PAKISTAN
Strategy Support Program

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE
IFPRI
A member of the CGIAR Consortium

WORKING PAPER No. 015 | January 2014

Allocative Inefficiency and Farm-Level Constraints in Irrigated Agriculture in Pakistan

Sanval Nasim, Ariel Dinar, Steven Helfand

Posted: 01/30/2014

THE PAKISTAN STRATEGY SUPPORT PROGRAM (PSSP) WOKRING PAPERS

ABOUT PSSP

The Pakistan Strategy Support Program (PSSP) is an initiative to strengthen evidence-based policymaking in Pakistan in the areas of rural and agricultural development. Funded by the United States Agency for International Development (USAID) and implemented by the International Food Policy Research Institute (IFPRI), the PSSP provides analysis in four areas: agricultural production and productivity; water management and irrigation; macroeconomics, markets and trade; and poverty reduction and safety nets. The PSSP is undertaken with guidance from the Government of Pakistan through the federal Planning Commission and a National Advisory Committee, and in collaboration with Innovative Development Strategies (Pvt) Ltd. (IDS), Islamabad, and other development partners. For more information, please visit pssp.ifpri.info.

ABOUT the COMPETITIVE GRANTS PROGRAM

The Competitive Grants Program (CGP) is a component of the PSSP that provides support to Pakistani researchers on topics addressing the PSSP and related objectives. The goals of the CGP are to strengthen social science research within the academic community of Pakistan and to produce quality papers on important development policy issues. While PSSP working papers are not classified as peer-reviewed final publications, the papers developed under the CGP have been presented in program conferences and subject to reviews at the interim and final report stages. The CGP is guided by an academic Research Advisory Committee. For more information on the CGP, please visit pssp.ifpri.info under the tab capacity strengthening/competitive grants program.

This working paper is an output from a CGP grant awarded in June 2012. It is also being circulated as Water Science and Policy Center Working Paper 02-1113, University of California, Riverside.

ABOUT THE AUTHORS

Sanval Nasim

Ph.D. Candidate, Department of Environmental Sciences and Water Science and Policy Center, University of California, Riverside (snasi001@ucr.edu).

Ariel Dinar

Professor of Environmental Economics and Policy, Department of Environmental Sciences and Director, Water Science and Policy Center, University of California, Riverside (ariel.dinar@ucr.edu).

Steven Helfand

Associate Professor of Economics, Department of Economics and Water Science and Policy Center, University of California, Riverside (steven.helfand@ucr.edu).

ACKNOWLEDGMENTS

We would like to acknowledge the United States Agency for International Development (USAID) and the International Food Policy Research Institute (IFPRI) for funding this study under the Pakistan Strategy Support Program. We thank an anonymous referee for her/his constructive and encouraging comments. A discussion of the paper with participants at an IFPRI seminar in Washington DC (November 11, 2013) provided us insightful guidance in the writing of the final draft. We also thank Dr. David Orden at IFPRI for his active support and suggestions throughout the course of the study and Dr. Ken Baerenklau at UC Riverside for his comments on the initial draft of the paper.

TABLE OF CONTENTS

Acknowledgments ..... **iii**
List of Tables and Figures ..... **v**
Introduction **7**
Review of Stochastic Frontier Approaches **8**
The Econometric Approach to Examining Efficiency 8
Applications of Stochastic Frontier Analysis 9
Modeling Allocative Inefficiency in a Profit Maximization Framework **11**
Data Sources and Descriptive Statistics of Variables in the PRHS Surveys **12**
The PRHS-I and PRHS-II Surveys 12
Descriptive Statistics of the Two PRHS Surveys 13
Agrarian Structure 13
Irrigation Water Availability 15
The Panel Dataset **20**
Empirical Specification and Variable Construction in the Panel Dataset 21
Description of Variables Used in the Econometric Model 22
Estimation Results **28**
Results from the Pooled Sample 28
Technical Efficiency 31
Allocative Efficiency of Groundwater 34
Results from the Kharif and Rabi Samples 38
Technical Efficiency (Season Samples) 39
Allocative Efficiency (Season Samples) 40
Summary and Conclusions **41**
References **44**
Appendix A **46**
Appendix B **57**
Appendix C **62**

LIST OF TABLES AND FIGURES

Table 1: Share of Plots by Tenure Classification (Owner-Cultivated and Leased-In Plots) 14
Table 2: Share of Area Operated by Tenure (%) 14
Table 3: Plot Size by Tenure Status (Kanals) 15
Table 4: Share of Plots that Receive Canal Irrigation (%) 15
Table 5: Share of Plots by Location on Watercourse (%)..... 16
Table 6: Location on Watercourse of Plots that Receive Canal Irrigation (%) 17
Table 7: Share of Plots with Groundwater Irrigation (%) 18
Table 8: Location on Watercourse of Plots that Use Groundwater Irrigation (%) 18
Table 9: Share of Plots that Use Canal and Groundwater Irrigation (%)..... 19
Table 10: Structure of the PRHS Dataset (households and % of total)..... 21
Table 11: Summary Statistics of the Variables in the Stochastic Profit System..... 24
Table 12: Estimated Elasticities of the Variable and Quasi-Fixed Inputs (standard errors in parentheses) across Household Groups 29
Table 13: Estimates of Technical Efficiency (standard errors of the means in parentheses) 31
Table 14: Estimates of Allocative Efficiency of Groundwater (standard errors of the means in parentheses)..... 34

Table A1: Landholdings Statistics (Kanals) of the PRHS survey 47
Table A2: Share of Landholding by Size Class (%)..... 47
Table A3: Farm Size at Selected Percentiles (Kanals) 47
Table A4: Number of Plots Owned (%)..... 47
Table A5: Plot Size in the PRHS Samples (Kanals) 47
Table A6: Tenure Classification..... 48
Table A7: Share of Area and Plot Size 50
Table A8: Share of Plots that Receive Canal Irrigation (%)..... 51
Table A9: Plot Location and Watercourse 51
Table A10: Plots and Irrigation 52

Table B1: Estimated Elasticities of the Variable and Quasi-Fixed Inputs (standard errors in parentheses) across Household Groups 57
Table B2: Estimates of Technical Efficiency (standard errors of the means in parentheses)..... 58
Table B3: Estimates of Allocative Efficiency of Groundwater (standard errors of the means in parentheses) 60

Table C1: Estimated Elasticities of the Variable and Quasi-Fixed Inputs (standard errors in parentheses) across Household Groups 62
Table C2: Estimates of Technical Efficiency (standard errors of the means in parentheses)..... 63
Table C3: Estimates of Allocative Efficiency of Groundwater (standard errors of the means in parentheses) 65

Figure 1: Cumulative Distribution Functions of Technical Efficiency by Tenancy Type 32
Figure 2: Cumulative Distribution Functions of Technical Efficiency for Households with and without Surface Water 33
Figure 3: Cumulative Distribution Functions of Allocative Efficiency of Groundwater Across Tenure Systems..... 35
Figure 4: Cumulative Distribution Functions of Allocative Efficiency of Groundwater Across Farms With and Without Access to Surface Water..... 36
Figure 5: Cumulative Distribution Functions of Allocative Efficiency for Farmers in the Kharif and Rabi Seasons..... 37
Figure 6: Allocative Efficiency versus Technical Efficiency for all Households 38

Figure B1: Cumulative Distribution Functions of Technical Efficiency by Tenancy Type..... 59
Figure B2: Cumulative Distribution Functions of Technical Efficiency for Households with and without Surface Water..... 59
Figure B3: Cumulative Distribution Functions of Allocative Efficiency of Groundwater Across Tenure Systems. 61
Figure B4: Cumulative Distribution Functions of Allocative Efficiency of Groundwater Across Farms with and without Access to Surface Water. 61

Figure C1: Cumulative Distribution Functions of Technical Efficiency by Tenancy Type..... 64
Figure C2: Cumulative Distribution Functions of Technical Efficiency for Households with and without Surface Water..... 64
Figure C3: Cumulative Distribution Functions of Allocative Efficiency of Groundwater Across Tenure Systems. 65
Figure C4: Cumulative Distribution Functions of Allocative Efficiency of Groundwater Across Farms with and without Access to Surface Water. 66

INTRODUCTION

Water for irrigation is a major concern 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 kilometers of main canals, tubewells in excess of 600,000, 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, farm-level constraints affect the degree and efficiency of utilization of water in Pakistan's agricultural sector (Briscoe and Qamar 2006). Some of the farm-level constraints that could lead farmers in Pakistan to misallocate inputs include but are not limited to: tenure, farm size, access to irrigation water, location on watercourse, access to credit, cultivation experience and access to water user associations.[1] Differences in incentives across these farm-level constraints 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. Pakistan's economic growth strategy, as laid out in 2011 in the report Pakistan: Framework for Economic Growth, 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 crop 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 crop yields with surface water availability alone may be misleading, because 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); however, the degree of utilization of both sources of irrigation water 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 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 farm-level constraints, one way of examining Pakistan's water-management problem is through estimating the allocative efficiency of irrigation water across a set of farm-level constraints. 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 farm-level constraints. Failure to account for input-specific allocative inefficiency might lead to biased estimates if the

[1] Agricultural tenure falls under three basic categories: owner-cultivators, fixed-rent tenants, and sharecroppers. According to the Government of Pakistan Statistics Division (2003), owner-cultivators operate approximately two-thirds of the total cultivable land.

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 facing specific farm-level constraints.

In this paper, we estimate the allocative inefficiency of groundwater in Pakistani agriculture and compare it across a set of farm-level constraints, using a panel dataset of rural households. The farm-level constraints include tenure, farm size, access to surface water and location on a watercourse. 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 a set of 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 policy work that we will focus on in our future work.

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 are discussed and descriptive statistics on agriculture and water across two provinces – Punjab and Sindh – are 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.

REVIEW OF STOCHASTIC FRONTIER APPROACHES

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 assumed to be 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 analyzing 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 considered a given. The frontier represents an ideal locus 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 measures 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.[2]

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 behavioral assumption on the producers, as discussed below.

A stochastic profit frontier applies to situations in which the behavioral 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. Parameters of this system of equations are 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 then 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.[3]

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.

---

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

[3] 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).

Idiong (2007) estimates a stochastic production frontier to analyze 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) analyze 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 labor and land, while other variable inputs were not significant determinants of production. This occurs because of 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.[4] 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 1 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.

[4] 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.

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.

MODELING 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.[5] 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:

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

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:[6]

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

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—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 (for convenience), is given by:

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

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.

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

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

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

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.

DATA SOURCES AND DESCRIPTIVE STATISTICS OF VARIABLES IN THE PRHS SURVEYS

This section begins with a discussion of the two datasets 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 descriptive analysis of tenancy, farm size and irrigation water in Pakistan.

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, the descriptive analysis in the following section focuses only on observations from Punjab and Sindh in the two PRHS waves. An earlier analysis of the agrarian structure of Pakistan using both the waves showed that the agrarian structure of Punjab and Sindh differs considerably from the agrarian structure of KP and Balochistan. The results for canal water and groundwater availability showed that more than 85 percent of plots in Punjab and Sindh in both time periods

receive either canal water, groundwater, or both. 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. Given that Punjab and Sindh account for 66 percent and 18 percent, respectively, of total cropped area in the country (Agricultural Census 2010), our sample covers nearly 85 percent of cultivated area in Pakistan.

Descriptive Statistics of the Two PRHS Surveys

AGRARIAN STRUCTURE

This section provides a description of tenancy and irrigation water availability at the level of households and plots across Punjab and Sindh provinces in the PRHS waves. Additional statistics on the agrarian structure across Punjab, Sindh, KP and Balochistan are provided in Appendix A.

Tenancy

Since independence, Pakistan has seen a rise in owner-cultivation and a steady decline in tenant farming, especially sharecropping (Cheema and Nasir 2010). Table 1 shows the share of plots under owner-cultivation and the share of plots leased-in under fixed-rent tenancy and under sharecropping. We 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. We report the shares by season in order to investigate potentially important differences.

