Pricing Farm Electricity, Water Use and Efficiency: The Case of Paddy Cultivation in Punjab

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Abstract

There has been a declining trend in groundwater depths in India and subsidies on farm electricity is seen as one of a key factors contributing to over-extraction of groundwater resources in the country raising concerns about its sustainability for irrigation. In this paper, we estimate the reduction in groundwater pumping under volumetric pricing of farm electricity for the state of Punjab where farm electricity is free. Further, we quantify gains in efficiency in terms of reduction of the deadweight loss under this pricing regime. We use parcel-level cost of cultivation data from the Ministry of Agriculture for the block period of 2011-12 to 2013-14 combined with data on groundwater depth and rainfall to estimate the production function for paddy using instrumental variable approach. This is used to get the estimates of the marginal product of water to compute the optimal level of water use at different levels of electricity price. We also quantify change in other inputs and paddy yields due to unit-price induced reduction in groundwater pumping. We find that the estimated marginal product of water at the irrigation volumes chosen by the farmers is very low. The average marginal product of water is estimated to be 34 kilograms for additional thousand cubic meters of water per hectare. Simulations show that increasing the price of electricity from current level of zero to the true cost of electricity supply leads to sharp cutbacks in water extraction using electric pumps. We show welfare gains in terms of reduction of the deadweight loss as a result of pricing agricultural electricity at the margin. We quantify average lump-sum subsidy that can be given to farmers as Direct Benefit Transfers into their bank accounts to keep their surplus unchanged.

Keywords: agricultural production function, deadweight loss, groundwater depletion, marginal product of water, volumetric pricing

JEL Codes: Q25, D24, D61, Q12

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1 Introduction

Groundwater use in Punjab exceeds natural recharge by 66 per cent in Punjab (Central Ground Water Board, 2019). Extraction at such rates have led to concerns about mining of groundwater to the point of no replenishment. A key factor contributing to the overextraction of groundwater is believed to be the policy of free electricity to the agricultural sector, and the cultivation of paddy, a water-intensive crop. Further, the burden of electricity subsidies is borne the state government and electricity boards, leading to underinvestment in maintenance of the grid, and erratic power supply, especially to the agricultural sector (Mukherji et al., 2012).

While a switch from free to volumetric pricing of farm electricity is expected to reduce the pumping of water, there are no estimates of the magnitude of reduction in water use that may be expected from a switch to unit pricing of power. Exceptions are studies of pilot interventions in some states, for instance Fishman et al. (2016) and Mitra et al. (2021), that used rebates as a form of volumetric pricing, however, their impacts are modest and mixed.

The first objective of this paper is to estimate the reduction in paddy irrigation volumes if electricity is supplied at its unit cost to the State Electricity Board. To do this, we estimate a production function for paddy, and use the estimated value of the marginal product of water use to obtain the derived demand for water at alternative electricity prices.

While a decrease in water pumped for paddy cultivation may arrest the rate of decline in groundwater in Punjab, there may be concerns of whether food security is negatively impacted, as reduced input use may also result in lower yields. However, overextraction of groundwater due to farm power subsidies suggests that the value of marginal product of water has a flat region, over which reducing water use leaves yields unaffected. So, we use the same exercise to quantify the magnitude of decrease (if any) in yields arising from unit price-induced reductions in water application.

A pricing regime that is lower than the costs of providing electricity also leads to deadweight losses. A second objective of this paper therefore is to quantify the gains in efficiency from unit pricing, using a partial equilibrium framework. The production function estimates are used to (a) compare the magnitude of losses per hectare to the state electricity board with free power, relative to the gains it can make if electricity is priced and (b) compute the magnitude of lump-sum transfers that would need to be made to farmers to leave their surplus unchanged.

The analysis in this study is based on the three year parcel-level panel data for the period 2011-12 to 2013-14 on costs of cultivation of paddy in Punjab taken from the Ministry of Agriculture and Farmers Welfare, Government of India, combined with the data on groundwater depths from the Central Ground Water Board and the rainfall data from Matsuura and Willmott (2015).

The identification of the production function parameters is a challenge on account of the familiar problems of endogeneity, arising out of simultaneity of choice. Input use by the farmer is dependent on various factors such as soil quality, elevation of the parcel, humidity, expected rainfall, etc. which are unobserved by the researcher. Panel data (with fixed effects) allows us to deal with unobserved time-invariant heterogeneity. To address remaining sources of endogeneity, we use an instrumental variable approach, using input prices and groundwater depth. These are arguably exogenous, since all farmers in the sample are price takers in input markets.

We provide here a brief preview of the results. Using the production function estimates, we derive the marginal product of water. We find that the estimated marginal product of water at the irrigation volumes chosen by farmers is very low. The curvature of the marginal product of water function is convex but relatively flat in this range. The value of marginal product of water for an average parcel is estimated to be ₹365 per thousand cubic meters of water.

Based on simulations, we show that increasing the price of farm electricity from current level of zero to the average cost of electricity supply[1] leads to sharp cutbacks in water use whereas the reduction in yield is not as sharp. In particular, increasing the unit pricing of electricity from zero to ₹5.5 per kilowatt hour leads to a decline in groundwater extraction by 59 per cent while the decline in paddy yields is about 11 per cent assuming that other inputs remain unchanged. This suggests that a policy of pricing the electricity at margin can help reduce water use substantially on the intensive margin, but there is also a modest decline in yield levels.

Further, we show that when farm electricity is priced at the margin, the net welfare of the economy goes up. We quantify the gain in efficiency in terms of reduction of the deadweight loss. Currently, the Government of Punjab gives compensation to the state electricity board for the provision of free electricity to the farmers. With volumetric pricing, the state electricity board recovers this amount from the farmers since they pay for each unit of electricity consumption.

However, there is a reduction in the farmer surplus by 8 per cent. We show that an average lump-sum transfer by the government of ₹5927 per hectare to the farmers can keep their surplus unchanged. Moreover, this amount is 58 per cent lower than the average amount (₹10211 per hectare) the government pays to the state electricity board for provision of free farm electricity. In other words, we show that pricing electricity and thus, groundwater can result in a Pareto improvement and an increase in net welfare of the economy.

The study contributes to substantial literature that examines questions on pricing of groundwater and issues relating to water use efficiency in India, a subset of which includes, Somanathan and Ravindranath (2006); Shah (1993); Badiani-Magnusson and Jessoe (2018); Fishman et al. (2016); Meenakshi et al. (2012); Mukherji et al. (2009); Kumar (2005); Kumar et al. (2011); Singh (2012); and Shah and Chowdhury (2017). This essay makes two contributions. First, we provide an estimate of the marginal pro-

[1]The cost of supply of electricity is defined by Punjab State Electricity Regulatory Commision as the total cost incurred by the distribution utility (Punjab State Power Corporation Limited (PSPCL), in this case) for supply of electricity to the agricultural sector; see pg. 114: https://www.pserc.gov.in/pages/Tariff_order_for_PSPCL_2013-14.pdf.

ductivity of water for paddy cultivation in Punjab. This enables us to quantify change in groundwater extraction and yields at various electricity prices.

Second, we offer a possible policy framework for pricing agricultural power and quantify the amount of lump-sum transfer for the farmers to keep their welfare unchanged under a volumetric pricing regime. We also show a gain in efficiency in terms of reduction of the deadweight loss.

To the best of our knowledge, this is the first study that uses simulation to quantify the reduction in groundwater pumping and the efficiency gains under marginal cost pricing of electricity in agriculture.

The rest of the paper is organised as follows. In Section 2, we look at the existing literature relating to farm pricing and impact on groundwater use. Section 3 describes the data used in the study. Section 4 discusses the identification of the production function and derives the marginal product of water. Section 5 uses simulations to quantify the reduction in groundwater pumping under unit-pricing of farm electricity. Section 6 shows the gain in efficiency in terms of reduction in the deadweight loss under volumetric pricing of farm electricity and quantifies the amount of lump-sum transfer to keep the farmer welfare unchanged. Section 7 concludes.

2 Literature Review

There is a vast literature spanning diverse issues relating to groundwater irrigation across India. In this section, we provide a brief review of studies that estimate marginal product of water, examine the issue of groundwater depletion using pricing as a tool and discuss its welfare implications.

Somanathan and Ravindranath (2006)'s study based on a primary survey in Andhra Pradesh and Karnataka provide estimate of price elasticity of water demand to be -1 which means doubling the price of water reduces the quantity demanded to half. They estimate the average value of water to be ₹0.31 per cubic metre of water. They find that increasing the marginal price of electricity close to its true cost leads to reduction in groundwater extraction.

