4	100

Based on 2255 plots

PRHS-I(b)

	Groundwater Irrigation				
Canal Irrigation	Good Quality Groundwater	Medium Quality Groundwater	Poor Quality Groundwater	No Tubewell Irrigation	Total
Kharif Only	0.0	0.1	0.0	0.0	0.1
Rabi Only	0.0	0.0	0.0	0.0	0.0
Kharif and Rabi	0.8	0.5	0.0	15.8	17.0
No Canal Irrigation	20.7	4.1	0.0	58.0	82.9
Total	21.5	4.7	0.0	73.8	100

Based on 28 plots

PRHS-II

	Groundwater Irrigation				
Canal Irrigation	Good Quality Groundwater	Medium Quality Groundwater	Poor Quality Groundwater	No Tubewell Irrigation	Total
Kharif Only	14.5	1.2	0.9	16.6	33.2
Rabi Only	0.1	0.1	0.0	0.0	0.1
Kharif and Rabi	9.2	5.3	2.0	23.0	39.4
No Canal Irrigation	13.5	2.2	0.5	11.2	27.3
Total	37.2	8.7	3.4	50.8	100

Based on 1917 plots

Table 17 shows that most plots in the Punjab and Sindh have access to canal irrigation, groundwater irrigation or both. PRHS-I(a), for example, shows that 43% of plots had canal irrigation in both seasons, about 70 percent had it in at least one season, 60 percent had tubewell irrigation, and 86 percent had both types of irrigation. According to PRHS-II, the percentage of plots with canal irrigation in at least one season rose to 73 percent, with tubewell irrigation fell to 49 percent, and with one or the other rose to 89 percent. The pattern of changes highlights the substitutability of the water sources. Because over 85 percent of plots used irrigation in one form or another, the analysis of allocative efficiency of irrigation water will cover the overwhelming majority of plots in these two regions.

There was a large share of plots (58%) in KP and Balochistan PRHS-I(b) that neither received canal water nor groundwater. These plots are most likely rain-fed. Thus, their inclusion in the analysis of irrigation water-use would not have been ideal.

Plots located at the head of the watercourse that did not use groundwater (9 percent in PRHS-I(a) and 13 percent in PRHS-II) probably rely solely on canal water irrigation. Therefore, in Table 18 we cross-tabulate canal and groundwater use for plots located at the head of the watercourse.

18: Share of Plots Located at Head of Watercourse that Receive Canal and Groundwater Irrigation (%)

PRHS-I

Canal Irrigation	Groundwater Irrigation: Good Quality Groundwater	Medium Quality Groundwater	Poor Quality Groundwater	No Tubewell Irrigation	Total
Kharif Only	12.2	2.0	4.1	5.8	24.1
Rabi Only	0.0	0.0	0.3	1.0	1.4
Kharif and Rabi	15.3	6.4	4.1	48.1	73.9
No Canal Irrigation	0.3	0.0	0.0	0.3	0.7
Total	27.8	8.5	8.5	55.3	100

Based on 295 plots

PRHS-I(a)

Canal Irrigation	Groundwater Irrigation: Good Quality Groundwater	Medium Quality Groundwater	Poor Quality Groundwater	No Tubewell Irrigation	Total
Kharif Only	13.5	2.3	4.5	6.4	26.6
Rabi Only	0.0	0.0	0.4	1.1	1.5
Kharif and Rabi	16.9	7.1	4.5	43.1	71.5
No Canal Irrigation	0.4	0.0	0.0	0.0	0.4
Total	30.7	9.4	9.4	50.6	100

Based on 267 plots

PRHS-I(b)

Canal Irrigation	Groundwater Irrigation: Good Quality Groundwater	Medium Quality Groundwater	Poor Quality Groundwater	No Tubewell Irrigation	Total
Kharif Only	0.0	0.0	0.0	0.0	0.0
Rabi Only	0.0	0.0	0.0	0.0	0.0
Kharif and Rabi	0.0	0.0	0.0	96.4	96.4
No Canal Irrigation	0.0	0.0	0.0	3.6	3.6
Total	0.0	0.0	0.0	100.0	100

Based on 28 plots

PRHS-II

Canal Irrigation	Groundwater Irrigation: Good Quality Groundwater	Medium Quality Groundwater	Poor Quality Groundwater	No Tubewell Irrigation	Total
Kharif Only	15.0	0.9	1.9	21.5	39.3
Rabi Only	0.0	0.3	0.0	0.0	0.3
Kharif and Rabi	13.7	8.7	0.9	37.1	60.4
No Canal Irrigation	0.0	0.0	0.0	0.0	0.0
Total	28.7	10.0	2.8	58.6	100

Based on 321 plots

In Punjab and Sindh, in either period, all plots that were located at the head of the watercourse either used canal water or groundwater (PRHS-I(a) and PRHS-II). There were no plots that did not use some form of irrigation. In PRHS-I(a) only 0.37 percent of plots located at the head did not use canal water and these plots all had access to good quality groundwater. In PRHS-II all plots located at the head had access to canal irrigation. Of the plots at the head with access to canal water in both seasons, around 40 percent still chose to use groundwater irrigation. For those plots that only had access to canal water in the kharif season, the percentage also using groundwater rose to 75% in PRHS-I(a) and 45 percent in PRHS-II. In KP and Balochistan, the plots located at the head of the watercourse do not use groundwater. 96 percent of the plots located at the head use canal water in both kharif and rabi, while 4 percent use no form of irrigation. Similarly, we cross-tabulate canal water and groundwater availability for plots located at the tail of the watercourse in Table 19.

Table 19: Share of Plots Located at Tail of Watercourse that Receive Canal and Groundwater Irrigation (%)

PRHS-I					
	Groundwater Irrigation				
Canal Irrigation	Good Quality Groundwater	Medium Quality Groundwater	Poor Quality Groundwater	No Tubewell Irrigation	Total
Kharif Only	23.4	4.4	4.8	5.2	37.6
Rabi Only	0.7	0.4	1.1	0.8	2.9
Kharif and Rabi	12.7	9.4	4.1	32.5	58.6
No Canal Irrigation	0.7	0.0	0.0	0.3	0.9
Total	37.3	14.1	9.9	38.7	100
Based on 758 plots					
PRHS-I(a)					
	Groundwater Irrigation				
Canal Irrigation	Good Quality Groundwater	Medium Quality Groundwater	Poor Quality Groundwater	No Tubewell Irrigation	Total
Kharif Only	25.1	4.7	5.1	5.5	40.5
Rabi Only	0.7	0.4	1.1	0.9	3.1
Kharif and Rabi	12.6	10.1	4.4	28.6	55.7
No Canal Irrigation	0.7	0.0	0.0	0.0	0.7
Total	39.2	15.2	10.7	34.9	100
Based on 704 plots					
PRHS-I(b)					
	Groundwater Irrigation				
Canal Irrigation	Good Quality Groundwater	Medium Quality Groundwater	Poor Quality Groundwater	No Tubewell Irrigation	Total
Kharif Only	0.0	0.0	0.0	0.0	0.0
Rabi Only	0.0	0.0	0.0	0.0	0.0
Kharif and Rabi	13.0	0.0	0.0	83.3	96.3
No Canal Irrigation	0.0	0.0	0.0	3.7	3.7
Total	13.0	0.0	0.0	87.0	100
Based on 54 plots					
PRHS-II					
	Groundwater Irrigation				
Canal Irrigation	Good Quality Groundwater	Medium Quality Groundwater	Poor Quality Groundwater	No Tubewell Irrigation	Total
Kharif Only	22.3	1.2	0.7	29.0	53.1
Rabi Only	0.0	0.0	0.0	0.0	0.0
Kharif and Rabi	10.8	4.7	4.5	27.0	46.9
No Canal Irrigation	0.0	0.0	0.0	0.0	0.0
Total	33.1	5.8	5.2	55.9	100
Based on 601 plots					

Table 19 indicates that across the two PRHS waves (comparing PRHS-I(a) and PRHS-II) in Punjab and Sindh all the plots located at the tail had access to canal water and/or groundwater. In PRHS-I(a) over 99 percent of plots located at the tail had access to canal water and 60 percent of plots had access to groundwater. In PRHS-II all the plots located at the tail had access to canal irrigation and 45 percent of plots had access to groundwater. Data for PRHS-I(a) shows that the majority of the plots (65%) located at the tail received both canal water and groundwater. In PRHS-II the combined use was 44 percent. Again, the plots that only used canal water in the kharif were more likely to also use groundwater. In KP and Balochistan 83 percent of plots located at the tail had access to canal water in kharif and rabi but did not use groundwater irrigation.