Results in Table 1 show that the majority of the plots were owner-cultivated in both the kharif and rabi seasons. Based on PRHS-I, owner-cultivated plots in Punjab and Sindh accounted for 57 percent of the total in the kharif season, and 59 percent in the rabi season. Table 1 also shows that owner-cultivation of plots is slightly more common in the rabi season. The share of plots leased-in by sharecroppers was almost three times the share of plots leased-in by fixed-rent tenants in both seasons and periods.

The share of owner-cultivated plots remained relatively constant over time (between the two PRHS waves), rising by 2.4 percentage points in the kharif season and by 1 percentage point in the rabi season. Leasing-in by fixed-rent tenants increased between 1 and 2 percentage points, while 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 less than 30 percent of cultivated plots. This is consistent with the long-term national trend.

Table 1: Share of Plots by Tenure Classification (Owner-Cultivated and Leased-In Plots)

	PRHS-I	PRHS-II
Kharif		
Owner-Cultivated	57.1	59.5
Leased-In by Fixed-Rent Tenants	8.5	10.8
Leased-In by Sharecroppers	34.4	29.7
Number of Plots	1591	1583
Rabi		
Owner-Cultivated	59.2	60.2
Leased-In by Fixed-Rent Tenants	9.4	10.8
Leased-In by Sharecroppers	31.4	29.0
Number of Plots	1,578	1,563

Area and Farm Size by Tenure Status

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 2, 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. Over time, the area under owner-cultivation increases while the area under sharecropping falls.

Table 2: Share of Area Operated by Tenure (%)

	PRHS-I	PRHS-II
Owner-Cultivated	57.8	66
Fixed-Rent	10.9	10
Sharecropped	31.2	24
Total	100	100

The area under owner-cultivated exceeds that under fixed-rent tenancy, and the area under sharecropping reflects the combination of the number of farms under each form of tenure and average farm size. Table 3 reports descriptive statistics on plot size by tenure for owner-cultivated and leased-in plots. The results show that fixed-rent plots had the same median area as sharecropped plots, which was higher than the area of owner-cultivated plots. Fixed-rent tenants had the largest mean plot size, followed by owner-cultivators. Over time, there was

little change in the median area of sharecropped and fixed-rent plots, while the median plot area of owner-cultivated increased by 2 kanals.[7]

Table 3: Plot Size by Tenure Status (Kanals)

PRHS-I				
	Mean	Median	Standard Deviation	Number of Plots
Owner-Cultivated	35.0	18.0	59.9	1064
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-II				
	Mean	Median	Standard Deviation	Number of Plots
Owner-Cultivated	34.3	20.0	47.6	915
Leased-In by Fixed-Rent Tenants	43.9	24.0	115.8	180
Leased-In by Sharecroppers	31.0	24.0	25.6	490

IRRIGATION WATER AVAILABILITY

In this section, we examine the irrigation water supply characteristics of the plots in Punjab and Sindh in the PRHS samples. This comparison allows us to determine 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.

Canal Irrigation

In the PRHS datasets, households were 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 4 presents the distribution of plots with respect to canal irrigation.

Table 4: Share of Plots that Receive Canal Irrigation (%)

Canal Irrigation	PRHS-I	PRHS-II
Kharif Only	24.0	33.2
Rabi Only	1.6	0.1
Kharif and Rabi	41.7	39.4
No Canal Irrigation	32.8	27.3
Number of Plots	2,355	1,917

The majority of plots in Punjab and Sindh received canal irrigation in both kharif and rabi. 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 rose by 9 percentage points in the second period.

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 5 reports the location of the plots on a watercourse.

[7] 8 kanals equals 1 acre or 0.405 hectares.

Table 5: Share of Plots by Location on Watercourse (%)

Location	PRHS-I	PRHS-II
Head	17.1	23.0
Middle	37.7	33.8
Tail	45.2	43.1
Number of Plots	1,569	1,393

Table 5 shows that nearly 45 percent of the plots in Punjab and Sindh in the first period 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. Not shown in Table 5 is the fact that 786 plots (33 percent) in PRHS-I and 524 plots (27 percent) 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 6 for Punjab and Sindh.

Table 6 shows that the share of plots located on the watercourse that did not receive canal irrigation dropped from 0.8 percent to 0 percent over time. Thus, in these provinces location on the watercourse did guarantee access to canal irrigation. Not shown in Table 6 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 reliability of access to irrigation water. For example, plots located at the head were almost 30 percent more likely to have irrigation water in both seasons, relative to plots at the tail. The advantage, relative to plots in the middle of the course, declined from 11 percent 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.

Table 6: Location on Watercourse of Plots that Receive Canal Irrigation (%)

PRHS-I

	Location on Watercourse			
Canal Irrigation	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	17.0	37.8	45.2	100

Based on 1,568 plots

PRHS-II

	Location on Watercourse			
Canal Irrigation	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 1,393 plots

Nearly 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 7 reports the share of plots that had different qualities of groundwater and the share of plots that did not have groundwater irrigation.

Table 7: Share of Plots with Groundwater Irrigation (%)

Groundwater Irrigation	PRHS-I	PRHS-II
Good-Quality Groundwater	40.0	37.2
Medium-Quality Groundwater	11.0	8.7
Poor-Quality Groundwater	8.6	3.4
No Tubewell Irrigation	40.4	50.8
Number of Plots	2,256	1,917

A large share of the plots in Punjab and Sindh in both periods did not use groundwater for irrigation. The share of plots that did not use groundwater for irrigation increased from 40.4 percent to 50.8 percent over time. In both periods, groundwater-irrigated plots generally received good-quality water. Plots that did not use groundwater for irrigation might rely on canal water for irrigation instead. We examine this possibility in the subsequent tables.

Groundwater use might depend on the location of plots on the watercourse. In Table 8, we provide cross-tabs of groundwater availability and the location of plots on the watercourse.

Table 8: Location on Watercourse of Plots that Use Groundwater Irrigation (%)

PRHS-I

	Location on Watercourse			
Groundwater Irrigation	Head	Middle	Tail	Total
Good-Quality Groundwater	5.3	13.9	17.7	36.9
Medium-Quality Groundwater	1.6	5.4	6.9	13.9
Poor-Quality Groundwater	1.6	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 1,560 plots

PRHS-II

	Location on Watercourse			
Groundwater Irrigation	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 1,393 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 for irrigation. Interestingly, they were also less likely to have good-quality groundwater irrigation. In the first period, for example, plots with no tubewell for irrigation fell from 50 percent at the head to 35 percent at the tail of the watercourse. In the same period, plots with good-quality groundwater rose from 31 percent at the head to 39 percent at the tail. The differences in both use and quality became less pronounced over time.

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 water would be more likely to use groundwater. Therefore, we now provide cross-tabs on canal water availability with groundwater use in Table 9. Unlike in Table 8, the data now include plots that are not located on a watercourse.

Table 9: 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	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 2,255 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 1,917 plots

Table 9 shows that most plots in the Punjab and Sindh have access to canal water, groundwater, or both. In the first period, for example, 43 percent of plots had canal water 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, tubewell irrigation

fell to 49 percent, and with one or the other it rose to 89 percent. The pattern of changes highlights the substitutability of the water sources. Because more than 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 Punjab and Sindh.

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 is 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 tenancy and water characteristics in Punjab and Sindh have 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. 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 above findings and the structure of the two PRHS waves lead us to the creation of the panel dataset at the household level, as explained in the next section. We use this panel dataset to estimate the allocative inefficiency of water.

THE PANEL DATASET

In order 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 1,316 agricultural households from the Punjab and Sindh provinces. PRHS-II was restricted to the same two provinces, and includes 1,035 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 more than 80 percent of total cultivated area in the provinces. 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), and 547 households 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 obtaining 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 either considerable measurement error or that they were operating with a different technology. The final sample used for the estimation included 1,900 observations drawn from 492 kharif households and 458 rabi households observed in each period.

Table 10 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.[8] The data indicate that the geographical distributions of both households and plots are similar across the two survey waves. 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.

[8] 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.

Table 10: Structure of the PRHS Dataset (households and % of total)

	Punjab	Sindh	Punjab and Sindh
PRHS-I			
Number of agricultural	694	622	1,316
households	(37)	(33)	(70)[9]
Number of plots	1,350	1,007	2,357
	(38)	(29)	(67)[10]
PRHS-II			
Number of agricultural	608	535	1,143
households	(53)	(47)	(100)
Number of plots	1,078	839	1,917
	(56)	(44)	(100)
Number of Households Included in the Panel Estimation			
	Punjab	Sindh	Punjab and Sindh
Kharif	209	283	492
	(42)	(58)	(100)
Rabi	342	116	458
	(75)	(25)	(100)

Total observations included in the panel estimation: 1,900.
Note: Data in parentheses shows households in provinces as a percentage of the total in each survey.

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 are: maize, sorghum, groundnuts, sesamum, and chilies, while the minor rabi crops are: 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 average of the calculated 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.[11]

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

[9] Of the 1,316 households in Punjab and Sindh, 53 percent are in Punjab and 47 percent are in Sindh.
[10] Of the 2,357 plots in Punjab and Sindh, 57 percent are in Punjab and 43 percent are in Sindh.
[11] We obtained the GDP deflator from State Bank of Pakistan's *Handbook of Statistics on Pakistan Economy 2010*.

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 di-ammonium phosphate (DAP), urea, and manure, while capital includes the hours of tractor and thresher/harvester use.

Groundwater is measured in hours. The power of the tubewells' pumps affects the rate of groundwater extraction. In Pakistan, 90 percent of farmers extract groundwater using 16- to 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- to 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 same type of tubewell, no information is lost by keeping the quantity of groundwater as hours. The price of groundwater is in rupees per hour.

Farmers in Pakistan have fixed surface-water allocations per unit of land. 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 (allocation is fixed per unit of land).

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 first estimate a model with the households observed in each season pooled together. We differentiate seasons by the intercept only. To control for differences in the model parameters across seasons, we would have to include an interaction of a 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 a significant increase 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. As an alternative, we also estimate the model for each season separately.

Description of Variables Used in the Econometric Model

Table 11 provides summary statistics of output, variable inputs, quasi-fixed inputs, and control variables across the kharif and rabi seasons 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 11 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 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 level 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 level of own female labor is only slightly higher than the mean level 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:

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

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 11: 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)	19,928.42	18,049.48	12,203.83	131.18	72,124.73
Hired Labor (days)	10.36	0.00	21.10	0.00	205.42
Fertilizer (index Rs./ha)	4,047.45	2,858.32	4,899.69	0.00	52,476.20
Groundwater (hours/ha)	61.25	0.00	135.35	0.00	1,731.47
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)	3,308.90	2,320.84	3,682.35	0.00	41,615.92
Surface Water (Rs./ha)	308.71	200.77	510.71	0.00	7,413.16
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[12]					
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

Note: Descriptive statistics calculated from 466 observations.

[12] The tenure variables were not included in the estimation because they have very little variation over time. Since we later compare the technical efficiency and allocative efficiency estimates across tenure, we present the descriptive statistics on these variables in the table.

Table 11: (Continued)

Kharif 2003 Variable	Mean	Median	St. Dev.	Min	Max
Output, Variable Inputs and Quasi-fixed Inputs					
Output (index Rs./ha)	27,605.41	21,110.62	21,812.67	693.14	193,819.40
Hired Labor (days)	14.58	4.88	24.33	0.00	202.63
Fertilizer (index Rs./ha)	4,352.80	3,214.51	4,740.71	0.00	57,719.08
Groundwater (hours/ha)	71.36	0.00	167.03	0.00	1,593.64
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)	3,808.48	2,109.69	8,895.50	0.00	162,576.80
Surface Water (Rs./ha)	242.53	98.84	370.59	0.00	3,294.74
Water Variables					
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

Note: Descriptive statistics calculated from 466 observations.