Badiani-Magnusson and Jessoe (2018) examine the impact of agricultural electricity subsidies on groundwater extraction for a sample of districts in India for the period 1995-2004. They use variations in average price of electricity across these districts to capture variations in agricultural electricity subsidies. Taking into account district and year unobservables, they find that agricultural subsidies increase groundwater extraction and that the price elasticity of groundwater demand is -0.18. They show that the district demand for groundwater declines by 0.417 million cubic metres for every unit increase in the average price of electricity. Note that as practically all states in India had flat rate pricing regimes in the time period of their study, there was no variation in the marginal or unit price of electricity, which was virtually zero, in their sample.

Meenakshi et al. (2012) quantify the impact of a policy relating to agricultural electricity pricing in West Bengal using data from primary survey. They find reduction in pumping hours in the summer season with change in policy from flat rate tariff to metered tariff, although no impact was seen in cropping patterns and output.

A study based in Gujarat by Fishman et al. (2016) illustrates the impact of a politically feasible pilot intervention in 2012 on the demand for groundwater. Under the intervention, farmers with previously no meters were voluntarily asked to install meters and compensation was given for every unit of electricity saved by farmers below some pre-specified threshold, following the voluntary adoption of meters in the region. The authors find no decline in farmer's electricity or water use. Based on qualitative interviews, they hypothesize that the insignificant results could be due to farmers' lack of knowledge regarding low cost water saving technologies or social norms governing the use of water.

Mitra et al. (2021) examines the impact of a similar pilot intervention called "*Pani Bachao, Paisa Kamao*" in 2018 in Punjab on farmer-reported number of pumping hours and feeder-level electricity consumption. Under this scheme, farmers were entitled to some pre-specified units of 8-hours of uninterrupted supply of electricity and the enrolled farmers were provided cash compensation of ₹4 for each unit of electricity saved below this amount. The authors find significantly lower irrigation hours for the farmers enrolled in the scheme with no impact on crop yield. They also find a reduction of about 30 per cent in the power consumption for these agricultural feeders.

Kumar (2005) examines the impact of the policy of volumetric pricing of water/energy in the Banaskantha district of North Gujarat. They find a reduction in demand for groundwater and electricity usage under this policy regime.

Kumar et al. (2011) analyses the impact of electricity pricing on groundwater use efficiency using data from primary survey in a sample of four districts located in Gujarat, Bihar and Uttar Pradesh. They provide estimates for water productivity of various crops cultivated in these districts. They find that marginal cost pricing of electricity encourages the farmers to use groundwater resources more efficiently by shifting to low water intensive crops and reducing the amount of groundwater extraction per unit of land.

Recently, a study by Gill and Nehra (2018) has quantified the over-usage of groundwater in Haryana and the level of inefficiency in power consumption in agricultural sector in the state. According to the authors, power subsidies particularly in Haryana and Punjab, play a major role in promoting the cultivation of water-intensive crops like rice, in these states. They show that actual irrigations are twice those recommended, and suggest that these additional irrigations effectively have a marginal product of zero. Overirrigation may be a natural response to the uncertainty in electricity supply induced water availability.

Welfare implications under various pricing regimes are also examined in literature. Shah (1993) opposes volumetric pricing with an argument that such a change could reduce net social welfare following reduction in demand for water and electricity and reduction in farmer surpluses. However, recent studies find an increase in welfare under volumetric pricing regime. Badiani-Magnusson and Jessoe (2018) shows a gain in efficiency in terms of reduction in the deadweight loss when agricultural electricity subsidies are reduced by 50 per cent. The study by Kumar (2005) shows a positive impact of volumetric pricing regime on the physical water use efficiency.

To our knowledge, this is the first study that uses parcel-level panel data to estimate the marginal product of water use in agriculture for paddy cultivation in Punjab that enables us to quantity reduction in groundwater pumping under volumetric pricing of farm electricity using a simulation-based analysis.

3 Description of the Data and Variables

The dataset used in this study pertains to Punjab farmers who cultivated paddy in *kharif* seasons of 2011-12, 2012-13 and 2013-14. It is a parcel-level panel dataset on agricultural inputs, output, and other water-related variables.

3.1 Agricultural Output and Inputs

The primary source of data is the cost of cultivation surveys conducted by the Directorate of Economics and Statistics, Ministry of Agriculture and Farmers Welfare, Government of India. It provides detailed plot-level information on agricultural output and inputs of selected crops in physical as well as monetary terms for a sample of farmers for each season.

The surveys use a three-stage stratified sampling design taking tehsils, villages and operational holdings as the first, the second and the third stage sampling units, respectively. Each state is divided into homogeneous agro-climatic zones based on cropping pattern, soil type, rainfall etc. Tehsils are selected in the sample from each zone with probability proportional to the area under selected crops, and with replacement. Within each of these tehsils, villages are selected in the sample using the same procedure. In each selected village, operational holdings are classified according to area into five size classes or groups, namely, area less than 1 hectare, between 1 to 2 hectares, 2 to 4 hectares, 4 to 6 hectares and above 6 hectares. Two holdings are selected from each size class using simple random sampling without replacement.

The dataset used in this study is for the water intensive crop paddy which is cultivated on about two-thirds of the cropped area in the sample in the *kharif* season. The data collection is carried out as a rotating panel such that a new set of villages are sampled after every three years.[2] In this study, we use the data for the three-year panel from 2011-12 to 2013-14.[3] Punjab has three agro-climatic zones. Out of 30 tehsils sampled from the state in the first stage, paddy is cultivated in 27 tehsils.

Farmers sometimes cultivate paddy on multiple plots of the same parcel.[4] Since plots of the same parcel have identical soil characteristics, it is appropriate to do a parcel-level analysis rather than a plot-level analysis. We aggregate the amount of inputs used and paddy output produced across plots of the same parcel. The sample consists of an unbalanced panel of 504 parcels on which paddy is cultivated by 238 farmers on at least one parcel in the three years.[5]

The inputs considered for this analysis are human labour, machine labour and irrigation per unit of cropped area. These constitute about 63 per cent of the cost of cultivation, out of which the share of human labour costs per hectare is 41 percent, the share of machine labour costs per hectare is 15 per cent, and the share of irrigation costs which includes costs of pump maintenance is 7 per cent. Thus, these inputs constitute the majority of the costs of cultivation of paddy in Punjab during the period of study.[6]

Table 1 presents the summary statistics for yield, crop area and input use per hectare for paddy cultivation. The average yield of paddy in the sample is 64.4 quintals per hectare

[2] The sample of villages selected from Punjab during the period 2011-12 to 2013-14 in the second stage of sampling are depicted in Figure A1.

[3] The plot-level summary data under cost of cultivation scheme is retrieved from: `https://eands.dacnet.nic.in/Plot-Level-Summary-Data.htm`. The data on additional variables from cost of cultivation surveys used in this study such as irrigation hours by pump-type and horsepower rating of the pump were acquired by the author from the Ministry of Agriculture on request in September, 2018. The panel data from 2011-12 to 2013-14 was the most recent available at that date.

[4] A plot is defined as part of the parcel which is designated for cultivation of a particular crop in a given season. A piece of land which has identical soil characteristics as defined by its texture, colour, topography, etc. and identical tenure is termed as a parcel. Any part of the land which differs in any of these (one or more than one) characteristics will be classified as two separate parcels.

[5] On approximately 62 per cent of the parcels, paddy is cultivated in all three years, while on 20 per cent of the parcels, it is cultivated in two out of three years and on the remaining, it is cultivated in only one year.

[6] We consider the cost measure that includes imputed costs of owned inputs as well. Of the remaining costs, fertilizer constitutes 11 per cent, and insecticides constitute about 9 per cent of the cost per unit of area.

with the average area under paddy cultivation of 1.75 hectares.

Table 1: Summary statistics: Yield, crop area and input use

	Mean	Standard Deviation
Paddy yield (qtls./ha)	64.41	12.90
Crop area (ha)	1.75	1.50
Human labour (hrs/ha)	368.85	110.71
Machine labour (hrs/ha)	14.46	4.85
Water ('000 cu m/ha)	50.53	42.60
Rainfall	5.81	19.27
Submersible pump	22.19	35.61
Non-submersible pump	17.99	36.66
Diesel pump	4.54	15.97
Observations	1,225	

Note: The sample consists of 504 parcels on which 238 farmers cultivate paddy. There are 1,225 parcel-year observations for the period 2011-12 to 2013-14.
Source: Based on the cost of cultivation data from Directorate of Economics & Statistics, Ministry of Agriculture and Farmers Welfare, Government of India; rainfall data from Matsuura and Willmott (2015); groundwater depth data from Central Ground Water Board.