The analysis in this section suggests that in Punjab and Sindh a substantial number of plots use canal water and/or groundwater irrigation. Although a large share of the plots are canal irrigated only, there is a significant share of plots that utilize both canal water and groundwater irrigation.

The preliminary analysis of the PRHS datasets presented in this section shows that the agrarian structure in Punjab and Sindh has not changed substantially in the short time that elapsed between the two waves of the PRHS. This suggests that many households are likely to be cultivating the same plots over time. We also find that tenure arrangements on plots vary little across seasons. Unfortunately, the structure of the PRHS panel dataset does not permit us to identify plots uniquely over time. For this reason, the econometric analysis presented in Section 5 is conducted at the household level. The analysis above also shows that the agrarian structure of Punjab and Sindh differs considerably from the agrarian structure of KP and Balochistan. Therefore, our results are valid only for Punjab and Sindh. However, given that Punjab and Sindh account for 66% and 18%, respectively, of total cropped area in the country (Agricultural Census, 2010), our sample covers nearly 85 percent of cultivated area in the country.

The results for canal water and groundwater availability show that more than 85 percent of plots in Punjab and Sindh in both time periods (PRHS-I(a) and PRHS-II) receive either canal water, groundwater, or both. The majority of these plots are irrigated by canal water exclusively, although a high share of plots are irrigated by both canal water and groundwater. In KP and Balochistan almost 60 percent of plots neither receive canal water nor groundwater. Therefore, even if there were panel data for these provinces, KP and Balochistan would probably require a separate study of the efficiency of irrigation water. The above findings and the structure of the two PRHS waves lead us to the creation of the panel dataset at the household level, as is explained in the next section. It is this panel dataset that is used to estimate allocative inefficiency.

5. The Panel Dataset

To form a panel dataset of agricultural households we aggregated plot level information on agricultural production, tenure, and plot characteristics up to the household level. PRHS-I includes 1316 agricultural households from the Punjab and Sindh provinces. PRHS-II was restricted to the same two provinces, and includes 1035 households from PRHS-I and an additional 108 agricultural households that were not observed in PRHS-I.

We constructed the panel by including households that appeared in the same season in both waves of the survey and produced at least one of the five main crops: wheat, IRRI-rice, basmati rice, cotton and sugarcane. These crops comprise over 80 percent of total cultivated area. IRRI-rice, basmati rice, cotton and sugarcane are kharif crops while wheat is a rabi crop. There were 636 households observed in kharif 2000 and kharif 2003, while 547 households were observed in rabi 2001 and rabi 2004. We pooled the observations for the two seasons. Around 170 households dropped out of the analysis due to missing observations on tenure and other key variables. After the initial estimation results, a small group of additional households were also removed from the sample because their level of technical efficiency was discretely higher than the remaining households, suggesting that they were operating with a different technology. The final sample used for the estimation included 1870 observations drawn from 466 kharif households and 469 rabi households observed in each period.

Table 20 presents the structure of PRHS-I and PRHS-II for included households that appear in both waves and either own or operate agricultural land. The Table shows data on both leased-in and leased-out plots.[16] The data indicate that the geographical distributions of both households and plots are similar across the two survey waves.

[16] Thus, some plots might be counted twice here. In our analysis we use leased-in plots since information on agricultural production is collected from owner-cultivators and tenants who lease-in land.

Households and plots in Punjab represent 53 percent and 56 percent of the total in PRHS-II, and when restricting PRHS-I to only include Punjab and Sindh, households and plots in Punjab account for 53 percent and 57 percent.

Table 20: Structure of the PRHS Dataset (households and % of total)

	Punjab	Sindh	Punjab and Sindh
PRHS-I			
Number of agricultural	694	622	1316
households	(37)	(33)	(70)[17]
Number of plots	1350	1007	2357
	(38)	(29)	(67)[18]
PRHS-II			
Number of agricultural	608	535	1143
households	(53)	(46)	(100)
Number of plots	1078	839	1917
	(56)	(44)	(100)

Number of Households Included in the Panel Estimation

	Punjab	Sindh	Punjab and Sindh
Kharif	223	243	466
	(48)	(52)	(100)
Rabi	335	114	469
	(76)	(24)	(100)

Total observations included in the panel estimation: 1870.
Note: Data in parentheses shows households in provinces as a percentage of the total in each survey.

5.1 Empirical Specification and Variable Construction in the Panel Dataset

Because the production function in our model is defined over a single output, we had to aggregate the output of several crops for each household. We created separate output quantity indices for the kharif and rabi crops since we differentiated households by season. The output quantity indices included the five main crops and several minor crops. The minor kharif crops included maize, sorghum, groundnuts, sesamum and chilies, while the minor rabi crops included barley, rapeseed, sunflower seed, potato, onion, tomato, peas and spices. We used The Elteto-Koves-Schultz (EKS) method to construct the quantity index. The advantage of this method is that it controls for spatial variation in prices. The approach involved calculating a matrix of Fisher Price Indices using the prices of these crops in each community as a base. We then took the geometric

[17] Of the 1316 households in Punjab and Sindh 53 percent are in Punjab and 47 percent are in Sindh.
[18] Of the 2357 plots in Punjab and Sindh 57 percent are in Punjab and 43 percent are in Sindh.

average of these Fisher Price Indices to construct the EKS Fisher Price Index. We generated the output quantity index by dividing the total revenue from all the crops by the EKS Fisher Price Index. We deflated the prices in PRHS-II to the PRHS-I survey period.[19]

We use three variable inputs: hired labor, fertilizer and groundwater. Own male labor, own female labor, capital and surface water are treated as quasi-fixed inputs. Both variable and quasi-fixed inputs were normalized by total cropped area (Ha). This normalization allows us to exclude land as an input in the production function and keeps the number of estimated parameters within a reasonable limit.

PRHS-I only has information on the cost of hired labor. PRHS-II has data on the number of days of both male and female hired labor. To get a measure of the quantity of hired labor for households in PRHS-I we divided the cost of hired labor by a weighted average of the community level male and female wage rates. We calculated the weights from the ratio of the number of days of male hired labor and the number of days of female hired labor in PRHS-II. Since we cannot disaggregate the quantity of hired labor by gender in PRHS-I, we constructed a quantity index of aggregate hired-labor in PRHS-II. We first constructed an index of male and female wage rates using the EKS method and then divided the total cost of hired labor by the EKS Fisher Price Index. We used the same method to construct fertilizer and capital quantity indices. Fertilizer includes diammonium phosphate (DAP), urea and manure, while capital includes the hours of tractor and thresher/harvester use.

Groundwater is measured in hours. The power of tubewells pumps affects the rate of groundwater extraction. In Pakistan 90 percent of farmers extract groundwater from 16-20 horsepower Chinese tubewell pumps (Qureshi, 2012). Since we do not have information on the type of tubewell pumps used by each farmer, we assume that they used the 16-20 horsepower Chinese tubewells. Hence, we measure the quantity of groundwater with some error. The Chinese pumps extract groundwater at a rate of 1 cubic foot per second. We could use this extraction rate to convert the number of hours of pump use into cubic feet of groundwater applied. Since we assume all farmers use the

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[19] We obtained the GDP deflator from State Bank of Pakistan's *Handbook of Statistics on Pakistan Economy 2010*.

same type of tubewell, no information is lost by keeping the quantity of groundwater in hours. The price of groundwater is in rupees.

Farmers in Pakistan have fixed surface water allocations and thus we cannot treat surface water as a variable input. Therefore, we cannot estimate the allocative inefficiency of surface water within the current framework. Moreover, both PRHS-I and PRHS-II do not have information on the quantity of surface water applied by farmers. In our analysis we include the cost of surface water as an input. The normalization of the cost of surface water by total cropped area provides a reasonable measure of the quantity of surface water since surface water allocations to farms in Pakistan depend on farm size.

As mentioned earlier, the econometric analysis is conducted at the household-level. To control for time varying heterogeneity at the plot-level, we include the shares of environmental and locational characteristics of plots in total household farm area. These include the share of total farm area with access to canal water, the share of total farm area at the head, middle and tail of a watercourse, and the share of total farm area that receives good, medium and poor quality groundwater.