Table 11: (Continued)

Rabi 2001 Variable	Mean	Median	St. Dev.	Min	Max
Output, Variable Inputs and Quasi-fixed Inputs					
Output (index Rs./ha)	17,202.39	16,498.57	11,439.18	328.16	113,547.10
Hired Labor (days)	7.27	0.00	18.30	0.00	254.99
Fertilizer (index Rs./ha)	4,561.10	3,527.96	6,190.17	0.00	103,274.20
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)	3,262.66	2,784.13	2,101.54	0.00	21,294.75
Surface Water (Rs./ha)	177.10	8.90	268.67	0.00	2,223.95
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

Note: Descriptive statistics calculated from 469 observations.

Table 11: (Continued)

Rabi 2004 Variable	Mean	Median	St. Dev.	Min	Max
Output, Variable Inputs and Quasi-fixed Inputs					
Output (index Rs./ha)	21,735.97	18,251.73	14,421.25	1,372.55	140,782.20
Hired Labor (days)	7.35	0.00	18.77	0.00	197.68
Fertilizer (index Rs./ha)	3,760.11	3,323.59	2,926.60	0.00	23,300.35
Groundwater (hours/ha)	47.21	24.71	110.40	0.00	1,976.84
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)	5,560.94	3,364.77	10,582.67	344.24	140,338.90
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

Note: Descriptive statistics calculated from 469 observations.

ESTIMATION RESULTS

Results from the Pooled Sample

The translog production function contains second-order terms for all inputs. Therefore, the individual parameter estimates can be difficult to interpret. As an alternative, Table 12 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:

$$E_n = \beta_n + \sum_k \beta_{nk} lnx_k + \sum_q \delta_{nq} lnz_q \quad For\ each\ n \quad (7)$$

In the overall sample, groundwater has the largest percentage impact on output per hectare, followed by fertilizer. A 1 percent increase in groundwater per hectare leads to a 0.18 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 nearly 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. The impact of own male labor on output per hectare is negative and significant for owner-cultivators and fixed-rent tenants. This suggests that own male labor is unconstrained on owner-cultivated and fixed-rent farms. However, own female labor has a positive and statistically significant impact on output per hectare on sharecropped plots, which suggests that own female labor is constrained on sharecropped 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. In contrast, the impact of own female labor is greater on small farms.

Groundwater 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.

These results 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 the findings 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 12: Estimated Elasticities of the Variable and Quasi-Fixed Inputs (standard errors in parentheses) across Household Groups

	Overall		
Hired Labor	0.00047***		
	(0.00003)		
Fertilizer	0.10782***		
	(0.01008)		
Groundwater	0.17554***		
	(0.01108)		
Own Male Labor	-0.01710		
	(0.01200)		
Own Female Labor	0.07404*		
	(0.04134)		
Capital	-0.01692		
	(0.01574)		
Surface Water	0.00709		
	(0.01141)		
	Owner cultivated	**Fixed-rent**	**Sharecropped**
Hired Labor	0.00045***	0.00044***	0.00053***
	(0.00004)	(0.00004)	(0.00004)
Fertilizer	0.11064***	0.10935***	0.10454***
	(0.01034)	(0.01022)	(0.00978)
Groundwater	0.24946***	0.26402***	0.01110***
	(0.01565)	(0.01656)	(0.00174)
Own Male Labor	-0.03095**	-0.02921**	0.01752
	(0.01328)	(0.01278)	(0.01388)
Own Female Labor	0.08022	0.07948	0.05744**
	(0.05695)	(0.05704)	(0.02414)
Capital	-0.01903	-0.02039	-0.01085
	(0.01750)	(0.01793)	(0.01624)
Surface Water	0.00290	0.00345	0.01470
	(0.01355)	(0.01382)	(0.04067)

	Small farm (<4 ha)	Medium farm (4 to 10 ha)	Large farm (>10 ha)
Hired Labor	0.00047***	0.30911***	0.32900***
	(0.00003)	(0.01067)	(0.01136)
Fertilizer	0.10812***	0.10640***	0.10770***
	(0.01011)	(0.00995)	(0.01007)
Groundwater	0.18628***	0.09995***	0.22212***
	(0.01174)	(0.00648)	(0.01398)
Own Male Labor	-0.01535	-0.00851	-0.00525
	(0.01260)	(0.01134)	(0.01203)
Own Female Labor	0.07108**	0.07405	0.07441
	(0.03126)	(0.05608)	(0.05615)
Capital	-0.01779	-0.01388	-0.01268
	(0.01544)	(0.01657)	(0.01685)
Surface Water	0.00837	0.00717	0.00892
	(0.01307)	(0.01254)	(0.01329)

	With surface water	Without surface water
Hired Labor	0.00052***	0.00046***
	(0.00004)	(0.00004)
Fertilizer	0.10686***	0.10970***
	(0.00999)	(0.01025)
Groundwater	0.00998***	0.27428***
	(0.00150)	(0.01725)
Own Male Labor	-0.01772	0.00178
	(0.01288)	(0.01409)
Own Female Labor	0.07870*	0.05880
	(0.04260)	(0.03884)
Capital	-0.01523	-0.01761
	(0.01579)	(0.01802)
Surface Water	0.00699	0.00987
	(0.01291)	(0.04076)

	Kharif	Rabi
Hired Labor	0.28784***	0.00045***
	(0.00993)	(0.00003)
Fertilizer	0.10662***	0.10905***
	(0.00997)	(0.01020)
Groundwater	0.00994***	0.24049***
	(0.00150)	(0.01511)
Own Male Labor	-0.01505	-0.01596
	(0.01270)	(0.01165)
Own Female Labor	0.07661*	0.07173*
	(0.04116)	(0.04266)
Capital	-0.01477	-0.01805
	(0.01542)	(0.01611)
Surface Water	0.00736	0.00708
	(0.01135)	(0.01309)

Note: Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Technical Efficiency

The technical efficiency estimates are producer specific. Table 13 reports descriptive statistics on technical efficiency decomposed across different groups of households.

Table 13: Estimates of Technical Efficiency (standard errors of the means in parentheses)

	Mean	Median	Min	Max
Overall	0.25 (0.00)	0.20	0.01	1.00
Owner-Cultivated	0.22 (0.01)	0.17	0.01	0.99
Sharecropped	0.30 (0.01)	0.25	0.02	1.00
Fixed-Rent	0.23 (0.02)	0.18	0.01	0.80
Small Farm (<4 ha)	0.24 (0.00)	0.19	0.01	1.00
Medium Farm (4 to 10 ha)	0.27 (0.01)	0.22	0.01	0.98
Large Farm (>10 ha)	0.27 (0.02)	0.22	0.02	0.99
With Surface Water	0.28 (0.01)	0.22	0.01	1.00
Without Surface Water	0.19 (0.00)	0.17	0.01	0.90
Head of Watercourse	0.28 (0.01)	0.24	0.01	1.00
Middle of Watercourse	0.27 (0.01)	0.21	0.01	0.99
Tail of Watercourse	0.25 (0.01)	0.19	0.02	1.00
Rabi	0.24 (0.01)	0.19	0.02	0.99
Kharif	0.26 (0.01)	0.21	0.01	1.00

The overall mean technical efficiency of the households in the sample is 25 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 higher than the mean and median technical efficiencies of owner-cultivators and fixed-rent tenants. The median technical efficiency of sharecroppers is 8 percentage points higher than the median technically efficiency of owner-cultivators. We plot the cumulative distribution functions of technical efficiency across tenure type in Figure 1 in order to determine 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

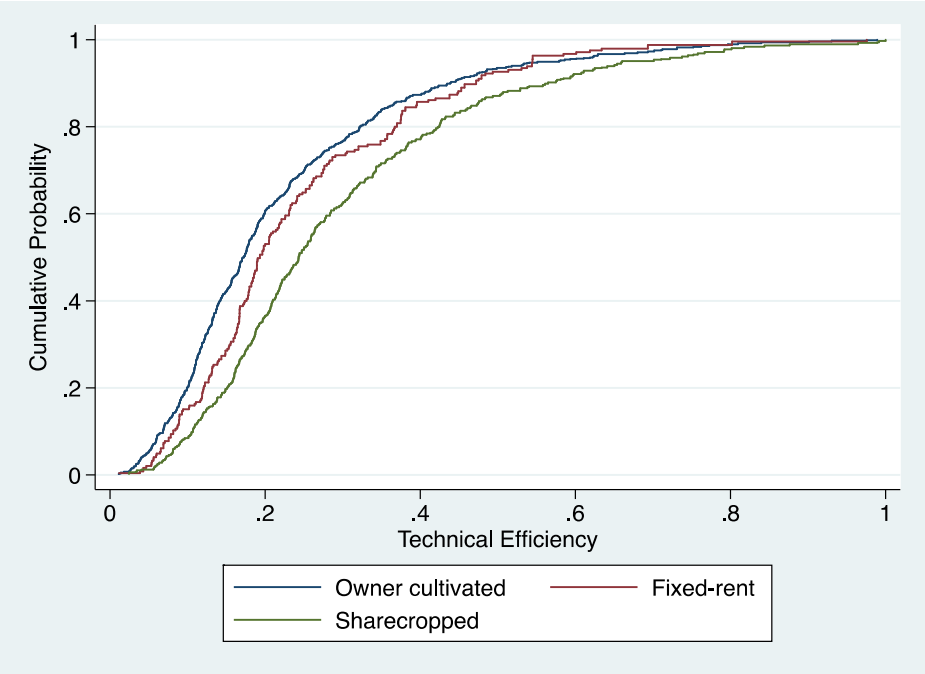
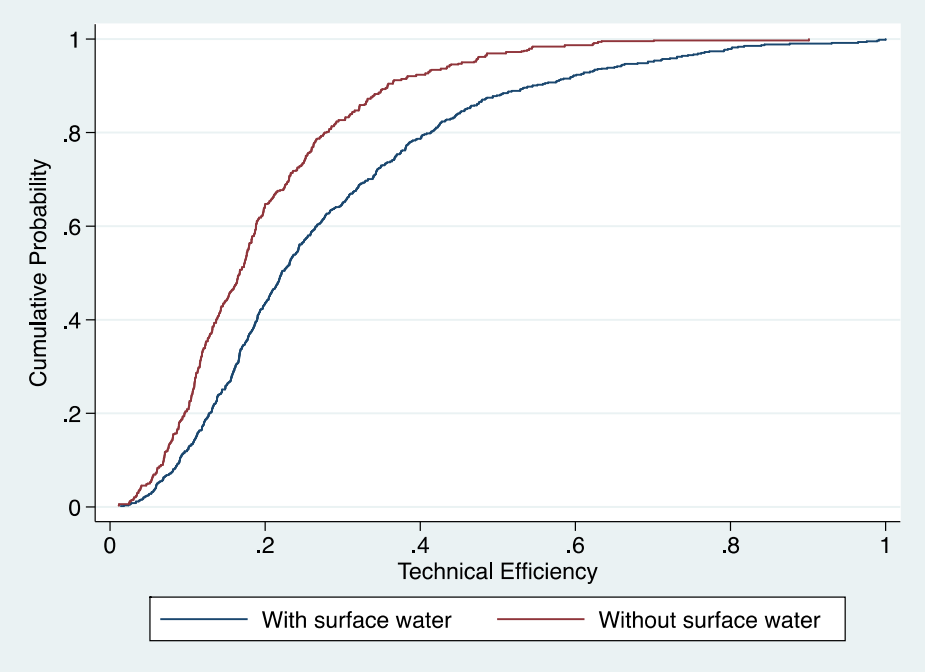


Figure 1 shows that the cumulative distribution function of technical efficiency for sharecroppers lies everywhere to the right of the cumulative distributions of owner-cultivators and fixed-rent tenants. The distributions for owner-cultivators and fixed-rent tenants are similar at all levels of technical efficiency. The figure shows that in comparison to the 48 percent of sharecroppers that operate at a technical efficiency level of 25 percent or higher, only 30 percent and 35 percent of owner-cultivators and fixed-rent tenants operate above that level. This is an important finding that is consistent with Jacoby and Mansuri (2009), who do not find evidence of significant differences in the productivity of sharecroppers and owner-cultivators in Pakistan. These 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. The mean and the median values differ by 9 and 5 percentage points, respectively, 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 of technical efficiency for households with surface water dominates the distribution for households without surface water at all levels of technical efficiency. The figure shows that about 40 percent of households with surface water operate at a technical efficiency level of 0.25 or more, while only around 20 percent of households without surface water operate at a similar level.