The average human labour use (the sum of family labour, attached labour and casual labour hours) in paddy cultivation is 369 hours per hectare. The share of casual labour in total human labour is the highest at 49 per cent, followed by 42 per cent for family labour, and 9 per cent for attached labour.[7]

Machine labour is an aggregate of owned and hired machine hours. The average machine hours used for paddy cultivation is 14 hours, of which 70 per cent is owned and the remaining is hired.

[7]Attached labour work for a particular farmer on the basis of a contract. However, casual labour is free to work on the farm of any farmer and is usually paid on a daily basis.

3.2 Water Variables

3.2.1 Rainfall

The data on rainfall is taken from Matsuura and Willmott (2015). It is a GIS-gridded dataset which provides point estimates of monthly rainfall (in millimeters) across the globe with a resolution of $0.5° \times 0.5°$ for the period 1900-2014. Tehsil-level rainfall is estimated for the period 2011-12 to 2013-14 by taking the weighted average of the grid points which lie within a 50 kilometer radius of the tehsil centre, where the inverse of shortest distance from tehsil centre to the grid point are taken as weights, for every period. Tehsil-level rainfall for *kharif* season are computed by aggregating monthly rainfall estimates for July, August, September and October.

3.2.2 Groundwater

The data on groundwater levels is taken from Central Ground Water Board, Government of India. This dataset provides the depth of groundwater measured in meters below ground level (mbgl) for a sample of observation wells spread throughout the country. This study uses data on pre-monsoon groundwater levels since paddy cultivation in Punjab is undertaken in the *kharif* season. The tehsil-level groundwater depth for each year is constructed by taking a simple average of pre-monsoon groundwater levels of all the observation wells located in the tehsil corresponding to the sampled village.

3.2.3 Total water for paddy cultivation

In order to take into account the total amount of water used by the farmer, we construct the water variable (measured in cubic meters). It includes groundwater extracted using electric/diesel pumps and rainfall on a given parcel.[8]

[8] Canal irrigation and conjunctive use of canal and groundwater irrigation have not been considered in the computation of the total water use. This is a data limitation. In the cost of cultivation data, the entries for canal irrigation charges are all zero and therefore, uninformative. Further, there is no other variable in the dataset that captures water use from canals.

For this, we first compute the amount of groundwater extracted using the following equation,[9]

$$I_{ijt} = \frac{1}{g \times GW_{jt}} \sum_k (E_k \times HP_k \times IrrHours_{ijtk}) \tag{1}$$

where i denotes parcel, j denotes tehsil, t denotes year, and k denotes the type of pump. I_{ijt} represents the mass of water extracted (in kilograms) on parcel i in tehsil j in year t. g denotes acceleration of gravity which is 9.8 m/s^2 on the surface of the earth at the sea level. The pre-monsoon groundwater depth (in meters) at the tehsil-level is denoted by GW_{jt}.

The efficiency of pump type k is denoted by E_k. A pump is considered to be 100% efficient if the mechanical horsepower input is equal to the horsepower output. However, pumps are usually never fully efficient. The efficiency of the pump gets reduced because of various factors such as energy losses due to friction, etc. There are three types of irrigation pumps used by farmers, namely, electric submersible, electric centrifugal and diesel pumps. There are technological differences between these pumps such that the efficiency of electric pumps is the higher than that of diesel pumps. The efficiency of an electric pump is between 70 to 80 per cent whereas that of a diesel pump is between 30 to 40 per cent (NSW Farmers Association, 2013). Since the pump efficiency of electric pumps is almost double than that of diesel pumps, this needs to be taken into consideration for computing the amount of groundwater extracted. In this study, we assume the efficiency of electric pumps to be 75 per cent and that of diesel pumps to be 35 per cent.

HP_k denotes the horsepower of pump type k (converted to watts). In this study, we use average horsepower of the pump across all the parcels in a given year for each pump type.[10] The difference in the means of the horsepower ratings is not significant across the

[9] Lifting a mass (in this case, water) against gravity requires energy, which is power applied over time. Here, we use the standard equation to compute the same. Multiplying equation 1 through by $g \times GW_{jt}$, we get the left hand side in the form of Mass times acceleration times distance, and the right hand side in the form of Power multiplied by time: both being manifestations of work done.

[10] The data on horsepower by pump type is taken by the author from the Ministry of Agriculture on request. There is a high variability in the data on actual horsepower ratings such that some of the them do not correspond to the range of horsepower rating of the pumps available in the market. Also, we do not expect to see high variability in horsepower ratings of the pumps on parcels in the same region. Thus, we have taken average horsepower by pump type in this analysis.

years. The average horsepower of the electric submersible pump is 12 HP, for the electric non-submersible pump is 5 HP and for the diesel pump is 8 HP.

$IrrHours_{ijtk}$ denotes the irrigation pumping hours on parcel i in tehsil j for the k^{th} type of pump in year t. The data on irrigation hours by pump type for the three years is taken by the author from the Ministry of Agriculture on request. The irrigation pumping hours are converted into seconds for consistency in units in equation 1.

The mass of groundwater extracted for irrigation using pumps (in kilograms) is obtained using equation 1. The total volume of water use (in cubic meters) is computed by aggregating the volume of groundwater extracted and the amount of rainfall for every parcel.[11]

The submersible pumps usually operate at higher groundwater depths as compared to the centrifugal pumps (Sekhri, 2014). In our sample, the electric submersible pumps operate at an average groundwater depth of 21.1 meters, while the electric non-submersible and the diesel pumps operate at an average depth of 7.5 meters and 6.8 meters, respectively.

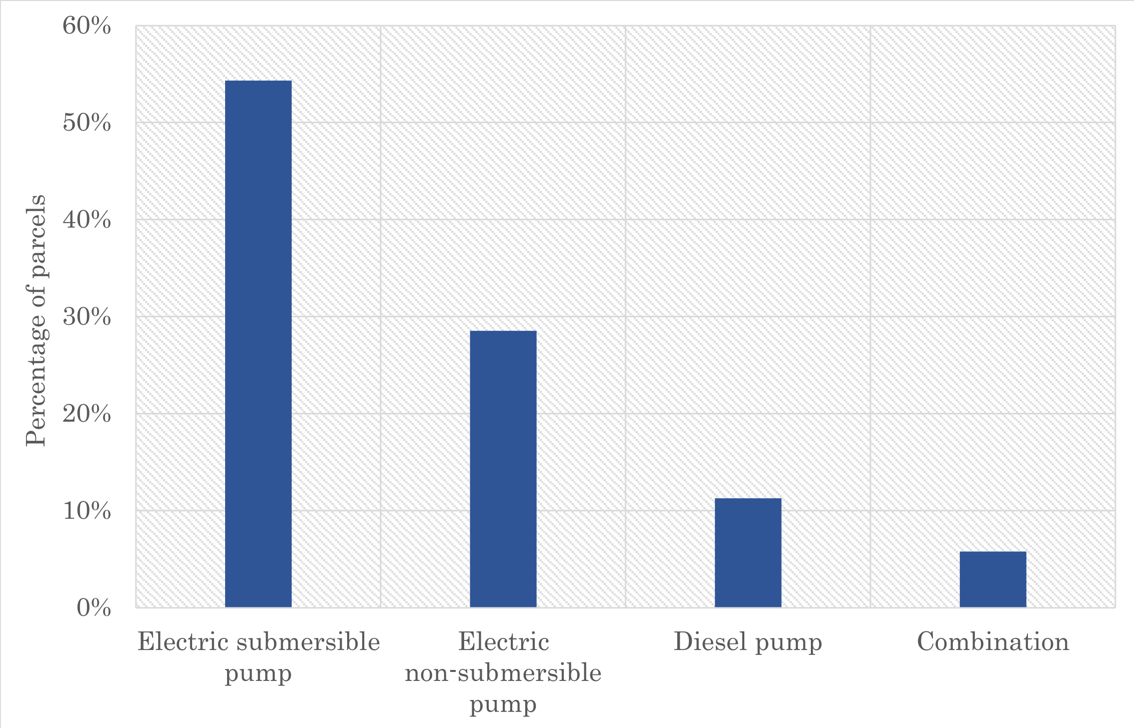
The distribution of parcels by the type of pump is presented in Figure 1. The electric submersible pumps are used to extract groundwater on about 54 per cent of the parcels, the electric non-submersibles are used on 29 per cent of the parcels and the diesel pumps are used on 11 per cent of the parcels. A combination of electric and diesel pumps is used on about 5 per cent of the parcels.