We include a season dummy to estimate a model with the households observed in each season pooled together. To control for differences in the model parameters across seasons we would have to include an interaction of the season dummy with all the linear and second order variables in the translog production function. This would considerably inflate the number of parameters in the model and decrease the degrees of freedom. Moreover, with a system of equations inflation in the number of parameters would increase the computational burden of the estimation process. Because elasticities are not constant when using a translog, and depend on the values of the inputs, separate elasticities and levels of technical and allocative inefficiency can be calculated by season. In future research we plan to estimate separate models for each season and compare the results to the pooled model presented here.

5.2 Description of Variables Used in the Econometric Model

Table 21 provides summary statistics of output, variable inputs, quasi-fixed inputs, and control variables across the kharif and rabi seaons in periods 1 and 2. In the table we have normalized the output quantity index by the mean output index price in each season and period to get a measure of crop revenue per hectare across each season and period. We also report hired labor in number of days so that it can be compared with own farm labor. We divided the total expenditure on hired labor by a weighted average of male and female wage rates to get hired labor in days. These normalizations facilitate interpretation, but do not affect the econometric estimates.

Table 21 shows that the median output per hectare in kharif increased about 17 percent across the two periods. The median values of all inputs except capital and surface water are higher in kharif 2003 relative to kharif 2000. The water and tenure variables change very little in the kharif season across the two periods. The median output per hectare in rabi 2004 is about 11 percent higher than in rabi 2001. The median value of surface water in rabi 2004 is considerably higher than in rabi 2001, but the mean value is only slightly higher. The mean and median values of fertilizer in rabi drop slightly over time. The mean and median values of water and tenure variables in rabi are similar across the two periods.

In both periods the mean value of the hours of groundwater per hectare is higher in kharif than in rabi, but the median value in kharif is zero. This suggests that but the share of households that use groundwater is greater in rabi, but that households use more hours of groundwater per hectare in kharif than in rabi. The water variables show that the share of total area that receives groundwater of any quality is greater in rabi than in kharif. The mean and median values of surface water are higher in kharif than in rabi across both periods. Since surface water is highly limited in rabi a larger proportion of farmers supplement surface water with groundwater in rabi. The share of total area that receives canal irrigation is also higher in kharif than in rabi. Farmers grow wheat (a low water intensity crop) in rabi and cotton, rice, and sugarcane (high water intensity crops) in kharif and hence their use of surface water per hectare is higher in kharif than in rabi.

Own male labor is the dominant form of labor across both periods and seasons. The mean value of hired labor is slightly higher in kharif. Since households grow labor-intensive crops in kharif they supplement their own labor with hired labor. The mean value of own female labor is only slightly higher than the mean value of hired labor across seasons.

All of the inputs in the sample contain at least some zero values. To account for the zero values in the translog production function we follow Battese and Broca (1997) by adding a dummy variable λ_n in the production function and transforming lnx_n to lnx_n^* where:

$$\lambda_n = \begin{cases} 0 \; if \; x_n = 0 \\ 1 \; if \; x_n > 0 \end{cases} \quad \text{and } x_n^* = ArgMax(x_n, 1 - \lambda_n)$$

The above transformation implies that when the input x_n is applied, $x_n^* = x_n$, but when x_n is not applied $x_n^* = 1$. The inclusion of λ_n signifies that the intercept term differs between farmers that apply the input and farmers that do not apply the input.

Table 21: Summary Statistics of the Variables in the Stochastic Profit System

Kharif 2000

Variable	Mean	Median	St. Dev.	Min	Max
Output, Variable Inputs and Quasi-fixed Inputs					
Output (index Rs./ha)	19928.42	18049.48	12203.83	131.18	72124.73
Hired Labor (days)	10.36	0.00	21.10	0.00	205.42
Fertilizer (index Rs./ha)	4047.45	2858.32	4899.69	0.00	52476.20
Groundwater (hours/ha)	61.25	0.00	135.35	0.00	1731.47
Own Male Labor (days/ha)	71.86	28.71	113.45	0.00	864.87
Own Female Labor (days/ha)	13.89	0.00	41.79	0.00	593.05
Capital (index Rs./ha)	3308.90	2320.84	3682.35	0.00	41615.92
Surface Water (Rs./ha)	308.71	200.77	510.71	0.00	7413.16
Water Variables					
Surface Water (% area)	85.11	100.00	35.24	0.00	100.00
Head of Watercourse (% area)	16.75	0.00	35.58	0.00	100.00
Middle of Watercourse (% area)	29.78	0.00	43.43	0.00	100.00
Tail of Watercourse (% area)	40.09	0.00	46.64	0.00	100.00
Good Quality Groundwater (% area)	46.47	0.00	49.63	0.00	100.00
Medium Quality Groundwater (% area)	10.20	0.00	29.98	0.00	100.00
Poor Quality Groundwater (% area)	11.40	0.00	31.65	0.00	100.00
Tenure Variables[20]					
Owner-cultivated (% area)	57.55	100.00	46.51	0.00	100.00
Fixed-rent (% area)	6.63	0.00	21.08	0.00	100.00
Sharecropped (% area)	35.81	0.00	46.51	0.00	100.00

466 observations

[20] The tenure variables were not included in the estimation because they have very little variation over time. Since we later compare

Kharif 2003

Variable	Mean	Median	St. Dev.	Min	Max
Output, Variable Inputs and Quasi-fixed Inputs					
Output (index Rs./ha)	27605.41	21110.62	21812.67	693.14	193819.40
Hired Labor (days)	14.58	4.88	24.33	0.00	202.63
Fertilizer (index Rs./ha)	4352.80	3214.51	4740.71	0.00	57719.08
Groundwater (hours/ha)	71.36	0.00	167.03	0.00	1593.64
Own Male Labor (days/ha)	64.41	44.48	68.84	0.00	590.09
Own Female Labor (days/ha)	17.53	6.18	29.34	0.00	261.93
Capital (index Rs./ha)	3808.48	2109.69	8895.50	0.00	162576.80
Surface Water (Rs./ha)	242.53	98.84	370.59	0.00	3294.74
WaterVariables					
Surface Water (% area)	84.66	100.00	35.93	0.00	100.00
Head of Watercourse (% area)	17.96	0.00	37.08	0.00	100.00
Middle of Watercourse (% area)	29.35	0.00	43.81	0.00	100.00
Tail of Watercourse (% area)	37.56	0.00	46.89	0.00	100.00
Good Quality Groundwater (% area)	42.42	0.00	49.24	0.00	100.00
Medium Quality Groundwater (% area)	7.73	0.00	26.60	0.00	100.00
Poor Quality Groundwater (% area)	3.22	0.00	17.67	0.00	100.00
Tenure Variables					
Owner-cultivated (% area)	55.45	100.00	47.40	0.00	100.00
Fixed-rent (% area)	9.50	0.00	26.75	0.00	100.00
Sharecropped (% area)	35.05	0.00	46.40	0.00	100.00

466 observations

Rabi 2001

Variable	Mean	Median	St. Dev.	Min	Max
Output, Variable Inputs and Quasi-fixed Inputs					
Output (index Rs./ha)	17202.39	16498.57	11439.18	328.16	113547.10
Hired Labor (days)	7.27	0.00	18.30	0.00	254.99
Fertilizer (index Rs./ha)	4561.10	3527.96	6190.17	0.00	103274.20
Groundwater (hours/ha)	36.16	29.65	45.68	0.00	370.66
Own Male Labor (days/ha)	66.01	31.30	95.65	0.00	790.74
Own Female Labor (days/ha)	14.26	1.10	38.12	0.00	370.66
Capital (index Rs./ha)	3262.66	2784.13	2101.54	0.00	21294.75
Surface Water (Rs./ha)	177.10	8.90	268.67	0.00	2223.95
Water Variables					
Surface Water (% area)	39.44	0.00	48.70	0.00	100.00
Head of Watercourse (% area)	9.33	0.00	27.71	0.00	100.00
Middle of Watercourse (% area)	25.68	0.00	42.17	0.00	100.00
Tail of Watercourse (% area)	29.97	0.00	44.05	0.00	100.00
Good Quality Groundwater (% area)	54.51	100.00	49.44	0.00	100.00
Medium Quality Groundwater (% area)	13.69	0.00	34.18	0.00	100.00
Poor Quality Groundwater (% area)	5.66	0.00	23.03	0.00	100.00
Tenure Variables					
Owner-cultivated (% area)	65.78	100.00	43.95	0.00	100.00
Fixed-rent (% area)	8.55	0.00	24.14	0.00	100.00
Sharecropped (% area)	25.67	0.00	42.00	0.00	100.00