Table 13 also shows that technical efficiency of farms differs by the location of the farms on a watercourse. Farms located at the head of the watercourse and at the middle of the course have higher mean and median technical efficiency than farms located at the tail of a watercourse. The median technical efficiency of farms located at the head of the watercourse is 6 percentage points higher than the technical efficiency of farms located at the tail of the watercourse. The difference in technical efficiency among farms' locations along the water course should be attributed to water availability of farms at those locations, which is a result of the water allocation institution in Pakistan.

Our estimates of technical efficiency are lower than estimates in 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 (KP) 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, tends to produce lower estimates of technical efficiency compared with 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 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.

Allocative Efficiency of Groundwater

Table 14 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 14: Estimates of Allocative Efficiency of Groundwater (standard errors of the means in parentheses)

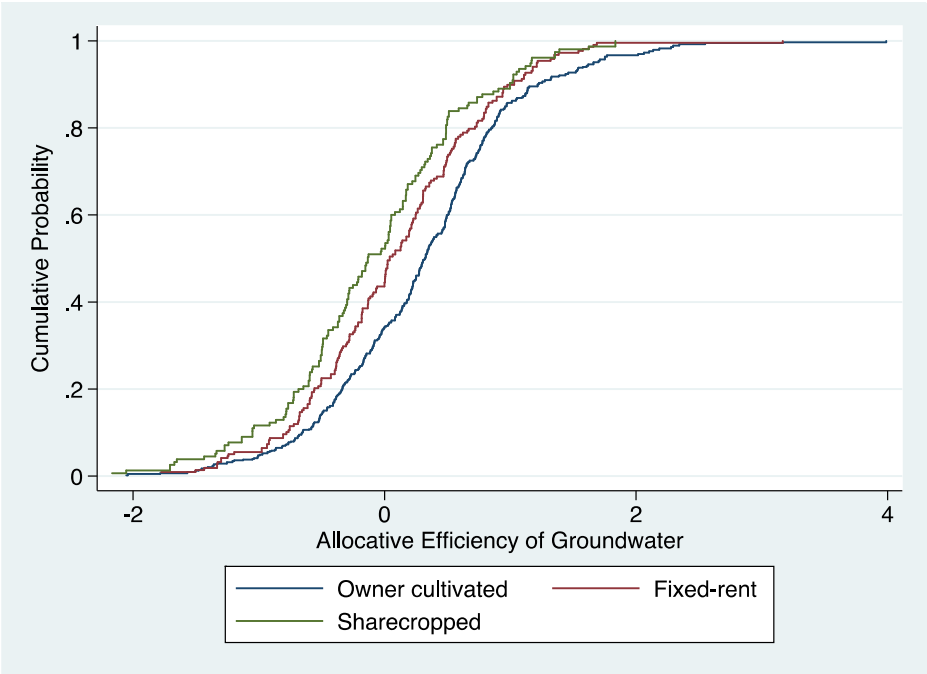
	Mean	Median	Min	Max
Overall	0.20 (0.02)	0.22	-2.17	3.99
Owner-Cultivated	0.31 (0.03)	0.32	-2.05	3.99
Sharecropped	-0.09 (0.08)	-0.15	-2.17	1.84
Fixed-Rent	0.04 (0.09)	0.06	-1.78	3.17
Small Farm (<4 ha)	0.28 (0.03)	0.27	-2.17	3.99
Medium Farm (4 to 10 ha)	-0.06 (0.07)	-0.05	-2.04	3.99
Large Farm (>10 ha)	-0.13 (0.10)	-0.13	-2.05	1.35
With Surface Water	0.07 (0.04)	0.06	-2.17	2.55
Without Surface Water	0.32 (0.03)	0.30	-1.57	3.99
Head of Watercourse	0.10 (0.08)	0.12	-2.05	2.06

Middle of Watercourse	0.07	0.08	-2.04	2.34
	(0.05)			
Tail of Watercourse	0.25	0.28	-2.17	2.55
	(0.04)			
Rabi	0.06	0.13	-2.05	2.10
	(0.03)			
Kharif	0.39	0.36	-2.17	3.99
	(0.05)			

Table 14 shows that the mean and median allocative efficiency are greater than zero: 0.20 and 0.22, 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 underutilize it. At the mean and median values of allocative efficiency, fixed-rent tenants are more efficient than owner-cultivators and sharecroppers. 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 suggests 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, had access to groundwater.[13]

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

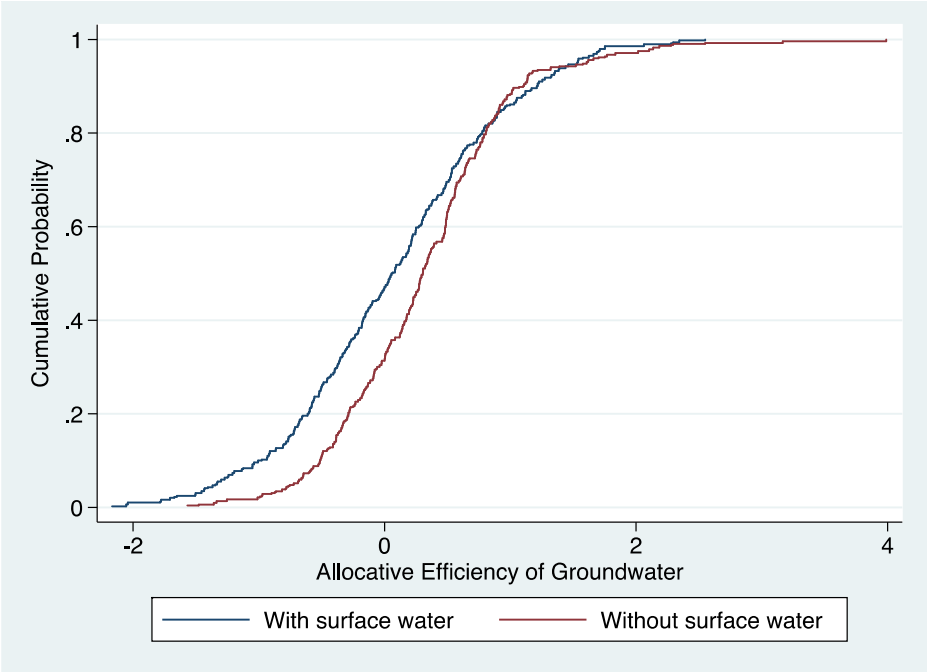


[13] These are shares of owner-cultivators and sharecroppers that have access to groundwater. The shares of owner-cultivators and sharecroppers that use groundwater are 67 percent and 24 percent, respectively.

Table 14 also shows that, on average, farmers with medium-sized farms allocate groundwater efficiently. The mean and median allocative efficiencies are quite close to zero. Small and large farmers, in contrast, are allocatively inefficient. The former over-utilize groundwater while the latter underutilize groundwater on average.

Farms with access to surface water are, on average, more allocatively efficient than farms without surface water, although 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. Nearly 75 percent of farms without surface water over-utilize groundwater. Farms with surface water are much more evenly balanced between over- and underutilization, 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

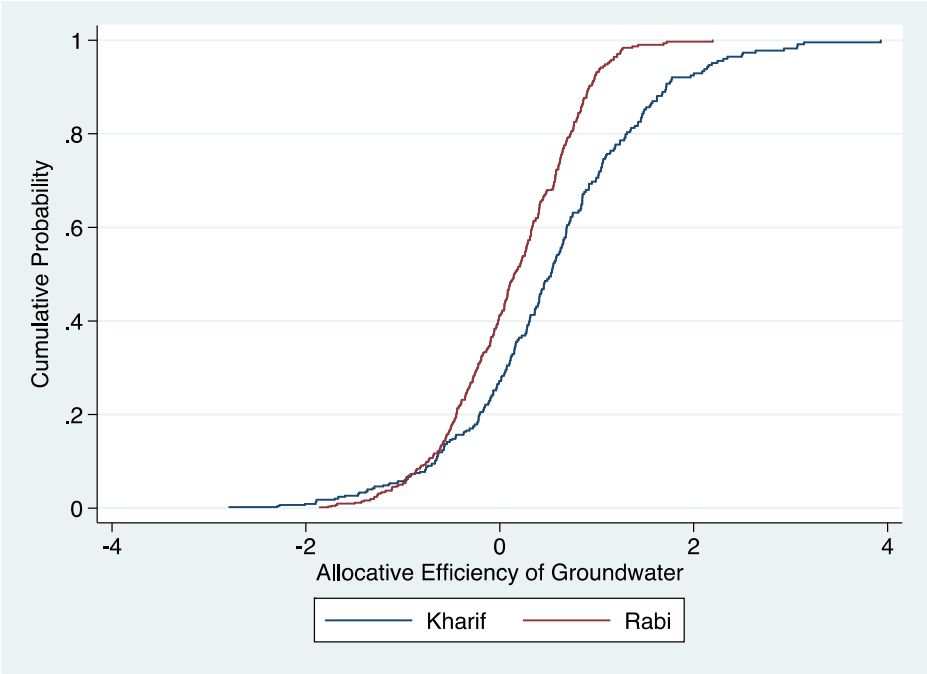


The allocative efficiency of groundwater varies by the location of the farms on a watercourse. However, farms at all three locations of a watercourse (head, middle and tail) tend to over-utilize groundwater. At the mean and median values of allocative efficiency, farms located at the middle of a watercourse are more efficient than farms located at the head and the tail of a watercourse. Farms at the tail of a watercourse are, on average, the most allocatively inefficient. Farms at the tail of a watercourse have a less reliable supply of surface water compared to farms located further up the watercourse and might compensate for the unreliable surface water supply by applying more groundwater.

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 intense crops) in

kharif, and wheat (low water intense 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

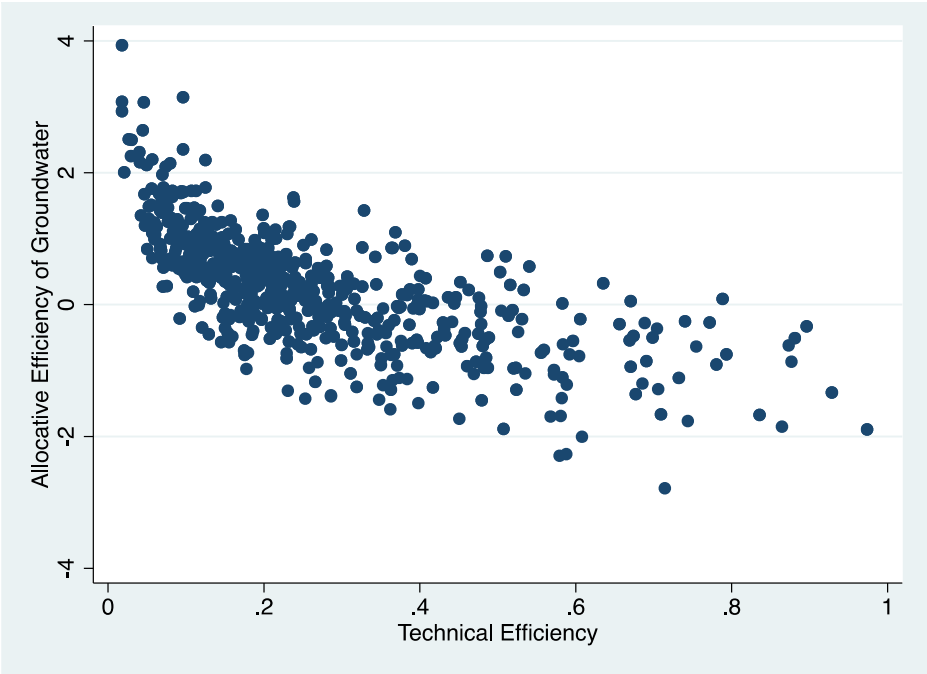


The allocative and technical efficiency estimates seem to follow a similar pattern. Sharecroppers on average tend to be more technically and allocatively efficient than owner-cultivators. Similarly, farms with access to surface water are more allocatively and technically efficient than farms without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

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 (0.25) 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 underutilize 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.