Paddy is a water intensive crop. The average water used for its cultivation is 50.5 thousand cubic meters per hectare (Table 1).[12] The share of groundwater use in the total water use is 88 per cent with electric submersible pumps being used on more than half of the parcels.

[11] I_{it} obtained in kilograms and rainfall in millimeters is converted to cubic meters of water using relevant conversion factor. 1 kilogram is equivalent to 0.001 cubic meter of water. Also, a rainfall of 1 millimeter supplies 10 cubic meters of water to each hectare of land.

[12] With an average paddy yield of 64.41 qtls./ha, the average water use is equivalent to 7845 liters for 1 kilogram of paddy. This translates to 5883 liters/kg for rice (for 75% recovery) or 5230 liters/kg (for two-thirds recovery). This is in line with the average water use of 5337 liters for 1 kg of rice cultivation in 2013-14 estimated by the Commission for Agricultural Costs and Prices (Government of India, 2015, p. 34).

Figure 1: Parcels by pump-type



Source: Based on the cost of cultivation data from the Directorate of Economics & Statistics, Ministry of Agriculture and Farmers Welfare, Government of India.

3.3 Average cost of farm power supply

The average cost of supply of electricity to the agricultural sector in Punjab for the period of study is ₹ 5.5 kilowatt hour (kWh) as estimated by Punjab State Electricity Regulatory Commission.[13] This is used in the simulation analysis.

4 Production Function Specification and Estimation

We first estimate the production function for paddy cultivation in Punjab using the three year parcel-level panel dataset. The estimates of the parameters of the production function are then used to compute marginal product of water.

To estimate the production function, we began with the flexible Translog specification. However, all the interaction terms and squared terms were jointly insignificant.[14] Thus,

[13]For details, see p. 119: https://docs.pspcl.in/docs/sesalesto20180719154236976.pdf.

[14]We do not reject the null hypothesis that the coefficients of squared and interaction terms in the

the Cobb-Douglas specification nested in the Translog function is an appropriate choice for the functional form in this sample. We first estimated the output production function. Since it exhibits constant returns to scale irrespective of the specification[15], we estimate the following yield production function,

$$\ln(y_{ijt}) = \beta_1 \ln(h_{ijt}) + \beta_2 \ln(m_{ijt}) + \beta_3 \ln(w_{ijt}) + \beta_4 V_{jt} + \lambda_t + \alpha_i + u_{ijt} \tag{2}$$

where i denotes parcel, j denotes tehsil, and t denotes year. The dependent variable $\ln(y_{ijt})$ is the natural logarithm of paddy yield on parcel i in tehsil j in year t. The explanatory variables $\ln(h_{ijt})$, $\ln(m_{ijt})$ and $\ln(w_{ijt})$ are logarithmic values of human labour hours, machine labour hours and volume of total water use, all taken in per hectare terms, on parcel i in tehsil j in year t.

The production function parameters β_1, β_2 and β_3 can be interpreted as partial elasticities of yield with respect to each corresponding input. We also include other inputs such as fertilizers, insecticides and seeds that might be important determinants of the crop yields.

The variance of monthly rainfall for tehsil j in year t is denoted by V_{jt}. It is the temporal variance estimated as the sum of squared deviations of rainfall for the months of July, August, September and October from the mean of rainfall across these four months, divided by the number of months, for tehsil j in year t. Various studies, for instance Auffhammer et al. (2012) and Fishman (2016), suggest that high temporal variability in precipitation in terms of drought or extreme rainfall has a negative impact on paddy yields in India. Thus, we control for the temporal variance of monthly rainfall in our model. β_4 denotes the impact of variance of monthly rainfall on paddy yields.

Time fixed effects are denoted by λ_t which capture the aggregate factors that affect the crop yield over time. Parcel fixed-effects denoted by α_i capture the unobserved parcel-specific time invariant heterogeneity such as soil quality, topography, etc. The random

translog specification are zero. Thus, they are jointly statistically insignificance with $\chi^2_{(6)} = 5.14$ (p-value=0.525). See Table B1 in the Appendix for detailed results.

[15] See Table B2 in the Appendix for detailed results.

error term is denoted by u_{ijt}. Cluster-robust standard errors are reported with clustering done at the parcel-level.

4.1 Empirical Strategy

Econometric issues pertaining to the identification of the production function parameters are discussed extensively in literature (Griliches and Mairesse, 1995; Olley and Pakes, 1996; Deaton, 1995). The estimation of the production function is susceptible to endogeneity issues. Input use by farmers is a choice variable which depends on various omitted variables, that include quality of land, elevation of the parcel, soil drainage, managerial ability of the farmer, etc. which are likely to be observed by the farmer but are unobserved by the econometrician and they are a part of the error term. Thus, observed input choices are correlated with the error term leading to biased estimates.

To the extent that some of these unobserved factors are time invariant, the use of parcel-level panel data and the fixed effects (FE) specification can address one source of endogeneity.

In order to address any remaining correlation between observed input choices and unobserved parcel-specific and time varying factors, we use the instrumental variable (IV) approach. We use a set of instrumental variables Z_{ijt} which are highly correlated to the endogenous inputs denoted by X_{ijt} (*relevance*) and uncorrelated to the error term u_{ijt}, conditional on other covariates (*exogeneity*).

The $\mathrm{FE}-\mathrm{IV}$ estimator is obtained using two stage least squares (2SLS) regression. In the first stage, $\ddot{X}_{ijt}$ is regressed on $\ddot{Z}_{ijt}$ and other exogenous variables. In the second stage, $\ddot{Y}_{ijt}$ is regressed on the fitted values of the endogenous variables from the first stage regression and the exogenous variables. Here, $\ddot{X}_{ijt}$, $\ddot{Y}_{ijt}$ and $\ddot{Z}_{ijt}$ are the within transformations of the corresponding variables. The within transformation of any variable s_{ijt} is,

$$\ddot{s}_{ijt} = s_{ijt} - \bar{s}_{ij.} = s_{ijt} - \frac{1}{3}\sum_{t=1}^{3} s_{ijt} \tag{3}$$

The FE − IV estimator can be expressed as,

$$\hat{b}_{FE-IV} = (\ddot{X}'\ddot{Z}(\ddot{Z}'\ddot{Z})^{-1}\ddot{Z}'\ddot{X})^{-1}(\ddot{X}'\ddot{Z}(\ddot{Z}'\ddot{Z})^{-1}\ddot{Z}'\ddot{Y}) \quad (4)$$

In our model, the endogenous variables are human labour, machine labour and water use. Production theory suggests some natural instruments for the three variables. From the input demand function, we know that the input prices determine the amount of inputs chosen by the farmer, satisfying the property of relevance of the instrument. Also, the input prices do not enter into the production function directly i.e. they affect output only through their impact on input choice, satisfying the property of exogeneity.

We instrument human labour using casual labour wages measured in rupees per hour, machine labour using the hired machine rent measured in rupees per hour, and water using own irrigation machine charges measured in rupees per hour and tehsil-level pre-monsoon groundwater depths measured in meters below ground level. All the input prices are taken in real terms.[16] Given the relatively small units of land being cultivated by large number of farmers in much of India, it is reasonable to assume that farmers are price takers at least in local input markets, and that these instruments are exogenous to the farmers. Each input price thus derived does exhibit variation both across space and time.

The advantage of the cost of cultivation surveys is that it provides data on input use in physical terms as well as expenditure on each of the these inputs in monetary terms at the parcel-level. This allows us to calculate input prices at the level of the parcel.

Casual labour wage per hour paid to the farmer working on parcel i in tehsil j year t is computed by dividing the total cost of casual labour in rupees by the number of hours of casual labour employed on that parcel. Similarly, hired machine rent and own irrigation charges are computed by dividing their respective total costs by the quantity of input use

[16] Input prices are converted in real terms using CPI-AL (Consumer Price Index for Agricultural Labourers) deflator keeping 2011 as the base year. The data on CPI-AL is taken from Labour Bureau, Government of India. See page 28: http://labourbureaunew.gov.in/UserContent/Annual_Rep_CPI_ALRL_2013_14.pdf

on each parcel.

The family labour component of the human labour is not a paid-out cost. It is imputed on the basis of prevailing wages for casual labour in the locality. Thus, we instrument human labour hours using casual labour wages. For similar reasons, we use hired machine rent as an instrument for the machine labour hours. In the case of water, we use irrigation machine charges per hour from own pumps as an instrument for water use since almost all the farmers in Punjab own an irrigation pump.[17] The irrigation charges for own pumps include the charges for lubricants and repair.