469 observations

Rabi 2004

Variable	Mean	Median	St. Dev.	Min	Max
Output, Variable Inputs and Quasi-fixed Inputs					
Output (index Rs./ha)	21735.97	18251.73	14421.25	1372.55	140782.20
Hired Labor (days)	7.35	0.00	18.77	0.00	197.68
Fertilizer (index Rs./ha)	3760.11	3323.59	2926.60	0.00	23300.35
Groundwater (hours/ha)	47.21	24.71	110.40	0.00	1976.84
Own Male Labor (days/ha)	41.64	26.36	53.33	0.00	484.33
Own Female Labor (days/ha)	11.75	2.64	23.43	0.00	204.27
Capital (index Rs./ha)	5560.94	3364.77	10582.67	344.24	140338.90
Surface Water (Rs./ha)	198.82	70.60	292.38	0.00	1530.46
Water Variables					
Surface Water (% area)	37.87	0.00	48.45	0.00	100.00
Head of Watercourse (% area)	13.74	0.00	33.52	0.00	100.00
Middle of Watercourse (% area)	23.17	0.00	41.21	0.00	100.00
Tail of Watercourse (% area)	25.69	0.00	42.70	0.00	100.00
Good Quality Groundwater (% area)	52.19	100.00	49.97	0.00	100.00
Medium Quality Groundwater (% area)	11.35	0.00	31.70	0.00	100.00
Poor Quality Groundwater (% area)	4.48	0.00	20.70	0.00	100.00
Tenure Variables					
Owner-cultivated (% area)	64.65	100.00	45.00	0.00	100.00
Fixed-rent (% area)	12.88	0.00	30.36	0.00	100.00
Sharecropped (% area)	22.47	0.00	40.58	0.00	100.00

469 observations

6. Estimation Results

Because the translog production function contains second order terms for all inputs, the individual parameter estimates can be difficult to interpret. As an alternative, Table 22 reports the elasticities of the variable and quasi-fixed inputs for the sample as a whole and across several types of households. The elasticities were calculated at the median values of the inputs for each type of household. The elasticity of output, E_n, with respect to input x_n, is given by:

$$E_n = \beta_n + \sum_k \beta_{nk} ln x_k + \sum_q \delta_{nq} ln z_q \qquad For\ each\ n \qquad (7)$$

In the overall sample, groundwater has the largest percentage impact on output per hectare, followed by fertilizer. A one percent increase in groundwater per hectare leads to a 0.22 percent increase in output per hectare. The elasticities of hired labor and own female labor are positive and statistically significant, but the elasticity of hired labor is close to zero. These elasticities differ significantly across types of households.

The impact of groundwater on output per hectare is significantly larger for owner-cultivators and fixed-rent tenants than for sharecroppers. This is explained by the higher share of farmers in these groups that use groundwater: 67 percent of owner-cultivators and 86 percent of fixed-rent tenants relative to only 24 percent of sharecroppers. Similarly, the impact of own female labor on output per hectare is larger for owner-cultivators and fixed-rent tenants than for sharecroppers. This suggests that own female labor is more constrained on owner-cultivated and fixed-rent farms.

When elasticities are compared across farm sizes the impact of hired labor becomes more pronounced. Because the importance of hired labor grows with farm size, this variable has a significantly larger impact on output per hectare on large and medium farms. The impact of own female labor is also greater on medium and large farms. Groundwater, in contrast, has a similar impact on output per hectare for small, medium and large farms.

Groundwater per hectare also has a significantly larger impact on output per hectare on farms that do not receive surface water relative to farms that receive surface water. This suggests that households that do not receive surface water would, at the margin, benefit considerably from additional groundwater irrigation.

Across seasons hired labor has a much larger impact on output per hectare in kharif than in rabi. Since households grow labor-intensive crops such as cotton, rice, and sugarcane in kharif, the marginal impact on output per hectare from an increase in hired labor is significantly higher in this season. Groundwater, in contrast, has a substantially larger impact on output per hectare in rabi than in kharif. Since rabi is the dry season and surface water supply is limited, households benefit from increasing the application of groundwater.

The results above have important implications because they identify where farmers are most constrained, and provide clues about how policy could most effectively influence the performance of farmers in Pakistani agriculture. Since groundwater and fertilizer have the highest elasticities across most groups, land productivity would benefit from a marginal increase in the use of these inputs. The findings suggest that policies could be designed to help farmers increase the application of fertilizer and groundwater. However, these findings do not address the question of whether farmers produce the maximum possible amount of output per hectare from their inputs. Nor do they address the issue of the suboptimal utilization of groundwater, which might require a different set of policies. We turn to these issues in the next subsections.

Table 22: Estimated Elasticities of the Variable and Quasi-fixed Inputs (standard errors in parentheses) across Household Groups

	Overall
Hired Labor	0.00^{***}
	(0.00)
Fertilizer	0.10^{***}
	(0.01)
Groundwater	0.22^{***}
	(0.01)
Own Male Labor	-0.012
	(0.01)
Own Female Labor	0.10^{***}
	(0.03)
Capital	0.01
	(0.02)
Surface Water	0.01
	(0.01)

	Owner cultivated	**Fixed-rent**	**Sharecropped**
Hired Labor	0.00^{***}	0.00^{***}	0.00^{***}
	(0.00)	(0.00)	(0.00)
Fertilizer	0.11^{***}	0.10^{***}	0.10^{***}
	(0.01)	(0.01)	(0.01)
Groundwater	0.25^{***}	0.26^{***}	0.03^{***}
	(0.01)	(0.01)	(0.00)
Own Male Labor	-0.03^{**}	-0.03^{*}	0.03
	(0.01)	(0.01)	(0.01)
Own Female Labor	0.11^{***}	0.13^{***}	0.04^{*}
	(0.03)	(0.04)	(0.02)
Capital	-0.00	-0.00	0.04^{*}
	(0.02)	(0.02)	(0.02)
Surface Water	0.00	-0.00	0.06
	(0.01)	(0.01)	(0.05)

	Small farm (<4 ha)	Medium farm (4 to 10 ha)	Large farm (>10 ha)
Hired Labor	0.00***	0.24***	0.31***
	(0.00)	(0.01)	(0.01)
Fertilizer	0.10***	0.10***	0.10***
	(0.01)	(0.01)	(0.01)
Groundwater	0.22***	0.20***	0.24***
	(0.01)	(0.01)	(0.01)
Own Male Labor	-0.02	-0.01	-0.01
	(0.01)	(0.01)	(0.01)
Own Female Labor	0.08***	0.11**	0.12***
	(0.02)	(0.04)	(0.04)
Capital	0.01	0.01	-0.00
	(0.01)	(0.02)	(0.02)
Surface Water	0.02	0.02	0.00
	(0.01)	(0.02)	(0.01)

	With surface water	Without surface water
Hired Labor	0.00***	0.00***
	(0.00)	(0.00)
Fertilizer	0.10***	0.10***
	(0.01)	(0.01)
Groundwater	0.02***	0.28***
	(0.00)	(0.01)
Own Male Labor	-0.01	0.00
	(0.01)	(0.01)
Own Female Labor	0.11***	0.06*
	(0.03)	(0.02)
Capital	0.01	0.03
	(0.01)	(0.02)
Surface Water	0.01	0.05
	(0.01)	(0.05)

	Kharif	Rabi
Hired Labor	0.25***	0.00***
	(0.01)	(0.00)
Fertilizer	0.10***	0.10***
	(0.01)	(0.01)
Groundwater	0.02***	0.24***
	(0.00)	(0.01)
Own Male Labor	-0.01	-0.01
	(0.01)	(0.01)
Own Female Labor	0.10***	0.09***
	(0.03)	(0.03)
Capital	0.01	0.01
	(0.02)	(0.02)
Surface Water	0.02	0.02
	(0.01)	(0.02)

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

6.1 Technical Efficiency

The technical efficiency estimates are producer specific. Table 23 reports descriptive statistics on technical efficiency decomposed across different groups of households.