Figure 6: Allocative Efficiency versus Technical Efficiency for all Households



Results from the Kharif and Rabi Samples

Tables B1 (appendix B) and C1 (appendix C) show the elasticities of the variable inputs and quasi-fixed inputs in the kharif and rabi samples. The elasticities are calculated at the median values of the inputs and are reported across the overall samples and several household characteristics. In the overall samples fertilizer has the largest impact (0.78) in kharif while groundwater has the largest impact (0.30) in rabi. Groundwater does not have a statistically significant impact on output per hectare in kharif. The elasticity of own male labor is statistically significant and positive in rabi suggesting that own male labor is constrained on farms in the rabi. Moreover, the overall samples show that surface water has a positive and significant impact (0.04) on output per hectare in rabi. This implies that surface water is constrained on farms in rabi. These results show that a marginal increase in the use of both groundwater and surface water would have a significant impact on land productivity in rabi only.

Across tenure, groundwater has the largest impact on output per hectare on owner-cultivated and fixed-rent farms when rabi farmers are considered. The elasticity of groundwater is zero across all types of tenure in kharif. Surface water has a significant impact on output per hectare on owner-cultivated and sharecropped farms in rabi. Moreover, the elasticity of capital is positive and significant for sharecropped farms in rabi.

When elasticities are compared across farm size, the impact of hired labor is larger on medium and large farms. This impact is significantly more pronounced in rabi. The impact of groundwater on output per hectare is similar across small, medium and large farms in rabi and is zero across the three farm sizes in kharif. The elasticity of surface water is also significant and similar in rabi and equal to zero in kharif across small, medium and large farms.

Groundwater per hectare has the largest impact on land productivity on rabi farms with surface water. The impact of groundwater on output per hectare in kharif is zero on farms with and without surface water. Table C1 also shows that surface water has a significant impact on output per hectare on farms without surface water. These are farms that are not located on the watercourse and are most likely irrigated with surface water purchased from neighboring farms.

The results from the separate seasons show that a marginal increase in the use of both groundwater and surface water would have a significant impact on land productivity in rabi only. These inputs are not constrained in kharif and a marginal increase in these inputs in kharif will not have a positive impact on output per hectare. Fertilizer, on the other hand, has a significantly larger impact on land productivity in kharif than in rabi. Output per hectare in kharif would benefit from a marginal increase in the use of fertilizer.

Technical Efficiency (Season Samples)

Tables B2 and C2 present the producer-specific technical efficiency estimates from the kharif and rabi samples across different household characteristics. In kharif the overall mean technical efficiency of households is 18 percent while in rabi the overall mean technical efficiency of households is 26 percent. The mean and median technical efficiency of sharecroppers is higher than the mean and median technical efficiency of owner-cultivators and fixed-rent tenants in kharif. In rabi the mean technical efficiency of fixed-rent tenants is higher than the mean technical efficiency of sharecroppers and owner-cultivators. However, at the median values of technical efficiency sharecroppers are more technically efficient than owner-cultivators and fixed-rent tenants.

In Figures B1 and C1 we plot the cumulative distribution functions of technical efficiency in kharif and rabi across tenure type. The distribution of technical efficiency for sharecroppers lies to the right of the distribution of technical efficiency for owner-cultivators in both seasons. In kharif, 40 percent of sharecroppers and 20 percent of owner-cultivators operate at a technical efficiency level of 20 percent or higher. In rabi, on the other hand, 70 percent of sharecroppers and 50 percent of owner-cultivators operate at a technical efficiency level of 20 percent or higher.

Tables B2 and C2 also show that the differences in the mean and median technical efficiencies across farm size and access to surface water are more pronounced in rabi than in kharif. Households with large farms in rabi are 9 percent (at the mean) and 12 percent (at the median) more technically efficient than households with small farms in rabi. In kharif the mean technical efficiency of households with medium farms is a percentage point greater than the mean technical efficiency of households with large farms. At the median, the technical efficiency of households with medium farms is a percentage point lower than the technical efficiency of households with large farms. Households with small farms in both seasons have the lowest mean and median values of technical efficiency.

The mean technical efficiency of households in rabi with access to surface water is 11 percent higher than the mean technical efficiency of households in rabi without access to surface water. This difference falls to 9 percent when the median values of technical efficiency are considered. In kharif the differences in the mean and

median technical efficiency of households with surface water and households without surface water are 3 percent and 2 percent respectively. Figures B2 and C2 show the plots of the cumulative distribution functions of technical efficiency in kharif and rabi across access to surface water. The gap in the distributions is more pronounced in rabi compared to kharif. In rabi, 75 percent of households with access to surface water and 45 percent of households without access to surface water operate at a technical efficiency level of 0.2 percent or higher. However, in kharif this difference is only 15 percent at the same level of technical efficiency.

When the location of the farms on a watercourse is considered, households with farms located at the head of the watercourse in kharif are 3 percent (at the mean) and 4 percent (at the median) more technically efficient than households with farms located at the tail of the watercourse. In rabi the mean technical efficiency of households with farms located at the middle of the watercourse is 2 percent higher than the mean technical efficiency of households with farms located at the head of the watercourse. However, at the median value the technical efficiency of households with farms located at the head of the watercourse is a percentage point greater than the technical efficiency of households with farms located at the middle of the watercourse. In both seasons, households with farms located at the tail of the watercourse have the lowest mean and median technical efficiency. The mean technical efficiency of households located at the tail of the watercourse in rabi is 7 percent higher than the mean technical efficiency of households located at the head of the watercourse in kharif. This demonstrates the superior technical efficiency of households in rabi compared to households in kharif.

Allocative Efficiency (Season Samples)

Tables B3 and C3 show the estimates of the allocative efficiency of groundwater from the kharif and rabi samples across several household characteristics. On average, households in kharif over-utilize groundwater while households in rabi underutilize groundwater. The median value of efficiency suggests that households are allocatively efficient in rabi.

The estimates across tenure show that owner-cultivators, sharecroppers and fixed-rent tenants over-utilize groundwater in kharif although sharecroppers tend to be more allocatively efficient than owner-cultivators and fixed-rent tenants. In rabi owner-cultivators over-utilize groundwater while sharecroppers and fixed-rent tenants underutilize groundwater. Owner-cultivators are more efficient than sharecroppers and fixed-rent tenants at both the mean and median values of allocative efficiency. The differences in allocative efficiency across tenure in kharif and rabi are explored further through the cumulative distributions given in figures B3 and C3. Figure B3 shows that all households under each type of tenure over-utilize groundwater in kharif. Figure C3 on the other hand shows that in rabi 60 percent of owner-cultivators over-utilize groundwater compared to sharecroppers.

Results across farm size show that in kharif large farms are more allocatively efficient than small and medium farms. In rabi, however, small farms are more allocatively efficient, compared to medium and large farms. Groundwater is over-utilized in kharif across all farm sizes. In rabi, groundwater is on average underutilized across all farm sizes. However, at the median value of efficiency small farms in rabi tend to over-utilize groundwater.

The results of allocative efficiency across access to surface water differ across seasons, as well. In kharif, households with access to surface water and households without access to surface water over-utilize groundwater, although the former group tends to be more allocatively efficient. In rabi, households with surface water tend to underutilize groundwater while households without surface water tend to over-utilize ground water. Figure B4 presents the cumulative distribution of allocative efficiency across access to surface water in rabi. The figure shows that 60 percent of households in rabi without access to surface water over-utilize groundwater, compared to 30 percent of households in rabi with access to surface water.

The estimates across location on a watercourse show that households with farms located at the head, middle and tail of the watercourse over-utilize groundwater in kharif. The mean allocative efficiency of groundwater is similar for households with farms at the head and the middle of the watercourse. Households with farms at the tail of the watercourse are more allocatively inefficient compared to households with farms located at the head and the middle of the watercourse. In rabi, households, on average, underutilize groundwater across all

three locations on a watercourse (head, middle and tail). At the median value of allocative efficiency households with farms located at the tail of the watercourse tend to over utilize groundwater. Households with farms located at the head of the watercourse are on average more allocatively efficient than households with farms located at the tail of the watercourse. However, when the median value of allocative efficiency is considered, households located at the tail of the watercourse are more allocatively efficient than households with farms located at the head of the watercourse.

The results of the allocative efficiency of groundwater by season and across different household characteristics show that all farmers in kharif over utilize groundwater. In rabi, a part of the distribution of allocative efficiency lies to the right of zero, which shows that some farmers underutilize groundwater in rabi. Policies designed to improve the allocative efficiency of groundwater need to take into account the differences in groundwater use across seasons.

SUMMARY AND CONCLUSIONS

This paper provided an empirical analysis of groundwater use in Pakistan's agricultural sector. Using a rural household panel dataset from Pakistan, which spans over 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. 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. The results of these simulations will be reported in a separate paper.

Pakistan's agrarian structure was examined across two provinces, two seasons, and two periods. 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.

The discussion on tenancy emphasized the importance and structure of tenure arrangements in Punjab and Sindh. It showed that owner-cultivation was the most common form of tenancy in Punjab and Sindh, 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 Punjab and Sindh, accounting for around 34 percent of the plots in PRHS-I. Fixed-rent tenancy, in contrast, comprised only around 10 percent 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 over time, although a modest decline in the importance of sharecropping was observed. 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 percent of plots had access to groundwater, 70 percent had access to surface water, and 50 percent had access to both. Overall, 85 percent of the agricultural plots in Punjab and Sindh had access to surface water, groundwater or both.

The paper also presents evidence on the availability of both forms of irrigation water in Punjab and Sindh, according to the position of the farms on the watercourse. 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 from the pooled sample 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. When the model was estimated for each season separately, the impact of groundwater on land productivity was not statistically significant. However, groundwater per hectare had the largest marginal impact on land productivity in rabi. The effect of surface water became pronounced in the rabi sample but was zero in the kharif sample. 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 in the future.

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, farm size, access to surface water and location on a watercourse. Allocative efficiency measures the extent to which the marginal product of an input differs from the price of the input. The inability of farmers to adjust to changes in relative input prices might 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 additional constraints on farmers. Future policy work will focus on examining the effect of these farm-level differential constraints 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. Since groundwater use depends on the availability of surface water, in future policy work we will simulate the effect of increasing the access to surface water on the allocative efficiency of groundwater.

The allocative efficiency of groundwater is also related to the location of the farms on a watercourse. Farms located at the head of the watercourse tend to be more allocatively efficient than farms located at the tail of the watercourse. Since the allocation of surface water is uniform (fixed per unit of land) across all locations of a watercourse, farmers located at the tail of the watercourse are at a disadvantage given the unreliable supply of surface water. Simulating the impact of a more equitable allocation of surface water across head and tail-end users on farms operations could shed light on the impact of such policy on changes in the allocative efficiency of 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 needs – 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. The policy simulations proposed above will take into account the seasonal differences in farm operations and farm-level constraints.

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 trade-off. 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 will take these interactions into account.

This paper 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 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.