A priori, we expect a negative relationship between the input demand and the input prices. Also, higher groundwater depths would mean higher unit cost of extraction of water and thus, lower amount of water extracted, implying a negative relationship between the groundwater depth and water use on the parcel.

Table 2 presents summary statistics for the instruments used, namely, casual labour wage, hired machine rent, own irrigation charges and tehsil-level pre-monsoon groundwater depth. The average casual labour wage is ₹33 per hour. The average hired machine rent is ₹851 per hour. The average own irrigation machine charges are ₹10 per hour. These are computed on the basis of cost of maintenance of farm machinery. The average pre-monsoon groundwater depth for regions under paddy cultivation is about 15 meters.

Table 2: Summary Statistics: Instrumental variables

Variable	Mean	Standard deviation		
		Overall	Between	Within
Casual labour wage (₹/hour)	32.91	4.11	2.99	2.98
Hired machine rent (₹/hour)	851.34	330.15	286.36	195.81
Own irrigation machine charges (₹/hour)	10.31	6.53	6.00	2.86
Pre-monsoon groundwater level (meters)	14.89	9.17	9.03	1.00

Source: Based on the cost of cultivation data from Directorate of Economics & Statistics, Ministry of Agriculture and Farmers Welfare, Government of India.

[17]More than 99 per cent of the farmers in the sample own irrigation machines. For the parcels where own irrigation pumps are not employed, we use tehsil averages of the own irrigation charges per hour as the instrument.

Table 3 presents the Cobb-Douglas production function estimates using fixed-effects regression (in other words, without instrumenting, and thus accounting only for time-invariant unobserved factors that may be associated with input choices). The various specifications add inputs sequentially, and include: (a) only water use per hectare as the explanatory variable; (b) human labour, machine labour and water use per hectare as the explanatory variables; (c) additional controls for variance in monthly rainfall; (d) fertilizer use per hectare and (e) insecticides per hectare in addition to other inputs.

Including fertilizer use (column (4)), insecticides (column (5)), and seeds (column (6)) does not alter the estimates of the coefficients of human labour, machine labour and water use per hectare (column (3)). Moreover, the coefficients of insecticides and seeds are statistically insignificant (columns (5) and (6)).

Table 3: Production Function Estimates: Fixed-effects regressions

Dependent variable: log (yield) in quintals/ha	(1)	(2)	(3)	(4)	(5)	(6)
log (human labour) in hours/ha		-0.097**	-0.082**	-0.078*	-0.076*	-0.073*
		(0.043)	(0.041)	(0.040)	(0.040)	(0.040)
log (machine labour) in hours/ha		0.027	0.025	0.023	0.024	0.024
		(0.023)	(0.023)	(0.022)	(0.023)	(0.023)
log (water) in cu m/ha	0.051*	0.061**	0.059**	0.054**	0.054**	0.052**
	(0.028)	(0.029)	(0.026)	(0.025)	(0.025)	(0.025)
log (fertilizer) in kg/ha				0.077**	0.078**	0.081**
				(0.031)	(0.031)	(0.033)
log (insecticides) in ₹/ha					-0.012	-0.012
					(0.017)	(0.017)
log (seeds) in ₹/ha						-0.035
						(0.066)
Variance of monthly rainfall			-0.000014***	-0.000014***	-0.000014***	-0.000014***
			(0.000003)	(0.000003)	(0.000003)	(0.000003)
Parcel fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,225	1,225	1,225	1,225	1,225	1,222
Number of parcels	504	504	504	504	504	503

Notes: i. Cluster-robust standard errors are reported in the parentheses with clustering at the parcel-level; ii. Asterisks denote the significance levels: *** p<0.01, ** p<0.05, * p<0.1.
Source: Based on the cost of cultivation data from the Directorate of Economics & Statistics, Ministry of Agriculture and Farmers Welfare, Government of India; rainfall data from Matsuura and Willmott (2015); groundwater depth data from the Central Ground Water Board.

Note that, contrary to our expectation from the production theory, the coefficient of human labour is negative in the fixed effect regressions. One of the reasons could be an unobserved variable which is not accounted for in the model and thus, it is a part of the error term. The perverse sign on human labour indeed disappears when instruments are used, as seen next.

Table 4 presents the production function estimates using instrumental variable (IV) approach along with parcel and year fixed-effects. The $\mathrm{FE} - \mathrm{IV}$ estimates correspond to our preferred specification (3) from Table 3, which includes human labour, machine labour, and water, in addition to the variance of rainfall. Columns (1), (2) and (3) are first-stage regressions with log of human labour, machine labour and water per hectare, respectively, as the dependent variables regressed on all the instruments and exogenous variables in the model. The coefficients of the instruments are statistically significant at 1% level of significance implying a strong correlation between the instruments and the endogenous variables, satisfying the condition of relevance. As expected, the sign of the coefficients of the instruments are negative.

When the instrument is weakly correlated with the endogenous variable conditional on other covariates, the instrument is said to be weak. The weak IV estimates may not be consistent and IV estimator is biased towards the OLS estimator (Angrist and Pischke, 2009).

The Sanderson-Windmeijer (SW) first-stage F-statistic is relevant in the case of multiple endogenous variables to test for weak identification of instruments (Sanderson and Windmeijer, 2016). A significant SW first-stage F-statistic under the null hypothesis that coefficients of instrument(s) in the first-stage regression are jointly equal to zero, is necessary but not sufficient for the identification of parameters of the model.[18] Stock and Yogo (2005) define weak instruments in terms of relative size of bias of the IV estimator as compared to that of the OLS estimator. They provide tabulated critical values for standard F-statistic by fixing the largest relative bias of 2SLS as compared to OLS which

[18]For details, see Sanderson and Windmeijer, 2016, p. 215.

is acceptable. These critical values depend on the number of endogenous variables, the number of instruments and the acceptable level of bias. For instance, at maximal bias of 10 percent relative to OLS, the instrument is not considered weak if the SW first-stage F-statistic is greater than the tabulated critical value at 10 per cent.

Table 4: Production Function Estimates: FE – IV regressions

	First-stage regressions			Second-stage regression
	log (human labour) in hours per ha	log (machine labour) in hours per ha	log (water use) in cu m per ha	log (yield) in quintals per ha
	(1)	(2)	(3)	(4)
log (human labour)				0.330*
				(0.197)
log (machine labour)				-0.043
				(0.085)
log (water use)				0.154***
				(0.047)
log (casual labour wages)	-0.282***	0.007	0.145	
	(0.055)	(0.088)	(0.108)	
log (hired machine rent)	0.004	-0.191***	-0.074**	
	(0.021)	(0.036)	(0.038)	
log (own irrigation charges)	0.028**	0.025	-0.100***	
	(0.013)	(0.023)	(0.029)	
Groundwater depth	-0.006	0.016**	-0.099***	
	(0.004)	(0.006)	(0.009)	
Variance of monthly rainfall	0.000004*	0.000003	0.000002	-0.000015***
	(0.000002)	(0.000003)	(0.000004)	(0.000003)
Year 2012 dummy	0.065***	0.035	0.012	-0.087***
	(0.020)	(0.032)	(0.043)	(0.030)
Year 2013 dummy	-0.052***	0.008	-0.127	0.042*
	(0.013)	(0.020)	(0.020)	(0.022)
Parcel fixed effects	Yes	Yes	Yes	Yes
Observations	1,131	1,131	1,131	1,131
Number of parcels	410	410	410	410
Sanderson-Windmeijer multivariate F-statistic	15.81	15.66	64.20	

Notes: i. Cluster-robust standard errors are reported in the parentheses with clustering at the parcel-level; ii. Asterisks denote the significance levels: *** p<0.01, ** p<0.05, * p<0.1.
Source: Based on the cost of cultivation data from Directorate of Economics & Statistics, Ministry of Agriculture and Farmers Welfare, Government of India; rainfall data from Matsuura and Willmott (2015); groundwater depth data from Central Ground Water Board.

The first-stage Sanderson-Windmeijer (SW) multivariate F-statistics for human labour, machine labour, and water are 15.81, 15.66, and 64.20, respectively (Table 4). These exceed the Stock-Yogo critical value for 10% IV relative bias implying that the instruments are not weak given maximal bias of 10 per cent relative to OLS.[19]

Since the number of instruments exceed the number of endogenous variables, we test for over-identifying restrictions using the Hansen's J statistic. For the estimated model, the $\chi^2_{(1)}$ statistic is 0.010 with the p-value of 0.92 which implies that the over-identifying restrictions are valid.