Table 23: Estimates of Technical Efficiency (standard errors of the means in parentheses)

	Mean	Median	Min	Max
Overall	0.33 (0.01)	0.26	0.02	1.00
Owner cultivated	0.27 (0.01)	0.22	0.02	0.99
Sharecropped	0.45 (0.01)	0.41	0.05	1.00
Fixed-rent	0.28 (0.02)	0.22	0.02	0.84
Small farm (<4 ha)	0.31 (0.01)	0.24	0.02	1.00
Medium farm (4 to 10 ha)	0.35 (0.01)	0.29	0.02	0.99
Large farm (>10 ha)	0.35 (0.01)	0.30	0.02	0.94
With surface water	0.36 (0.01)	0.31	0.02	1.00
Without surface water	0.27 (0.01)	0.22	0.02	0.99
Rabi	0.32 (0.01)	0.25	0.04	0.99
Kharif	0.34 (0.01)	0.27	0.02	1.00

The overall mean technical efficiency of the households in the sample is 33 percent. There is significant variation in the mean and median technical efficiency across certain groups of households. The mean and median technical efficiency of sharecroppers is considerably higher than the mean and median technical efficiencies of owner-cultivators and fixed-rent tenants. The median technical efficiency of sharecroppers (0.41) is nearly double the median technically efficient of owner-cultivators (0.22). We plot the cumulative distribution functions of technical efficiency across tenure type in Figure 1 in order to see whether the technical efficiency of sharecroppers dominates the technical efficiency of owner-cultivators and fixed-rent tenants at all levels of technical efficiency.

Figure 1: Cumulative Distribution Functions of Technical Efficiency by Tenancy Type

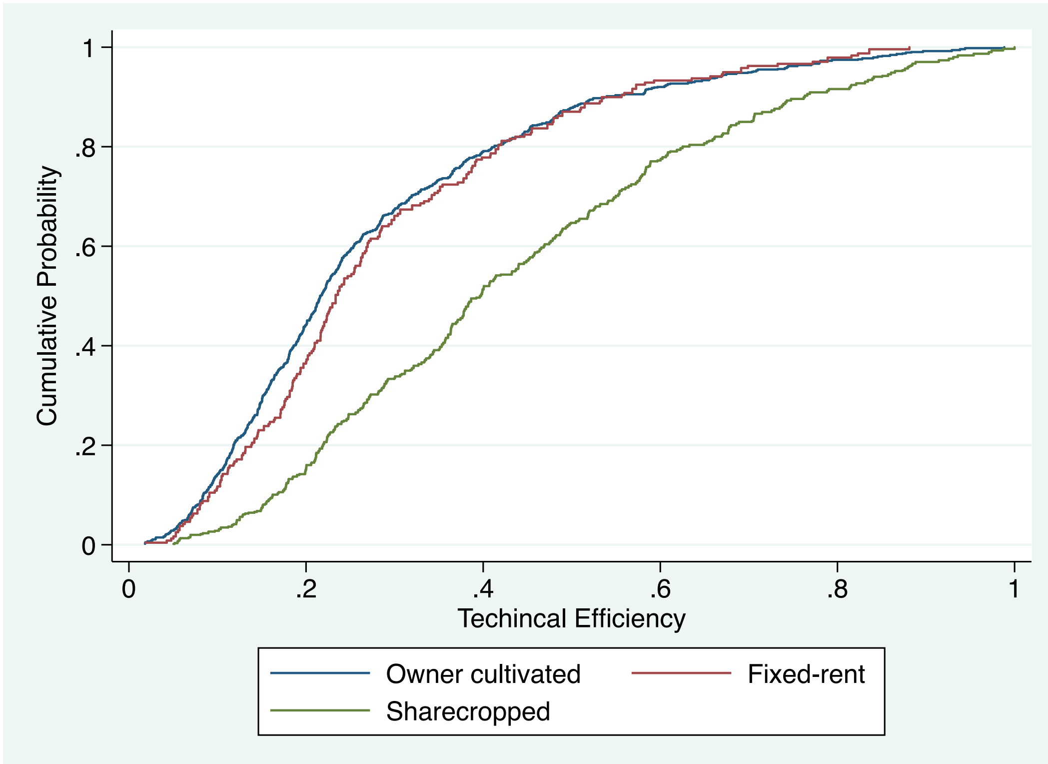
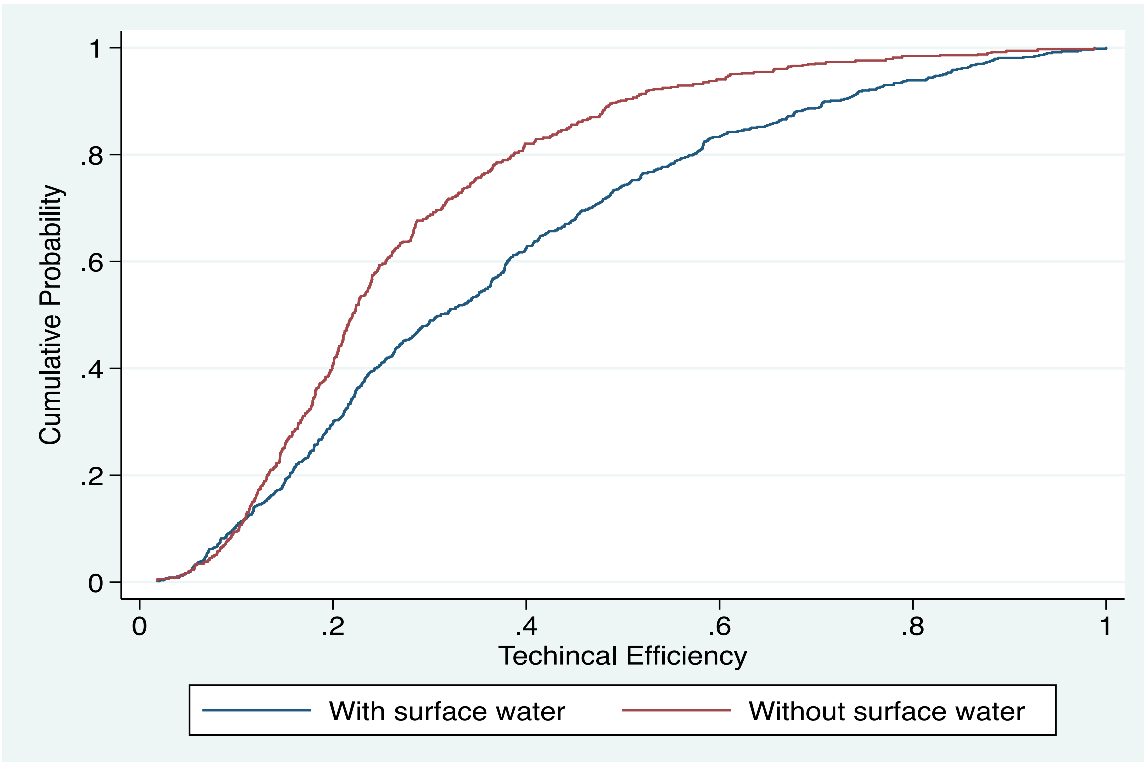


Figure 1 shows that the cumulative distribution function of technical efficiency for sharecroppers lies everywhere to the right of the cumulative distributions of owner-cultivators and fixed-rent tenants. The distributions for owner-cultivators and fixed-rent tenants are similar at all levels of technical efficiency. The figure shows that in comparison to the 50 percent of sharecroppers that operate at a technical efficiency level of 40 percent or higher, only 21 percent of owner-cultivators and fixed-rent tenants operate above that level. This is an important finding that is consistent with Otsuka and Hayami (1988) who do not find evidence of significant inefficiency of sharecroppers in their review of the empirical literature. The finding should be explored further in future research.

There is also a noticeable difference in the mean and median technical efficiency of households with access to surface water and households without surface water. Both the mean and the median values differ by 9 percentage points across the two groups. These differences are explored further in Figure 2 which shows the cumulative distribution functions of technical efficiency for households with and without surface water.

Figure 2: Cumulative Distribution Functions of Technical Efficiency for Households with and without Surface Water



The distribution for households with surface water dominates the distribution for households without surface water at technical efficiency levels greater than 0.10. The figure shows that about 40 percent of households with surface water operate at a technical efficiency level of 0.4 or more while only around 20 percent of households without surface water operate at a similar level.

Our estimates of technical efficiency are lower than a number of other studies on technical efficiency of farmers in Pakistan. Battese and Sohail (1996) estimated technical efficiency of a sample of wheat farmers across the four provinces of Pakistan under different specifications. Their estimates of mean technical efficiency ranged between 57 percent and 79 percent. Burki and Shah (1998) estimated a mean technical efficiency of 76 percent for farmers in five districts of Punjab. However, Ali et al. (1994) estimated a mean technical efficiency of 24 percent for a sample of farmers in Khyber Pakhtunkhwa province (known as the North West Frontier Province (NWFP) when that study was conducted). One possible explanation for such differences is that the previous studies focused on more homogenous groups of farmers that either specialized in single crops or belonged to districts in regions with homogeneous conditions. These studies also assumed that the technical efficiency term in the model followed a particular distribution. In our study we have a more heterogeneous sample of farmers across diverse locations and we treat technical efficiency as a fixed-effect without assuming it follows a specific distribution. Moreover, Thiam et al. (2001) conducted a meta-analysis of empirical estimates of technical efficiency in agricultural in the stochastic frontier literature. Their results show that the system of equations approach—which is our approach—produces lower estimates of technical efficiency compared to the single equation approach. The system of equation estimates they cite range from 17 percent to 73 percent.