REFERENCES

Abdulai, A. and H. Tietje (2007). Estimating technical efficiency under unobserved heterogeneity with stochastic frontier models: application to northern German dairy farms. *European Review of Agricultural Economics* 34: 393- 416.

Alene, A.D. and R.M. Hassan (2006). The efficiency of traditional and hybrid maize production in eastern Ethiopia: an extended efficiency decomposition approach. *Journal of African Economies* 15: 91-116.

Ali, F., A. Parikh and M.K. Shah (1994). Measurement of profit efficiency using behavioral and stochastic frontier approaches. *Journal of Applied Economics* 26: 181-188.

Battese, G.E. and S.S. Broca (1997). Functional forms of stochastic frontier production functions and models for technical inefficiency effects: a comparative study for wheat farmers in Pakistan. *Journal of Productivity Analysis* 8: 395-414.

Battese, G.E., S.J. Malik and M.A. Gill (1996). An investigation of technical inefficiencies of production of wheat farmers in four districts of Pakistan. *Journal of Agricultural Economics* 47: 37-49.

Briscoe, J. and U. Qamar (2006). *Pakistan's Water Economy: Running Dry*. Oxford University Press: Karachi.

Burki, A.A. and H.N. Shah (1998). Stochastic frontier and technical efficiency of farms in irrigated area of Pakistan's Punjab. *The Pakistan Development Review* 37: 275-291.

Cheema, A. and F. Naseer (2010). Poverty, mobility, and institutions in rural Sargodha: evidence for social protection reform. Report submitted to the Planning and Development Department (P&DD) of the Government of Punjab.

Chen, Z., W. Huffman and S. Rozelle (2009). Farm technology and technical efficiency: evidence from four regions in China. *China Economic Review* 20: 153–161.

Coelli, T., D. Rao, C.J. O'Donnell and G.E. Battese (2005). *An Introduction to Efficiency and Productivity Analysis*. New York: Springer.

Dinar, A., G. Karagiannis and V. Tzouvelekas (2007). Evaluating the impact of agricultural extension on farms' performance in Crete: a nonneutral stochastic frontier approach. *Agricultural Economics* 36: 135-146.

Dinar, A., T. Balakrishnan and J. Wambia (2004). Politics of institutional reforms in the water and drainage sector of Pakistan. *Environment and Development Economics* 9: 409-445.

Greene, W. (2008). The econometric approach to efficiency analysis Chapter 2 in *The Measurement of Productivity and Efficiency*, Oxford: Oxford University Press.

Government of Pakistan Statistics Division (2003). *Pakistan Agricultural Census 2000*. Lahore: Government of Pakistan Statistics Division Agriculture Census Organization.

Government of Pakistan Statistics Division (2012). *Pakistan Agricultural Census 2010*. Lahore: Government of Pakistan Statistics Division Agriculture Census Organization.

Government of Pakistan Planning Commission (2011). *Framework for Economic Growth.*

Hussain, I. ed. (2004). *Pro-poor Intervention Strategies in Irrigated Agriculture in Asia Poverty in Irrigated Agriculture: Issues and Options, Pakistan. Colombo and Manila*: IWMI and ADB.

Hussain, I., F. Marikar and W. Jehangir (2000). Productivity and performance of irrigated wheat farms across canal commands in the lower Indus Basin. *Research Report 44.* International Water Management Institute (IWMI), Colombo: IWMI.

Idiong, I.C. (2007). Estimation of farm level technical efficiency in small scale swamp rice production in cross river state of Nigeria: a stochastic frontier approach. *World Journal of Agricultural Sciences* 3: 653-658.

Jacoby, H. and G. Mansuri (2009). Incentives, supervision, and sharecropper productivity. *Journal of Development Economics* 88: 232-241.

Jacoby, H., R. Murgai and S.U. Rehman (2004). Monopoly power and distribution in fragmented markets: the case of groundwater. *Review of Economic Studies* 71: 783–808.

Kumbhakar, S.C. and C.A.K. Lovell (2000). *Stochastic Frontier Analysis*. Cambridge: Cambridge University Press.

Kumbhakar, S.C. and H.J. Wang (2006). Estimation of technical and allocative inefficiency: A primal system approach. *Journal of Econometrics* 134: 419–440.

Liu, Y. and R. Myers (2009). Model selection in stochastic frontier analysis with an application to maize production in Kenya. *Journal of Productivity Analysis* 31: 33–46.

Magalhães, M.M.D., H.M. Filho, M.R. Sousa, J.M. Silveira and A. Buainain (2011). Land reform in northeast Brazil: a stochastic frontier production efficiency evaluation. *Revista de Economia e Sociologia Rural* 49: 9-30.

Mahmood, M. (1999). Reforming the agrarian land market. In R. Faruqee (ed.), *Strategic Reform for Agricultural Growth in Pakistan* (69-86). Washington, DC: the World Bank.

Otsuka, K. and Y. Hayami (1988). Theories of share tenancy: a critical survey. *Economic Development and Cultural Change* 57: 31-68.

Qureshi, A.S. (2012). Personal Communication. Interview in Lahore, Pakistan, August 2012.

Qureshi, A.S., H. Turral and I. Masih (2004). Strategies for the management of conjunctive use of surface water and groundwater resources in semi-arid areas: a case study from Pakistan. *IWMI Research Report 86*. Colombo: International Water Management Institute.

Rahman, S. (2003). Profit efficiency among Bangladeshi rice farmers. *Food Policy* 28: 487–503.

Revoredo-Giha, C., C.E. Milne, P.M.K. Leat and W. Cho (2009). Efficiency of Scottish farms: a stochastic cost frontier analysis. *Agricultural Economics Review* 10: 17-35.

Shah, T., M. Hassan, M.Z. Khattak, P.R. Banerjee, O.P. Singh and S. Rehman (2009). Is irrigation water free? A reality check in the Indo-Gangetic Basin. *World Development* 37: 422–34.

State Bank of Pakistan (2010). *Handbook of Statistics on Pakistan Economy*. Karachi: State Bank of Pakistan.

Thiam, A., B.E. Bravo-Ureta and T. Rivas (2001). Technical efficiency in developing country agriculture: a meta-analysis. *Agricultural Economics* 25: 235–43.

World Bank (2006). *Pakistan Strategic Country Environmental Assessment*. Washington DC: The World Bank.

APPENDIX A

In the tables below, PRHS-I(a) includes observations only from Punjab and Sindh, and PRHS-I(b) includes observations only from Khyber-Pakhtunkhwa (KP) and Balochistan.

Table A1: 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	1,383	919	464	814

Table A2: 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	1,383	919	464	814

Table A3: 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	8,000	1,376	8,000	1,880

Table A4: 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	1,307	871	436	811

Table A5: 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	3,519	2,357	1,162	1,917

Table A6: Tenure Classification

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	1,749	1,228	521	1,213
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	1,817	1,229	588	1,210

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	2,057	1,591	466	1,583
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	2,138	1,578	560	1,563

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-Culti-vated	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 1,041 owner-cultivated, 147 fixed-rent, and 346 sharecropped plots

PRHS-I(a)

Tenure in Kharif (2000)	Tenure in Rabi 2001		
	Owner-Culti-vated	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-Culti-vated	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-Culti-vated	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

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 Sharecrop-pers
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 Sharecrop-pers
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 Sharecrop-pers
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 Rabi 2004	
Tenure in Kharif (2003)	Leased-In by Fixed-Rent Tenants	Leased-In by Sharecrop-pers
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		

Table A7: Share of Area and Plot Size

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

Plot Size by Tenure Status (Kanals)

PRHS-I				
	Mean	Median	Standard Devi-ation	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 Devi-ation	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 Devi-ation	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 Devi-ation	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 A8: 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	3,507	2,355	1,152	1,917

Table A9: Plot Location and Watercourse

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	1,742	1,569	173	1,393

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

PRHS-I

	Location on Watercourse			
Canal Irrigation	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 1,741 plots[14]

PRHS-I(a)

	Location on Watercourse			
Canal Irrigation	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 1,568 plots

PRHS-I(b)

	Location on Watercourse			
Canal Irrigation	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

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

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 1,393 plots

Table A10: Plots and Irrigation

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	3,328	2,256	1,072	1,917

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 1,733 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 1,560 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

	Location on Watercourse			
Groundwater Irrigation	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 1,393 plots

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 3,317 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 2,255 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

Canal Irrigation	Groundwater 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 1,917 plots

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

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

APPENDIX B

Estimation results from the sample restricted to households observed only in kharif are given below.

Table B1: Estimated Elasticities of the Variable and Quasi-Fixed Inputs (standard errors in parentheses) across Household Groups

	Overall		
Hired Labor	0.02*		
	(0.01)		
Fertilizer	0.78***		
	(0.02)		
Groundwater	0.00		
	(0.00)		
Own Male Labor	-0.05***		
	(0.01)		
Own Female Labor	0.02		
	(0.05)		
Capital	-0.01		
	(0.02)		
Surface Water	-0.02		
	(0.02)		
	Owner cultivated	**Fixed-rent**	**Sharecropped**
Hired Labor	0.02*	0.02*	0.00*
	(0.01)	(0.01)	(0.00)
Fertilizer	0.81***	0.80***	0.77***
	(0.02)	(0.02)	(0.02)
Groundwater	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)
Own Male Labor	-0.05***	-0.05***	-0.04***
	(0.02)	(0.01)	(0.01)
Own Female Labor	0.02	0.02	0.03
	(0.07)	(0.07)	(0.03)
Capital	-0.01	-0.01	-0.02
	(0.02)	(0.02)	(0.02)
Surface Water	0.00	0.00	-0.08
	(0.02)	(0.02)	(0.08)
	Small farm (<4 ha)	**Medium farm (4 to 10 ha)**	**Large farm (>10 ha)**
Hired Labor	0.00*	0.02*	0.02*
	(0.00)	(0.01)	(0.01)
Fertilizer	0.78***	0.77***	0.79***
	(0.02)	(0.02)	(0.02)
Groundwater	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)
Own Male Labor	-0.05***	-0.04***	-0.02
	(0.01)	(0.01)	(0.01)

Own Female Labor	0.03	0.00	0.01
	(0.04)	(0.07)	(0.07)
Capital	-0.01	-0.02	-0.01
	(0.02)	(0.02)	(0.02)
Surface Water	-0.03	-0.04	-0.00
	(0.03)	(0.03)	(0.02)
	With surface water	**Without surface water**	
Hired Labor	0.02*	0.00*	
	(0.01)	(0.00)	
Fertilizer	0.78***	0.81***	
	(0.02)	(0.02)	
Groundwater	0.00	0.00	
	(0.00)	(0.00)	
Own Male Labor	-0.05***	-0.05***	
	(0.01)	(0.02)	
Own Female Labor	0.02	0.02	
	(0.05)	(0.05)	
Capital	-0.01	-0.03	
	(0.02)	(0.02)	
Surface Water	-0.01	-0.08	
	(0.02)	(0.08)	

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table B2: Estimates of Technical Efficiency (standard errors of the means in parentheses)

	Mean	Median	Min	Max
Overall	0.18	0.15	0.01	1.00
	(0.00)			
Owner-Cultivated	0.16	0.13	0.01	0.86
	(0.01)			
Sharecropped	0.21	0.18	0.03	1.00
	(0.01)			
Fixed-Rent	0.18	0.11	0.04	0.92
	(0.03)			
Small Farm (<4 ha)	0.18	0.14	0.01	1.00
	(0.01)			
Medium Farm (4 to 10 ha)	0.20	0.15	0.01	1.00
	(0.01)			
Large Farm (>10 ha)	0.19	0.16	0.03	0.39
	(0.01)			
With Surface Water	0.19	0.15	0.01	1.00
	(0.00)			
Without Surface Water	0.16	0.13	0.01	0.86
	(0.01)			
Head of Watercourse	0.20	0.18	0.01	0.77
	(0.01)			
Middle of Watercourse	0.19	0.15	0.01	1.00