The $\mathrm{FE} - \mathrm{IV}$ estimation presented in Table 4 is the preferred specification, and is used to estimate the marginal product of water and further, for the simulation analysis.[20,21] The coefficients of human labour and water have expected positive sign and are significant (column (4) in Table 4). With a 1 per cent increase in labour use per hectare, the average paddy yield increases by 0.33 per cent, keeping the other inputs fixed. Also, each per cent increase in water use per hectare leads to an increase of 0.15 per cent in the average paddy yields, holding the other inputs fixed. The coefficient for machine labour is insignificant. The variance in monthly rainfall has a negative significant coefficient which means that higher variability in monthly rainfall impacts the yield of paddy adversely. The average predicted yield from the estimated production function is 71.8 quintals per hectare.

[19]The Stock-Yogo weak ID F test critical values for 5%, 10%, 15%, and 20% maximal IV relative bias are 16.85, 10.27, 6.71, 5.34, respectively. The first-stage SW F-statistic for water exceeds the Stock-Yogo critical value for 5% IV relative bias.

[20]In the production function specification with fertilizer as an explanatory variable, we tried instrumenting for fertilizer input using its price. However, there is hardly any variation in fertilizer prices across various parcels and years. Thus, fertilizer price cannot be used as an instrument for fertilizer input. Fertilizer is not included in the model as an explanatory variable, rather it is a part of the error term. It is orthogonal to the included explanatory variables. The coefficients of all the variables in OLS regression with log of fertilizer per hectare as the dependent variable and log of human labour, machine labour and water, all in per hectare terms, as explanatory variables were found to be insignificant. See Table B3 in the Appendix for detailed results. Thus, fertilizer being a part of the error term does not bias the estimates of the included variables.

[21]We estimated the production function and total water use at various levels of pump efficiencies for each pump-type. We have considered four alternative cases: (a) 40% pump efficiency for all pump types; (b) 35% for diesel pump, 40% for electric-centrifugal pump, and 75% for electric-submersible pump; (c) changed the efficiency of diesel pump to 25%; (d) additionally changed the pump efficiency of electric-submersible to 85%. This affects the estimated water use in absolute terms. However, we find that the production function estimates are similar across all the specifications. Further, there is no substantial change in the estimated marginal product of water which is used in the simulations. See Table B4 in the Appendix for detailed results. To what extent the welfare calculations reported later are sensitive to different levels of water use requires further research.

4.2 Marginal Product of Water

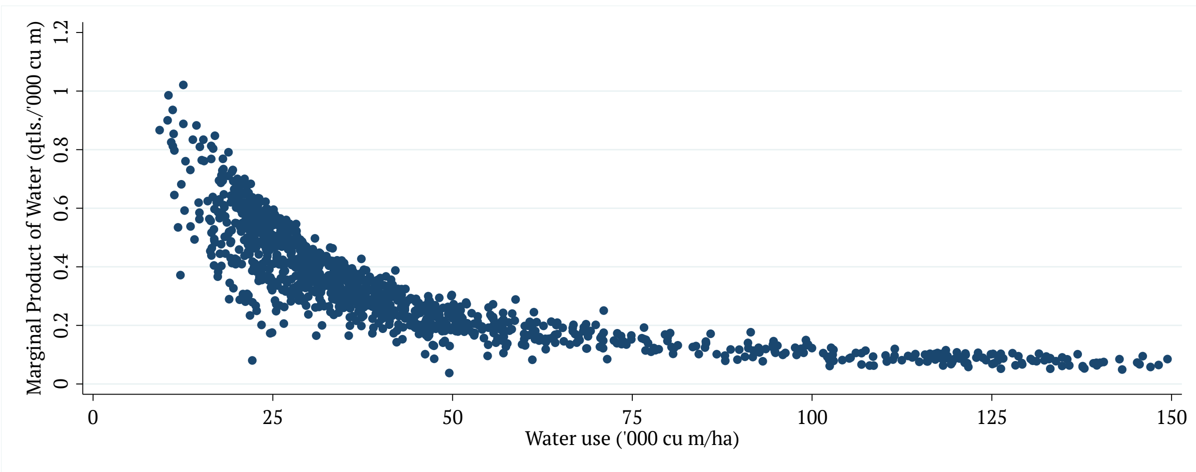
Using the estimates of the production function, we estimate the marginal product of water on every parcel as the partial derivative of the production function with respect to water.

The Cobb-Douglas production function can be written as[22],

$$y_{ijt} = A_i \, (h_{ijt})^{b_1} \, (m_{ijt})^{b_2} \, (w_{ijt})^{b_3} \, e^{b_4 V_{jt} + \lambda_1 d12 + \lambda_2 d13} \tag{5}$$

where b_1, b_2 and b_3 denote the coefficients of the estimated production function. The parcel-level productivities are denoted by A_i. The time dummies denoted by $d12$ and $d13$ take a value 1 if parcel is cultivated in 2012 and 2013, respectively and zero otherwise. The other notations are same as defined earlier, as in case of equation 2.

Figure 2: Estimated Marginal Product of Water Curve



Note: Largest 3% of the observations of water use have been dropped in the MPW curve.
Source: Based on the cost of cultivation data from the Directorate of Economics & Statistics, Ministry of Agriculture and Farmers Welfare, Government of India; rainfall data from Matsuura and Willmott (2015); groundwater depth data from Central Ground Water Board.

Differentiating equation 5 with respect to water use, we obtain the estimated marginal product of water (MPW_{ijt}) on parcel i in tehsil j in year t as,

$$MPW_{ijt} = A_i \, b_3 \, (h_{ijt})^{b_1} \, (m_{ijt})^{b_2} \, (w_{ijt})^{b_3 - 1} \, e^{b_4 V_{jt} + \lambda_1 d12 + \lambda_2 d13} \tag{6}$$

[22] e denotes the exponential function.

Figure 2 plots the estimated marginal product of water for all the parcels. On the horizontal axis is the total water use in thousand cubic meters per hectare. The marginal product of water is on the vertical axis, measured in quintals per thousand cubic meters of water per hectare. The estimated marginal product of water at the irrigation volumes chosen by the farmers is very low. The marginal product of water function is convex, as expected but relatively flat at the level of the average water application. This implies that additional units of water increase the amount of paddy output produced per hectare by a small amount and after a certain threshold, there is no increment in the the crop yields with additional units of water.

Table 5: Estimated Marginal Product of Water

	Mean	Bootstrap standard error	95% confidence intervals	
			Left	Right
Marginal Product of Water (qtls./ '000 cu m)	0.323	0.128	0.072	0.573

Notes: i. There are 504 parcels in the sample with 1,225 parcel-year observations;
ii. Clustered-robust bootstrap standard errors with 1000 replications along with normal-based 95% confidence intervals are reported. Clustering is done at the parcel-level.
Source: Based on the cost of cultivation data from the Directorate of Economics & Statistics, Ministry of Agriculture and Farmers Welfare, Government of India; rainfall data from Matsuura and Willmott (2015); groundwater depth data from Central Ground Water Board.

Table 5 presents summary statistics of the derived parcel-level estimates of the marginal product of water along with clustered bootstrap standard errors[23] and normal-based 95% confidence intervals. The average marginal product of water is 0.32 quintals for an additional thousand cubic meters of water per hectare.

We estimate the value of marginal product of water for parcel i in tehsil j in year t as MPW_{ijt} times the paddy price[24] in year t. The average value of marginal product of water is ₹365 per additional thousand cubic meters of water.

[23] Clustering is done at the parcel-level. 1000 replications are taken for computation of the bootstrap standard errors.

[24] Output price is converted into real terms using CPI-AL deflator keeping 2011 as the base year.

5 Water pumping and yields under unit pricing

In this section, we carry out simulations to estimate the reduction in groundwater pumping for paddy cultivation under volumetric pricing of farm electricity, keeping the quantities of other inputs constant. This is done for parcels on which farmers employ only electric pumps for the extraction of groundwater.[25]

We assume that the farmers are profit maximising agents. The unit cost of water (c_{ijt}) on parcel i in tehsil j in year t in the current scenario where agricultural electricity is free in Punjab, is estimated using the following optimum condition that equates the unit cost of water to the value of marginal product of water,[26]

$$c_{ijt} = P_t \times MPW_{ijt} \tag{7}$$

where P_t is the price of paddy in year t. The estimated cost of water reflects the pump maintenance costs. Using this and the parameters of the estimated production function, we simulate the optimal level of water use and paddy yields at different levels of electricity price. We vary the unit price of electricity starting from ₹0, which is currently the farm power price in Punjab, to ₹5.5 per kilowatt hour (kWh). The latter approximately corresponds to the average cost of supply of electricity to the agricultural sector in the state, as estimated by Punjab State Electricity Regulatory Commission for the period of study.