To verify our results we estimated several single-equation models using the stochastic frontier program in STATA. These included two fixed-effects models and four random-effects models. The random effects models assumed that technical efficiency followed a particular distribution. The estimate of mean technical efficiency based on both of the fixed-effects models was 21 percent. In the random-effects models the estimates of mean technical efficiency ranged between 37 percent and 74 percent. The estimate of mean technical efficiency in our fixed-effects system of equations model falls within the range of the mean technical efficiency estimates of the single equation models. Furthermore, the correlation between the estimates of technical efficiency in our model and the other six models that were estimated ranges between 0.55 and 0.64, suggesting that even though the means can be quite different, the estimates still contain much of the same information. This exercise suggests that the low estimated values of technical efficiency are likely to be a consequence of the considerable heterogeneity in our sample and the less restrictive assumptions about the technical efficiency term.

6.2 Allocative Efficiency of Groundwater

Table 24 presents descriptive statistics of the estimates of the producer-specific allocative efficiency of groundwater for farmers who apply groundwater. A positive value of allocative efficiency signifies over-utilization of groundwater and a negative value signifies under-utilization of groundwater. Allocative efficiency increases as its value approaches zero.

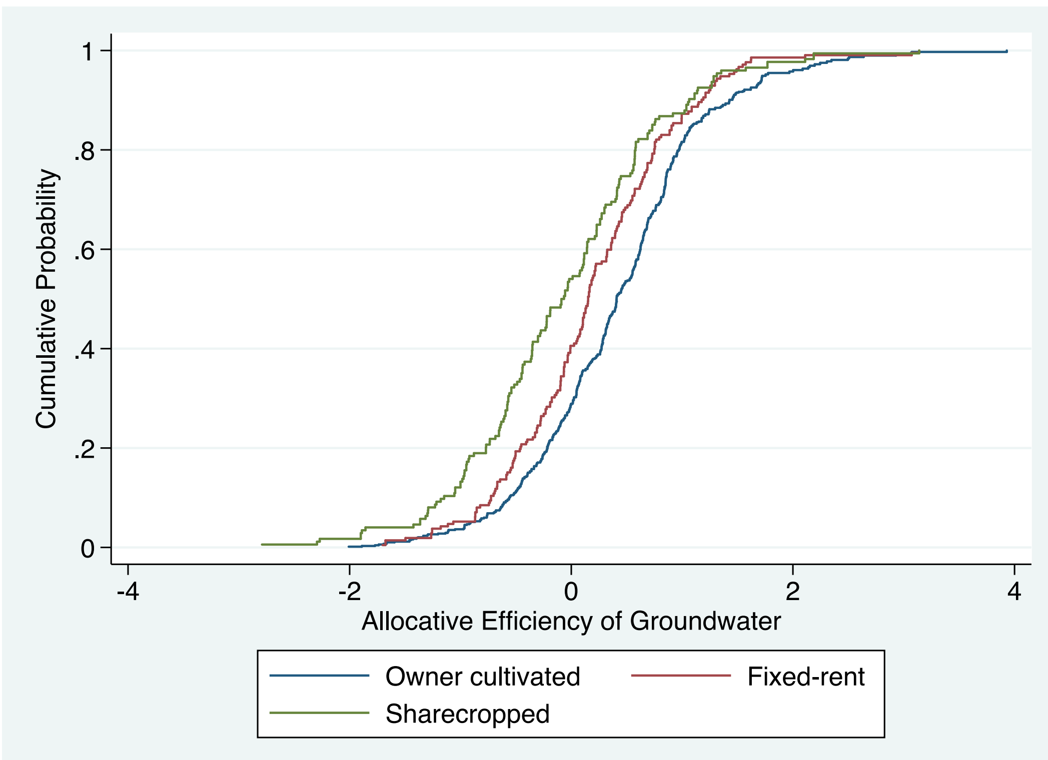
Table 24: Estimates of Allocative Efficiency of Groundwater (standard errors of the means in parentheses)

	Mean	Median	Min	Max
Overall	0.30 (0.03)	0.31	-2.79	3.93
Owner cultivated	0.43 (0.03)	0.41	-2.01	3.93
Sharecropped	-0.12 (0.09)	-0.21	-2.79	3.14
Fixed-rent	0.14 (0.11)	0.14	-1.68	3.14
Small farm (<4 ha)	0.41 (0.03)	0.41	-2.79	3.93
Medium farm (4 to 10 ha)	0.22 (0.05)	0.17	-2.27	3.07
Large farm (>10 ha)	-0.05 (0.07)	-0.01	-2.01	3.93
With surface water	0.14 (0.04)	0.14	-2.79	3.07
Without surface water	0.45 (0.03)	0.40	-1.67	3.93
Rabi	0.13 (0.03)	0.15	-1.86	2.20
Kharif	0.53 (0.05)	0.53	-2.79	3.93

Table 24 shows that the mean and median allocative efficiency are greater than zero: 0.30 and 0.31, respectively. Thus, households that use groundwater tend to over-utilize it. The decomposition of allocative efficiency across groups shows considerable variation and provides valuable insights. On average owner-cultivators and fixed-rent tenants over-utilize groundwater while sharecroppers under-utilize it. At the mean values of allocative efficiency, sharecroppers are more efficient than owner-cultivators and slightly more efficient than fixed-rent tenants because the mean value for sharecroppers is closer to zero. However, when we look at the median value, fixed-rent tenants are more allocatively efficient. For this reason, we once again examine the cumulative distribution functions in order to explore these differences in more detail.

Figure 3 presents the cumulative distribution functions of allocative efficiency of groundwater across tenure. The distribution for sharecroppers lies to the left of the distribution for owner-cultivators. The distribution for fixed-rent tenants lies uniformly between the other two distributions. Figure 3 shows that 54 percent of sharecroppers underutilize groundwater compared to around 29 percent of owner-cultivators. This is likely a reflection of the scarcity of groundwater on sharecropped plots relative to owned plots. Only 45 percent of sharecroppers compared with 72 percent of owner-cultivators, have access to groundwater.[21]

Figure 3: Cumulative Distribution Functions of Allocative Efficiency of Groundwater Across Tenure Systems.

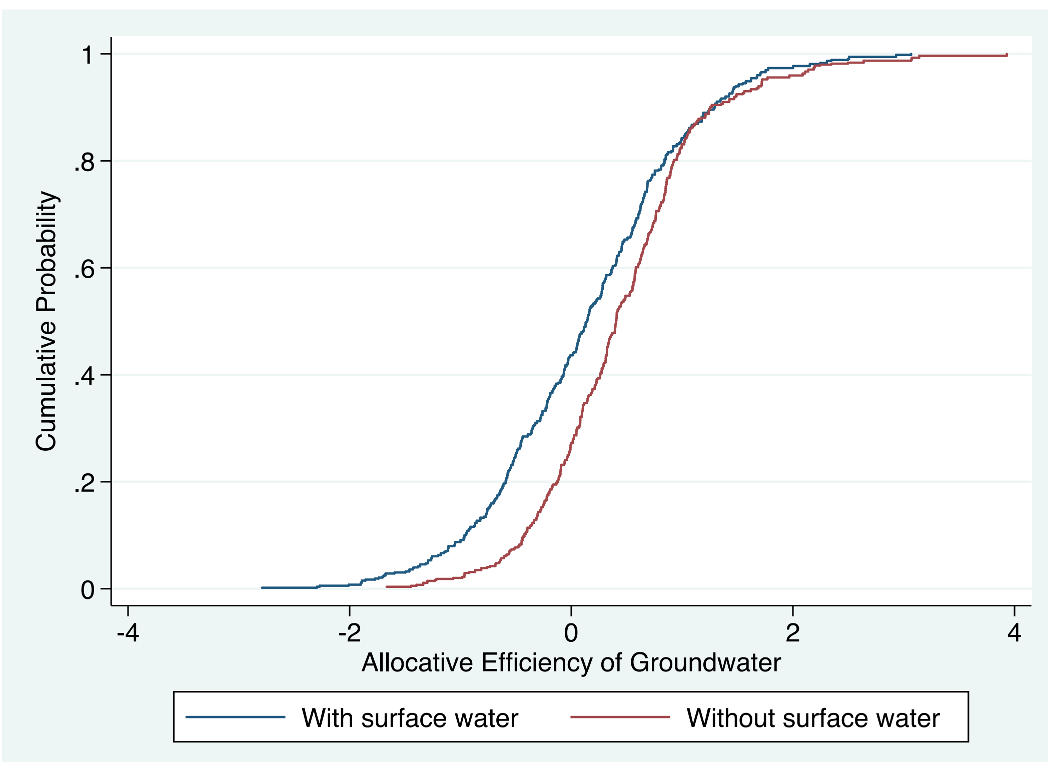


[21] These are shares of owner-cultivators and sharecroppers that have access to groundwater. The shares of owner-cultivators and sharecroppers that use groundwater are 67 percent and 24 percent respectively.