	(0.01)			
Tail of Watercourse	0.17	0.14	0.01	0.92
	(0.01)			

Figure B1: Cumulative Distribution Functions of Technical Efficiency by Tenancy Type

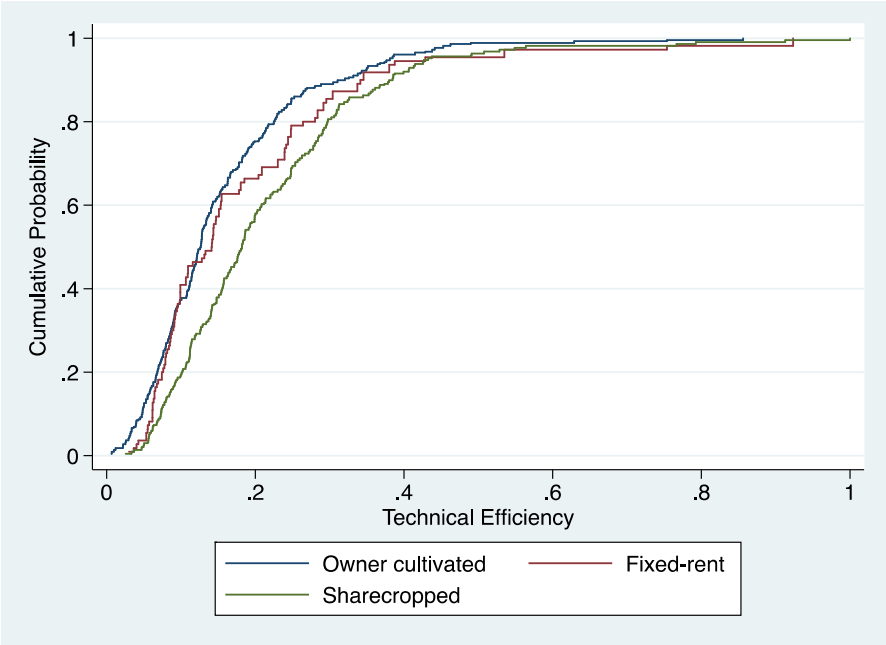


Figure B2: Cumulative Distribution Functions of Technical Efficiency for Households with and without Surface Water

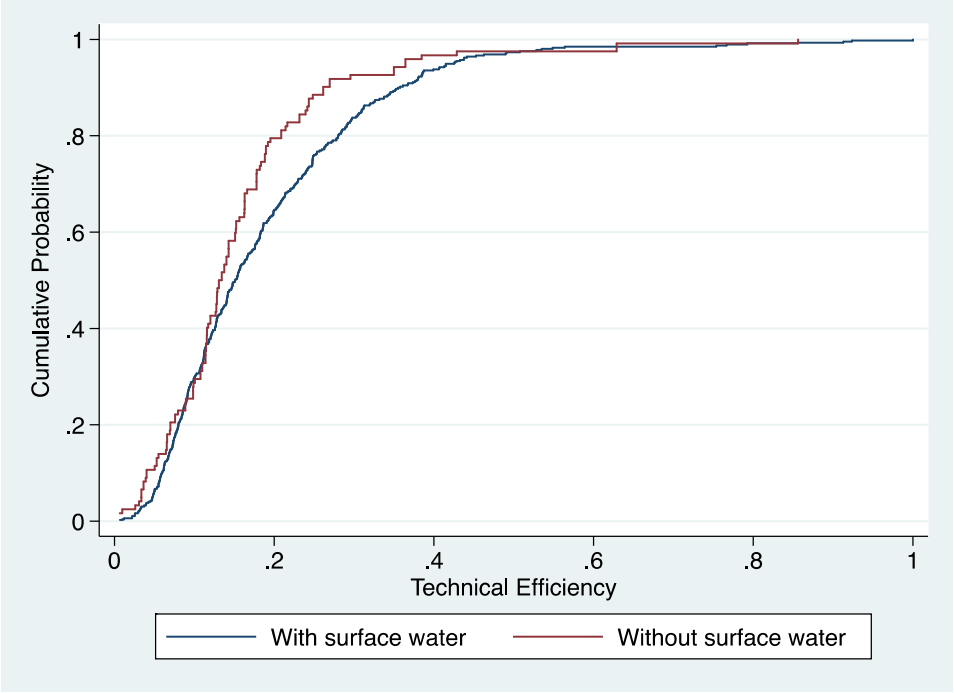


Table B3: Estimates of Allocative Efficiency of Groundwater (standard errors of the means in parentheses)

	Mean	Median	Min	Max
Overall	6.46 (0.05)	6.45	3.87	10.07
Owner-Cultivated	6.59 (0.06)	6.57	4.02	10.07
Sharecropped	5.91 (0.15)	5.68	3.87	7.89
Fixed-Rent	6.48 (0.15)	6.27	5.21	9.10
Small Farm (<4 ha)	6.61 (0.05)	6.56	3.87	10.07
Medium Farm (4 to 10 ha)	6.08 (0.12)	6.14	4.02	10.07
Large Farm (>10 ha)	6.01 (0.13)	5.94	4.18	7.42
With Surface Water	6.36 (0.05)	6.37	3.87	8.63
Without Surface Water	6.69 (0.10)	6.62	4.39	10.07
Head of Watercourse	6.31 (0.13)	6.37	4.34	8.15
Middle of Watercourse	6.31 (0.09)	6.35	4.02	8.42
Tail of Watercourse	6.48 (0.09)	6.44	3.87	8.63

Figure B3: Cumulative Distribution Functions of Allocative Efficiency of Groundwater Across Tenure Systems.

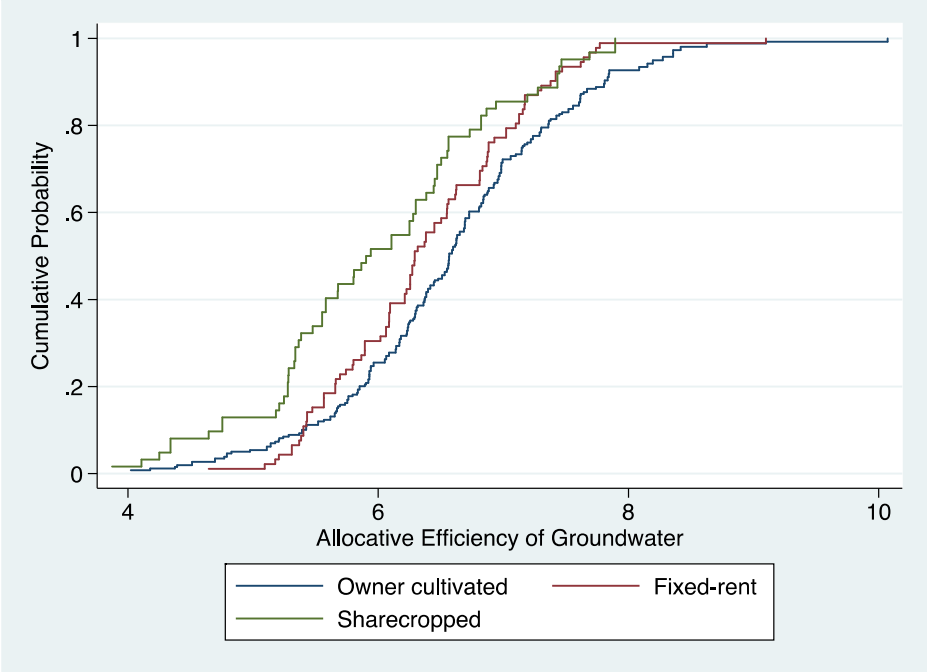
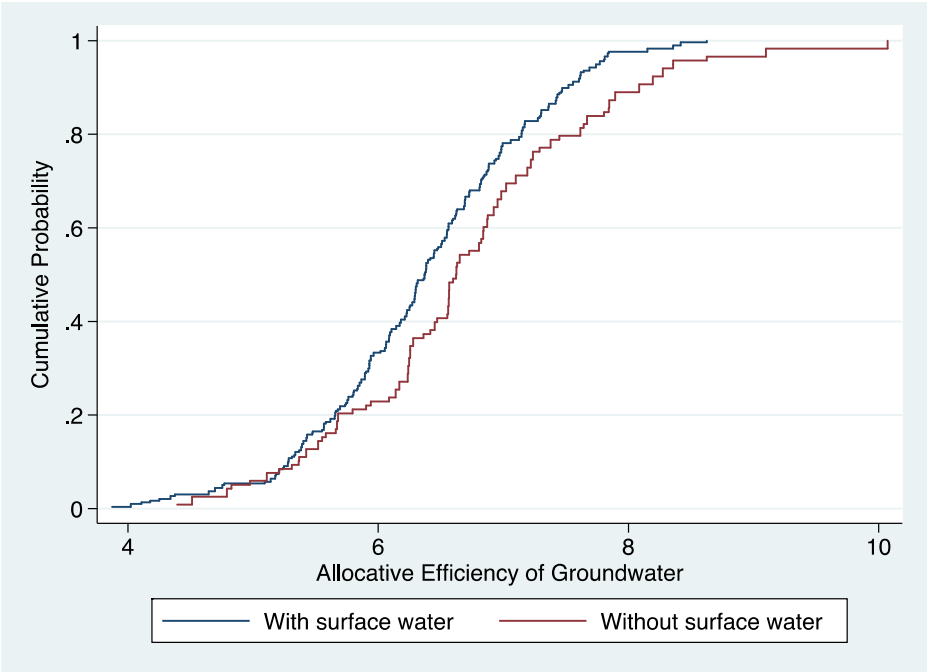


Figure B4: Cumulative Distribution Functions of Allocative Efficiency of Groundwater Across Farms with and without Access to Surface Water.



APPENDIX C

Estimation results from the sample restricted to households observed only in rabi are given below.

Table C1: Estimated Elasticities of the Variable and Quasi-Fixed Inputs (standard errors in parentheses) across Household Groups

	Overall		
Hired Labor	0.00***		
	(0.00)		
Fertilizer	0.06***		
	(0.01)		
Groundwater	0.30***		
	(0.01)		
Own Male Labor	0.05***		
	(0.01)		
Own Female Labor	-0.03		
	(0.03)		
Capital	0.02		
	(0.02)		
Surface Water	0.04***		
	(0.01)		
	Owner-Cultivated	**Fixed-Rent**	**Sharecropped**
Hired Labor	0.00***	0.00***	0.00***
	(0.00)	(0.00)	(0.00)
Fertilizer	0.06***	0.06***	0.06***
	(0.01)	(0.01)	(0.01)
Groundwater	0.32***	0.33***	0.01***
	(0.01)	(0.01)	(0.00)
Own Male Labor	0.05***	0.05***	0.05***
	(0.01)	(0.01)	(0.01)
Own Female Labor	-0.04	-0.04	-0.02
	(0.04)	(0.04)	(0.02)
Capital	0.01	0.01	0.04*
	(0.02)	(0.02)	(0.02)
Surface Water	0.02*	0.02	0.08**
	(0.01)	(0.01)	(0.04)
	Small Farm (<4 ha)	**Medium Farm (4 to 10 ha)**	**Large Farm (>10 ha)**
Hired Labor	0.00***	0.23***	0.28***
	(0.00)	(0.01)	(0.01)
Fertilizer	0.06***	0.06***	0.06***
	(0.01)	(0.01)	(0.01)
Groundwater	0.31***	0.30***	0.31***
	(0.01)	(0.01)	(0.01)
Own Male Labor	0.05***	0.04***	0.02**
	(0.01)	(0.01)	(0.01)