Every unit increase in the price of electricity is translated into incremental cost of water extraction given the groundwater depth and the horsepower rating of the pump. An increase in the price of farm electricity translates into higher cost of pumping water per hour which will impact water usage per hectare and thus, the yield of paddy.

[25] There are 11 per cent observations where only diesel pumps are employed and 5 per cent observations where there is conjunctive use of diesel and electric pumps. These observations are not considered for the simulation exercise.

[26] We assume here that the farmers know the amount of rainfall, since water is an aggregate of rainfall and irrigation from pumps.

To illustrate this, suppose that the price of electricity increases by ₹1 per kWh. This corresponds to ₹4 per hour for extraction of groundwater on the parcels that employ an electric non-submersible pump of 5 HP and ₹9 per hour for extraction of groundwater on the parcels that employ an electric submersible pump of 12 HP.[27]

Using equation 1, we estimate the amount of water (in thousand cubic meters) extracted in one hour on parcel i in tehsil j in year t that employ either type of the electric pump, given the tehsil-level groundwater depth, the horsepower rating of each pump-type and assuming that the efficiency of the electric pump is 75 per cent.

Dividing the incremental cost of water extraction in rupees per hour by the amount of water extracted in an hour on parcel i in tehsil j in year t, we obtain the incremental cost of water extraction δ_{ijt} measured in rupees per thousand cubic meters for parcel i in tehsil j in year t, due to one unit increase in the price of electricity.

We use the profit-maximizing condition to estimate the new optimal amount of water extracted using electric pumps ($\widetilde{w}_{it}^{E}$) on parcel i in tehsil j in year t due to an increase in cost of water by δ_{ijt} with the increment in power price.[28] This is evaluated at the parameters of the estimated production function and the new unit cost of water ($c_{ijt}+\delta_{ijt}$), keeping the other inputs quantities fixed,

$$c_{ijt} + \delta_{ijt} = P_t \times A_i \, b_3 \, (h_{ijt})^{b_1} \, (m_{ijt})^{b_2} \, (w_{jt}^{R} + \widetilde{w}_{ijt}^{E})^{b_3 - 1} \, e^{b_4 V_{jt} + \lambda_1 d12 + \lambda_2 d13}$$

$$\Rightarrow \quad \widetilde{w}_{ijt}^{E} = \left(\frac{c_{ijt} + \delta_{ijt}}{P_t \, A_i \, b_3 \, (h_{ijt})^{b_1} \, (m_{ijt})^{b_2} \, e^{b_4 V_{jt} + \lambda_1 d12 + \lambda_2 d13}} \right)^{\frac{1}{b_3 - 1}} - w_{jt}^{R} \tag{8}$$

Using the production function equation, we estimate the new optimum level of paddy yield $\widetilde{y}_{ijt}$ on parcel i in tehsil j in year t,

$$\widetilde{y}_{ijt} = A_i \, (h_{ijt})^{b_1} \, (m_{ijt})^{b_2} \, (w_{jt}^{R} + \widetilde{w}_{ijt}^{E})^{b_3} \, e^{b_4 V_{jt} + \lambda_1 d12 + \lambda_2 d13} \tag{9}$$

[27] 5 HP is equivalent to 3.73kW $\sim$ 4kW and 12 HP is equivalent to 8.95kW $\sim$ 9kW.

[28] As mentioned earlier, total water use is the sum of water extracted using pumps and rainfall. Since we consider here only parcels where electric pumps are employed for groundwater extraction, total water use is effectively the sum of water extracted using electric pumps (w_{it}^{E}) and rainwater (w_{jt}^{R}).

Table 6: Water extraction and yields for various electricity prices

Increase in the price of electricity (₹ /kWh)	Average incremental cost per unit of water (₹ / '000 cu m)	Water extraction per unit on area using electric pumps on an average parcel ('000 cu m/ha)		Estimated yield on an average parcel (qtls./ha)	
		Mean and std. error	95% confidence intervals	Mean and std. error	95% confidence intervals
0	0	44.68 (1.04)	L-42.64 R-46.72	73.59 (14.42)	L-45.33 R-101.84
1	60	36.08 (4.09)	L-28.05 R-44.11	71.55 (14.35)	L-43.41 R-99.68
1.5	90	32.88 (4.64)	L-23.78 R-41.98	70.67 (14.30)	L-42.65 R-98.69
2	120	30.16 (4.93)	L-20.50 R-39.82	69.86 (14.23)	L-41.96 R-97.77
2.5	151	27.81 (5.06)	L17.89 R-37.73	69.12 (14.17)	L-41.34 R-96.90
3	181	25.76 (5.10)	L-15.76 R-35.77	68.43 (14.11)	L-40.78 R-96.08
3.5	211	23.95 (5.09)	L-13.97 R-33.93	67.78 (14.04)	L-40.26 R-95.31
4	241	22.34 (5.04)	L-12.45 R-32.22	67.18 (13.98)	L-39.78 R-94.58
4.5	271	20.89 (4.97)	L-11.14 R-3.06	66.61 (13.92)	L-39.32 R-93.89
5	301	19.58 (4.88)	L-10.00 R-29.16	66.07 (13.86)	L-38.90 R-93.24
5.5	331	18.40 (4.79)	L-9.01 R-27.79	65.56 (13.80)	L-38.50 R-92.62

Notes: i. Simulation results are based on the parameters of the estimated production function and marginal product of water. This exercise is carried out for parcels that employ only electric pumps for groundwater extraction; ii. Clustered bootstrap standard errors with 1000 replications are reported in the parentheses. Clustering is done at the parcel-level. Normal-based 95% confidence intervals are also reported.
Source: Based on the cost of cultivation data from Directorate of Economics & Statistics, Ministry of Agriculture and Farmers Welfare, Government of India; rainfall data from Matsuura and Willmott (2015); groundwater depth data from Central Ground Water Board.

The summary statistics of the optimal levels of groundwater extraction and paddy yields from simulations are presented in Table 6. Here, we report the clustered bootstrap standard errors in the parentheses and normal-based 95% confidence intervals along with the average amount of groundwater extracted and average paddy yields at various increments of the unit cost of water.

There are 442 parcels in the sample where only electric pumps are used for groundwater extraction. The average amount of groundwater extraction on a parcel is 44.68 thousand cubic meters per hectare with the estimated paddy yield of 73.59 quintals per hectare. The simulations show that an increase in the price of electricity from its present level at zero to ₹5.5 per kWh leads to a reduction in the average amount of groundwater extraction to 18.40 thousand cubic meters per hectare while the average paddy yields reduce to 65.56 quintals per hectare. The results imply that pricing farm electricity at the margin causes a steep decline in the average groundwater extraction of about 59 per cent whereas the decline in the average paddy yields is about 11 per cent, assuming that other inputs remain unchanged. We obtain this result due to flat curvature of the estimated marginal product of water curve.

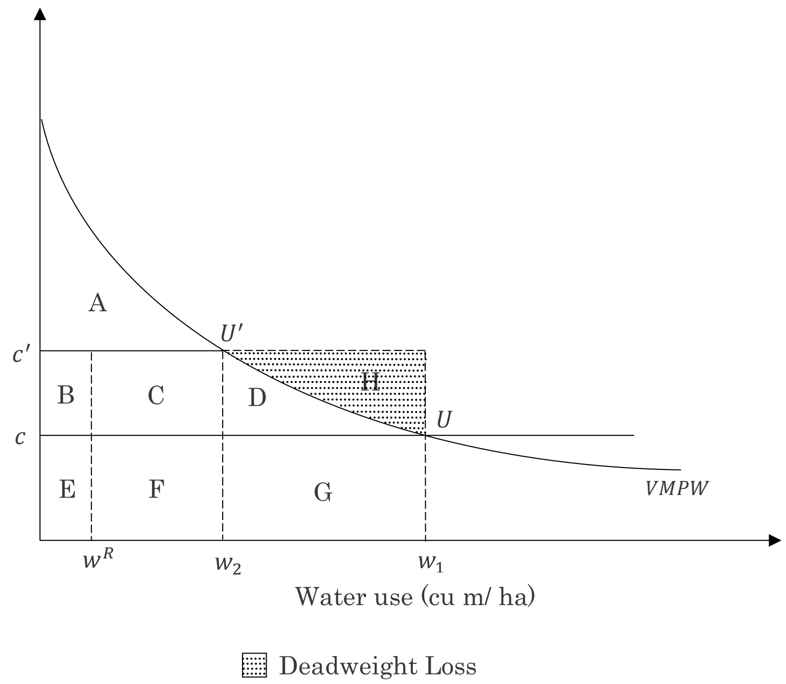
6 Welfare implications

In this section, we assess the welfare implications of volumetric pricing of farm electricity in Punjab. When electricity to the agricultural sector is priced lower than its cost of provision to the farmers (farm power is free in Punjab in the current scenario), there would be deadweight loss. We quantify the gains in efficiency from unit pricing of farm electricity in terms of reduction in the deadweight loss, under a partial equilibrium framework.