Table 24 also shows that on average large farmers efficiently allocate groundwater. The mean and median technical efficiencies are quite close to zero. Small and medium farmers, in contrast, are allocatively inefficient and over-utilize groundwater.

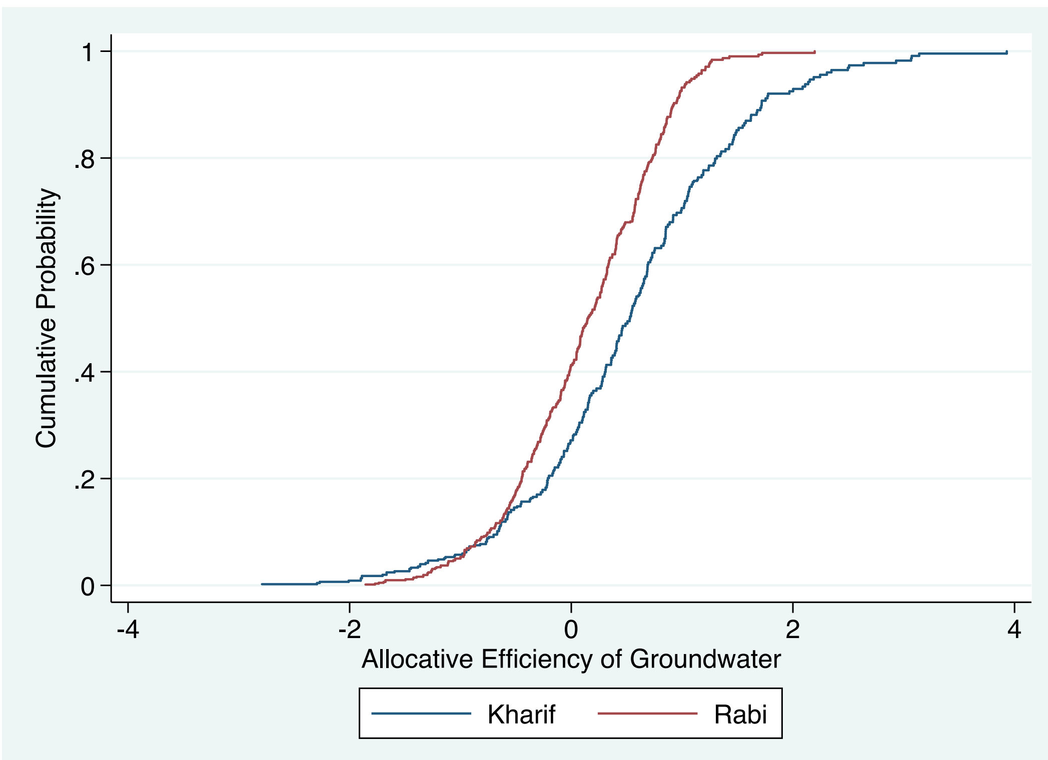
Farms with access to surface water are on average more allocatively efficient than farms without surface water, though both tend to over-utilize groundwater. The cumulative distribution functions of allocative efficiency of groundwater across these groups (Figure 4) shows that a large portion of the distribution for farms with surface water is strictly to the left of the distribution for farms without surface water. Close to 75 percent of farms without surface water over-utilize groundwater. Farms with surface water are much more evenly balanced between over and under-utilization, with 56 percent of them over-utilizing it. Most farmers in Pakistan use groundwater together with surface water. Therefore, farmers use less groundwater if their plot also receives surface water, which is cheaper, but less reliable, leading to additional policy related concerns.

Figure 4: Cumulative Distribution Functions of Allocative Efficiency of Groundwater Across Farms With and Without Access to Surface Water.



In terms of seasons, farmers in rabi tend to be more allocatively efficient than farmers in kharif, but both types of farmers over-utilize groundwater on average. The cumulative distributions of allocative efficiency for the two seasons are presented in Figure 5. It shows that 73 percent of farmers in kharif over-utilize groundwater versus 59 percent of farmers in rabi. In our sample farmers produce rice and sugarcane (high water intensity crops) in kharif, and wheat (low water intensity crop) in rabi. The choice of crop produced could explain the differences in groundwater utilization across seasons, both in terms of crop water needs and in terms of crop profitability. One would wonder what would have happened if farmers had additional options for cropping patterns across the two seasons, which is an important policy question.

Figure 5: Cumulative Distribution Functions of Allocative Efficiency for Farmers in the Kharif and Rabi Seasons



The allocative and technical efficiency estimates seem to follow a similar pattern. Sharecroppers on average tend to be more technically and allocatively efficient than owner-cultivators. Similarly, farms with access to surface water are more allocatively and technically efficient than farms without surface water, mainly because they have more flexibility in their allocation process. In order to explore the relationship between technical efficiency and allocative efficiency in more depth, Figure 6 graphs one variable against the other.

Figure 6: Allocative Efficiency versus Technical Efficiency for all Households

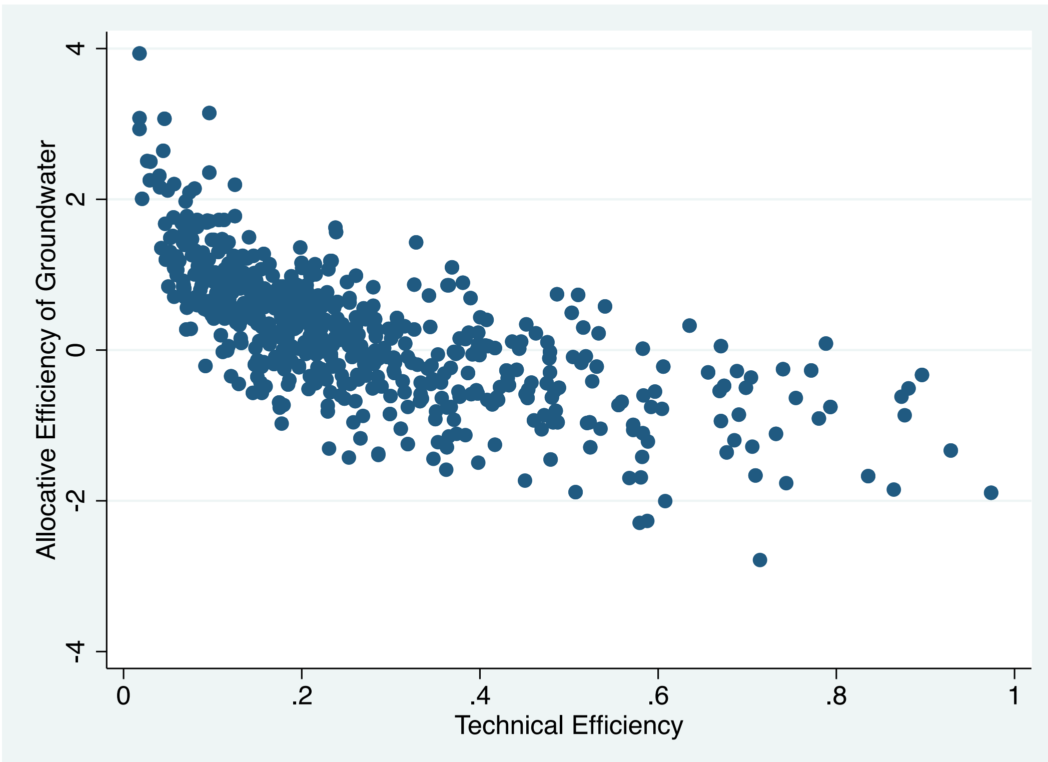


Figure 6 indicates a non-linear relationship between technical efficiency and allocative efficiency of groundwater. Farms with values close to the overall mean value of technical efficiency (0.33) are concentrated around the allocatively efficient level of groundwater. Farms with lower values of technical efficiency tend to have higher values of allocative inefficiency, suggesting over-utilization of groundwater. As technical efficiency increases, allocative efficiency falls, at first rapidly, and then more gradually. More technically efficient farms tend to under-utilize groundwater. These findings suggest that policies designed to increase technical efficiency need to take into account the resulting effect on allocative efficiency, and vice-versa. The trade-off is quite strong at low levels of technical efficiency, and becomes much weaker as technical efficiency levels rise.