Own Female Labor	-0.02	-0.05	-0.04
	(0.02)	(0.04)	(0.04)
Capital	0.02	0.01	0.01
	(0.02)	(0.02)	(0.02)
Surface Water	0.04***	0.03***	0.02*
	(0.01)	(0.01)	(0.01)
	With Surface Water	**Without Surface Water**	
Hired Labor	0.00***	0.00***	
	(0.00)	(0.00)	
Fertilizer	0.06***	0.06***	
	(0.01)	(0.01)	
Groundwater	0.19***	0.33***	
	(0.01)	(0.01)	
Own Male Labor	0.05***	0.06***	
	(0.01)	(0.01)	
Own Female Labor	-0.05	-0.03	
	(0.04)	(0.03)	
Capital	0.01	0.02	
	(0.02)	(0.02)	
Surface Water	0.02	0.08**	
	(0.01)	(0.04)	

Standard errors in parentheses
$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

Table C2: Estimates of Technical Efficiency (standard errors of the means in parentheses)

	Mean	Median	Min	Max
Overall	0.26	0.22	0.03	1.00
	(0.01)			
Owner-Cultivated	0.24	0.20	0.03	1.00
	(0.01)			
Sharecropped	0.30	0.27	0.03	0.89
	(0.01)			
Fixed-Rent	0.31	0.25	0.07	0.84
	(0.03)			
Small Farm (<4 ha)	0.25	0.21	0.03	1.00
	(0.01)			
Medium Farm (4 to 10 ha)	0.29	0.25	0.03	0.94
	(0.01)			
Large Farm (>10 ha)	0.34	0.33	0.07	0.84
	(0.04)			
With Surface Water	0.33	0.28	0.03	1.00
	(0.01)			
Without Surface Water	0.22	0.19	0.03	0.84
	(0.01)			
Head of Watercourse	0.28	0.25	0.03	0.76
	(0.02)			
Middle of Watercourse	0.30	0.24	0.04	0.89
	(0.01)			

Tail of Watercourse	0.27 (0.01)	0.23	0.03	1.00

Figure C1: Cumulative Distribution Functions of Technical Efficiency by Tenancy Type

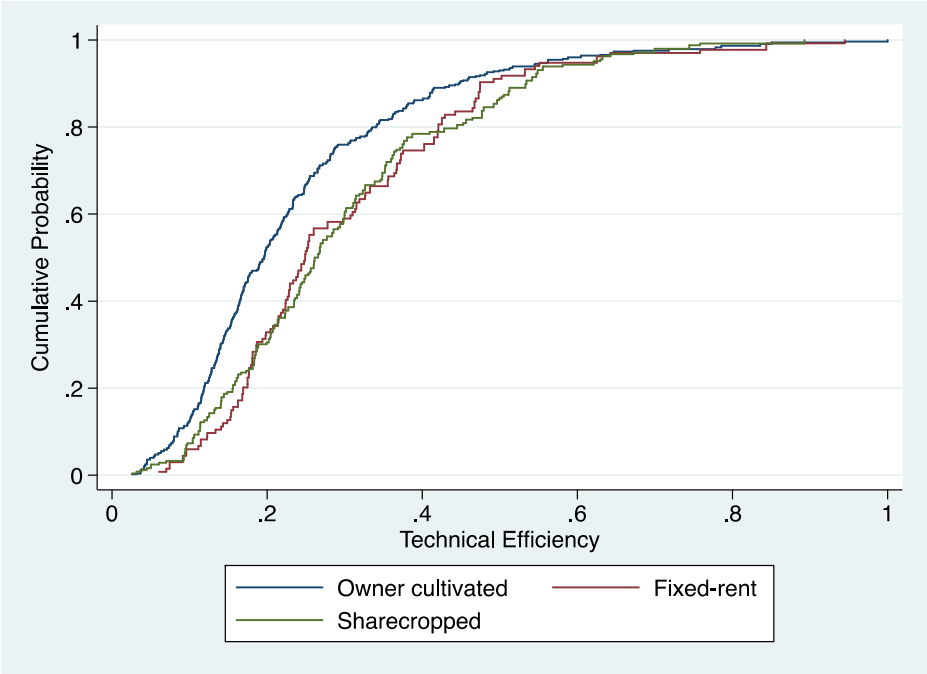


Figure C2: Cumulative Distribution Functions of Technical Efficiency for Households with and without Surface Water

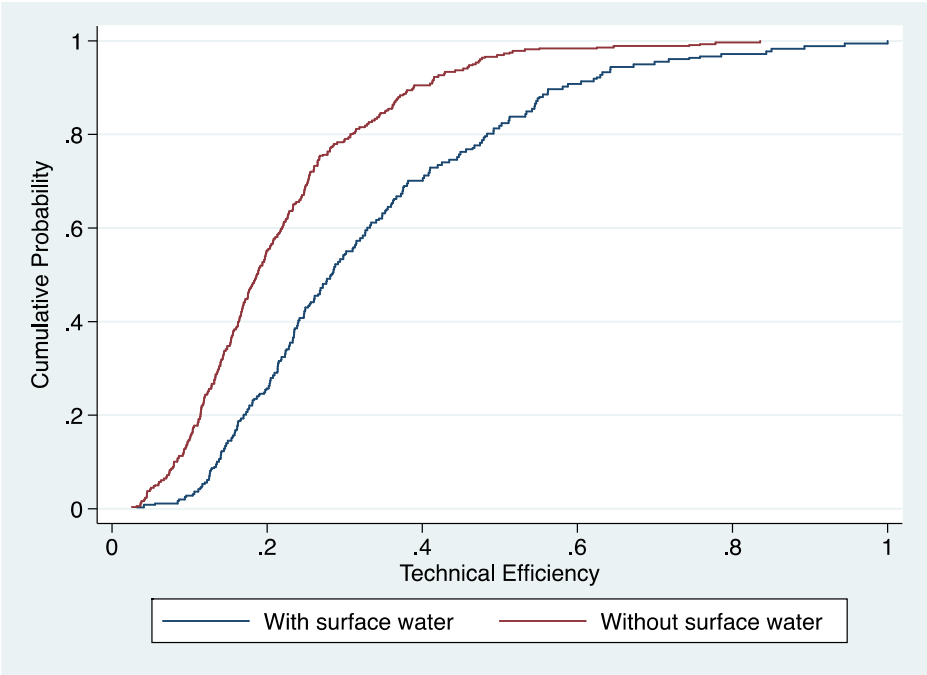


Table C3: Estimates of Allocative Efficiency of Groundwater (standard errors of the means in parentheses)

	Mean	Median	Min	Max
Overall	-0.06 (0.03)	0.00	-1.90	1.96
Owner-Cultivated	0.03 (0.03)	0.11	-1.64	1.96
Sharecropped	-0.19 (0.08)	-0.28	-1.47	1.31
Fixed-Rent	-0.34 (0.11)	-0.27	-1.90	1.05
Small Farm (<4 ha)	-0.01 (0.03)	0.05	-1.64	1.96
Medium Farm (4 to 10 ha)	-0.25 (0.07)	-0.29	-1.64	1.53
Large Farm (>10 ha)	-0.35 (0.17)	-0.17	-1.90	0.46
With Surface Water	-0.39 (0.05)	-0.42	-1.90	1.18
Without Surface Water	0.10 (0.03)	0.14	-1.47	1.96
Head of Watercourse	-0.13 (0.09)	-0.09	-1.43	0.98
Middle of Watercourse	-0.18 (0.05)	-0.17	-1.90	1.00
Tail of Watercourse	-0.01 (0.05)	0.10	-1.90	1.18

Figure C3: Cumulative Distribution Functions of Allocative Efficiency of Groundwater Across Tenure Systems.

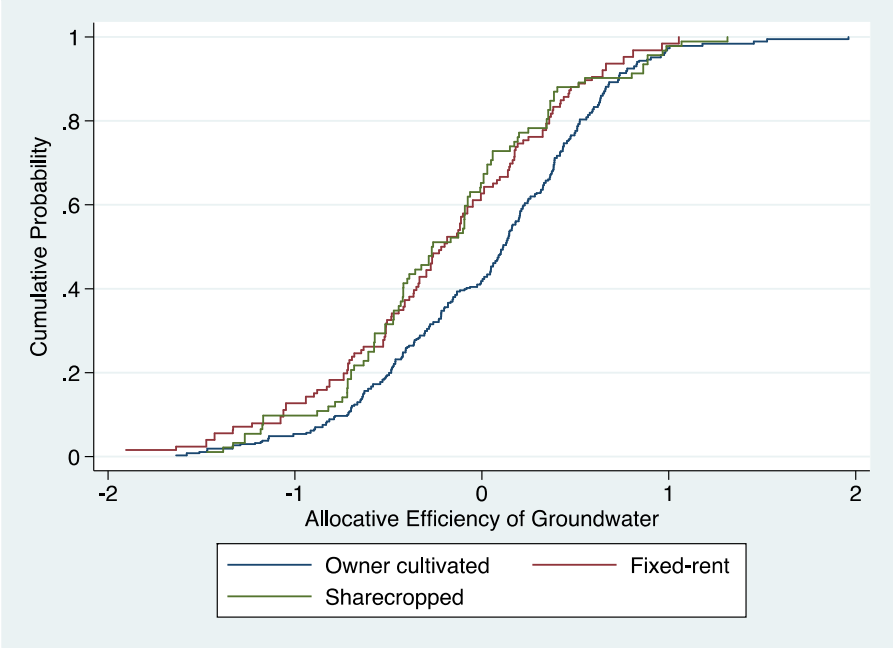
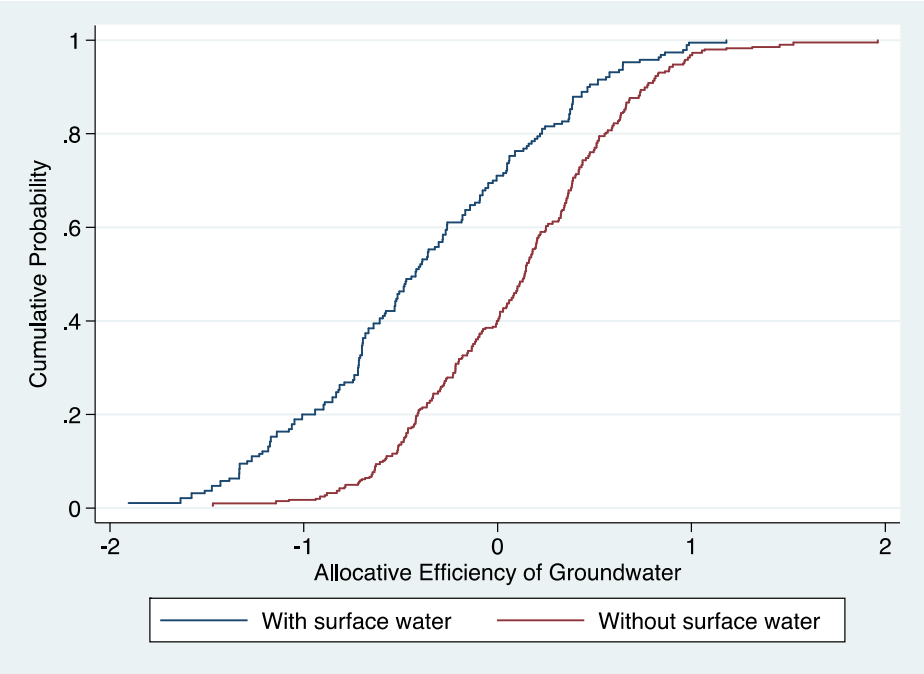


Figure C4: Cumulative Distribution Functions of Allocative Efficiency of Groundwater Across Farms with and without Access to Surface Water.



INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

2033 K Street, NW | Washington, DC 20006-1002 USA | T+1.202.862.5600 | F+1.202.457.4439 | Skype: ifprihomeoffice | ifpri@cgiar.org

This Working Paper has been prepared as an output for the Pakistan Strategy Support Program, funded by USAID, and has not been peer reviewed. Any opinions stated herein are those of the author(s) and do not necessarily reflect the policies or opinions of IFPRI.

Copyright © 2014, International Food Policy Research Institute. All rights reserved. To obtain permission to republish, contact ifpri-copyright@cgiar.org.