7. Summary and Conclusions

This paper concludes the first phase of a two-part study on the allocative efficiency of irrigation water in Pakistan's agricultural sector. Phase 1 provided an empirical analysis of groundwater use in irrigated agriculture. Using a rural household panel dataset from Pakistan spanning the period 2000-01 to 2003-04, we examined the utilization and allocative efficiency of groundwater, and compared it across a number of important farm characteristics. We found evidence that the efficiency of groundwater use varies considerably across these characteristics, including different types of tenure arrangements. The results from the study suggest avenues for policy research on the management of irrigation water across agricultural tenure systems and will form the basis for the next phase of the study. Simulations of the impact of a set of water policy reforms on the allocative efficiency of irrigation water, and on agricultural incomes and poverty, will shed light on the efficacy of these policy alternatives.

Pakistan's agrarian structure was examined across two sets of provinces, two seasons, and two years. The first set of provinces included Punjab and Sindh; the second set included Khyber Pakhtunkhwa and Balochistan. Because the PRHS-II dataset included households solely from Punjab and Sindh, the econometric analysis was restricted to these provinces. Similarly, because plots were not identified uniquely across the survey waves, the panel dataset was constructed at the household level. Households were analyzed in both the rabi and kharif seasons.

Median farm size in Punjab and Sindh was larger than in KP and Balochistan. However, KP and Balochistan had a small group of much larger farms than Punjab and Sindh. The mean and median farm size in Punjab and Sindh remained unchanged over time. This implies that structural changes in farm size over time should have very little impact on the allocative efficiency of groundwater that was estimated in this paper.

The discussion on tenancy emphasized the importance and structure of tenure arrangements in Pakistan. It showed that owner-cultivation was the most common form of tenancy in Pakistan, accounting for around 59 percent of the cultivated plots and a similar share of area in the first wave of the panel. Sharecropping was also quite important across the four provinces of Pakistan, accounting for around 32% of the plots in PRHS-I. Fixed-rent tenancy, in contrast, comprised only around 10% of the plots and area in the first wave of the survey. The share of plots, and the average plot area, under each form of tenancy varied little across regions and over time, although a modest decline in the importance of sharecropping in Punjab and Sindh was observed in PRHS-II. Almost all plots that were under one form of tenancy in kharif remained under the same tenancy form in rabi. Since incentives under each form of tenure differ, the relative stability of tenancy across seasons and years shows the relatively static nature of the institutional constraints on farmers in this period.

The descriptive analysis of irrigation water availability in Pakistan showed that irrigation is an important input in agricultural production in Punjab and Sindh. In these provinces, around 60% of plots had access to groundwater, 70% had access to surface water, and 50% had access to both. Overall, 85% of the agricultural plots in Punjab and Sindh had access to surface water, groundwater or both. In KP and Balochistan, in contrast, the majority of the plots neither received surface water nor groundwater. Thus, KP and Balochistan lack the irrigation infrastructure that could potentially improve land productivity in these regions.

The paper also presents evidence on the availability of both forms of irrigation water according to the position of the farms on the watercourse. In Punjab and Sindh, all the plots located at the head of the watercourse had access to surface water, groundwater, or both. Similarly, all the plots at the tail of the watercourse in these two provinces also had access to either one or both forms of irrigation. The analysis showed that irrigation availability and location on the watercourse were constraints that might influence the utilization of groundwater and should be included as control variables in the estimation of the allocative efficiency of groundwater.

The estimation of elasticities showed that groundwater per hectare had the largest marginal effect on output per hectare across most farm groups. Surface water per hectare, in contrast, did not have a significant effect on land productivity across any of a number of farm groups. Hussain et al. (2000) reached a similar conclusion. Low surface water charges have been suggested as a cause for over-use of surface water, poor maintenance of irrigation infrastructure (through lack of resource generation), and failure to move scarce water to higher value uses (Shah et al., 2009). It is likely that these factors contribute to the elasticity estimates for surface water. Increasing surface water charges might address these issues and will be explored further in Phase 2 of the project.

Estimation results show that sharecroppers operate closer to the production frontier than owner-cultivators, although there was a high degree of inefficiency for both groups. This result holds on average, and at every percentile of the technical efficiency distribution. Jacoby and Mansuri (2009) show that the average land productivity of owner-cultivators and supervised sharecroppers—the majority of sharecroppers in Pakistan—is statistically equal. Combining their results and ours suggests that sharecroppers compensate for other deficiencies—such as access to credit, capital, or irrigation—through superior technical efficiency.

The results for the allocative efficiency of groundwater showed significant differences in the utilization of groundwater across tenure and farm size. Since allocative efficiency measures the extent to which the marginal product of an input differs from the price of the input, differences in allocative efficiency across tenure and farm size might be explained by distortions in output and input prices, and by differential constraints. Wheat, rice and cotton prices in Pakistan, for example, have been kept below world market prices (Mahmood, 1999). If cropping patterns of sharecroppers and owner-cultivators differ, then the distortions in output prices might lead to differences in the utilization of groundwater by tenure arrangements. The inability of farmers to adjust to changes in relative input prices might also be related to the differential constraints that they face across groups. The literature review identified cultivation experience, access to credit, capital intensity, and agricultural extension as some of the constraints on farmers. Future policy work will focus on examining the effect of farm-level constraints, input and output price subsidies, and cropping patterns on groundwater use.

The market structure for groundwater might also explain part of the estimated allocative efficiency. Jacoby et al. (2001) show that tubewell owners in Pakistan have some market power over groundwater and charge a lower price to their share tenants compared to the price charged to other buyers. This price discrimination leads tubewell owners and their share tenants to use more groundwater per hectare on their land than buyers of groundwater. The allocative efficiency of groundwater across tubewell owners, their tenants, and purchasers of groundwater requires further investigation. In future work we plan to distinguish between farmers that pump their own groundwater and farmers that purchase groundwater.

Farms with access to both surface water and groundwater allocate groundwater more efficiently than farms that have access to only groundwater. Given the fixed allocations of surface water, and its unreliability, farms with access to surface water might not meet their irrigation requirements with surface water alone. These farms might use groundwater to meet possible irrigation deficits. However, farms with only groundwater do not have any additional source of irrigation to meet their water requirements. Hence, these farms might over-utilize groundwater.

Farms over-utilize groundwater across both seasons, but on average are more allocatively efficient in rabi than in kharif. Since rabi is the dry season, the shadow value of water from all sources is higher in rabi. Moreover, wheat—a crop with a relatively low level of water utilization—is the only major crop grown in rabi. It needs to be irrigated less frequently than rice and sugarcane—two of the three main kharif crops. As mentioned above the prices of wheat and rice have been kept below world prices. Simulating the impact of a change in relative output prices on farm operations could shed light on the change in the allocative efficiency of groundwater across seasons.

The analysis in this paper showed that improvement in the technical efficiency of farms is likely to have a complicated relationship with the allocative efficiency of groundwater. At low levels of technical efficiency—where many farms operate—there appears to be scope for improving technical and allocative efficiency simultaneously. But at higher levels of technical efficiency there is a tradeoff. Thus, the constraints that affect the technical efficiency of farms could also indirectly affect farms' allocative efficiency, but the direction of the impact would depend on the level of technical efficiency. Policy simulations in the second phase of this project will take these interactions into account.

The first phase of this study found evidence that suggests drawbacks and limitations of the current institutional environment of irrigation water management in Pakistan. In the second phase of this study, the analysis of the allocative efficiency of groundwater will address some of the most important water policy reforms that have been proposed. The efficacy of any proposed set of water policy reforms will depend on the prevailing institutional environment of water management. Placing potential reforms in this context should help to determine the feasibility of these policies. The combination of empirical and policy results could help fill a knowledge gap about alternatives for the sustainable and productive use of irrigation water in Pakistan.

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