Several simplifying assumptions are made for the welfare analysis. Firstly, we assume that the farmers are profit maximising agents. Secondly, we use the average cost of farm power supply by the state electricity board as the only consideration for power supply. We do not consider the timing and the quality of power supply which might be adversely affected by power cuts and voltage fluctuations. Thirdly, we examine the change in the demand for water and keep the demand for other inputs, like human labour and machine labour, fixed. By doing so, we ignore the complementarities between water and other inputs.

Figure 3 presents the value of marginal product of water curve and the optimal unit cost of water under free farm electricity denoted by c and under volumetric pricing of farm electricity denoted by c'. These are measured in rupees per thousand cubic meters

Figure 3: Efficiency gain with volumetric pricing of farm electricity



	Free electricity pricing	Volumetric pricing
Farmer surplus	A + B + C + D + E	A + B + E
Pump maintenance costs	F + G	F
SEB cost/recovery	− (C + D + H)	C

of water along the vertical axis. On the horizontal axis, we measure total water use in thousand cubic meters per hectare which is the sum of water from rainfall (w^R) and groundwater extracted using electric pumps (w^E). Surplus and costs accruing to farmers and state electricity board under both the pricing regimes are also presented in the figure.

In the case of free farm electricity, the equilibrium is obtained at U where the value of marginal product of water equates to the unit cost of water c incurred by the farmer. The optimum amount of water use is denoted by w_1. Farmer surplus is depicted by areas A, B, C, D and E. Area E is the benefit accruing to the farmers due of rainwater. The average pump maintenance costs paid by the farmer are depicted by areas F and G.

Under volumetric pricing of farm electricity, the new equilibrium is obtained at U'. The optimum amount of water use in this scenario is denoted by w_2 such that $w_2 < w_1$. The farmer surplus is depicted by areas A, B and E where areas B and E are benefits due to rainfall. The farmer pays an amount equivalent to area F as the pump maintenance costs and area C is equivalent to the amount paid by the farmers to the state electricity board (SEB) for extraction of $(w_2 - w_R)$ amount of water at a unit price of c'.

When farm electricity is free, areas C and D are the benefits accruing to the farmers since the cost of water incurred by the farmers does not reflect the actual cost of provision of electricity. This extra cost is borne by the state electricity board. The actual unit cost of provision of electricity is c' and thus, actual cost of water that is used by the farmers is depicted by areas C, D, H, F and G. The loss incurred by the state electricity board is depicted by sum of areas C, D and H. Area H depicts the deadweight loss which is the inefficiency since market equilibrium for water is not achieved when farm electricity is free (shaded region in Figure 3). There is a gain in efficiency by the amount of the deadweight loss when electricity is priced at the margin. Deadweight loss DW_{ijt} for parcel i in tehsil j in year t is estimated as,

$$\begin{aligned} DW_{ijt} &= c'_{ijt}(w_{1ijt} - w_{2ijt}) - \int_{VMPW(w_{1ijt})}^{VMPW(w_{2ijt})} VMPW(w_{ijt})\,\mathrm{d}w_{ijt} \\ &= c'_{ijt}(w_{1ijt} - w_{2ijt}) - \int_{w_{1ijt}}^{w_{2ijt}} P_t A_i\, b_3\, (h_{ijt})^{b_1}\, (m_{ijt})^{b_2}\, (w_{ijt})^{b_3 - 1}\, e^{b_4 V_{jt} + \lambda_1 d12 + \lambda_2 d13}\,\mathrm{d}w_{ijt} \end{aligned}$$

Using equation 7, the value of marginal product of water, $VMPW()$, is estimated for a given parcel-year at w_{1it} level of water use under free electricity and at w_{2it} level of water use under volumetric pricing.

We estimate the gains and the losses to the farmers and the state electricity board for each of the 442 parcels in the sample where only electric pumps are employed for groundwater extraction. This is done using the estimates of the parameters of the production function, the estimated marginal product of water and the unit cost of water estimated in earlier sections. The summary statistics of the results are presented in Table 7. Under free farm electricity pricing, the unit cost of water is ₹371 per thousand cubic meters of water. When the price of electricity is increased to ₹5.5 per kWh to reflect the average cost of provision of electricity in agricultural sector in Punjab, the unit cost of water increases to ₹702 per thousand cubic meters of water. With an increase in the price of farm electricity, there is a reduction in the average amount of water use from 50.25 thousand

Table 7: Welfare under volumetric pricing of farm electricity

	Mean	Bootstrap std. error
Free farm electricity pricing		
Farmer surplus (Rs./ha)	72328	14441.3
Pump maintenance costs (Rs./ha)	10903	4262.7
Loss to SEB/Gov. subsidy (Rs./ha)	10211	144.1
Deadweight loss (Rs./ha)	4285	2328.2
Volumetric pricing: Electricity priced at Rs. 5.5 per kWh		
Farmer surplus (Rs./ha)	66402	15611.3
Pump maintenance costs (Rs./ha)	4281	3917.2
Amount recovered by SEB (Rs./ha)	3472	2380.2
Lump-sum transfer to farmer (Rs./ha)	5927	2321.4

Notes: i. Surplus and costs are estimated using the parameters of the estimates of the production function and unit cost of water; ii. 442 parcels in the sample where electric pumps are employed for groundwater extracted are considered for these estimations.
Source: Based on the cost of cultivation data from the Directorate of Economics & Statistics, Ministry of Agriculture and Farmers Welfare, Government of India; rainfall data from Matsuura and Willmott (2015); groundwater depth data from the Central Ground Water Board.

cubic meters per hectare to 23.97 thousand cubic meters per hectare. Under free farm electricity pricing regime, the state electricity board is incurring a loss of ₹10211 per hectare and the government provides an equivalent compensation to the state electricity board for covering the cost of provision of electricity to the farmers. However, under volumetric pricing, the state electricity board is able to recover an average amount of ₹3472 per hectare.

Further, the average surplus of the farmer gets reduced from ₹72328 per hectare under free farm electricity to ₹66402 per hectare under volumetric pricing of farm electricity. In order to keep the surplus of the farmers unchanged, the government can provide an average lump-sum transfer of ₹5927 per hectare (Areas C and D in Figure 3) to the farmers which is smaller than the amount of compensation that the government gives to the SEB for free provision of farm electricity. We find that volumetric pricing of farm electricity along with the lump-sum transfers to the farmers can keep the farmer surplus unchanged, recover costs incurred by SEB, lower the subsidy burden and reduce the amount of groundwater extraction. Moreover, there is an efficiency gain by the amount of deadweight loss. The average deadweight loss is ₹4284.55 per hectare.

7 Conclusion

Farm power is heavily subsidised leading to concerns regarding overuse of groundwater resources, especially in states like Punjab where electricity supply to the farmers is free. The burden of the subsidies is borne by the state electricity board and thus, these policies incentivize wasteful use of energy and water resources.

Using parcel-level panel data for paddy cultivation in Punjab, constructed using costs of cultivation surveys from the Ministry of Agriculture, groundwater data from the Central Ground Water Board and rainfall data from Matsuura and Willmott (2015), we estimated the production function for paddy using parcel-level fixed effects and instrumental variable approach to deal with omitted variable bias. The marginal product of water curve derived using the estimates of the production function is convex and has a flat curvature in the range of irrigation volumes chosen by the farmer. The average value of marginal product of water is estimated to be ₹365 per thousand cubic meters of water. Using simulations, our study suggests that volumetric pricing of farm electricity results in a sharp decline of 59 per cent in the average groundwater extraction while the reduction in average paddy yields is 11 per cent which is relatively smaller.

However, our study is subject to certain limitations. The analysis is done in a partial equilibrium framework. The simulations do not take into account the change in input use other than that of water at different levels of electricity prices. Thus, our simulation results provide a first approximation to the reduction in water use and yields under volumetric pricing. Moreover, the study does not consider timing and the quality of power supply in this analysis and uses the average cost of power supply by the SEB as the only consideration of electricity supply.

We provide welfare implications under volumetric pricing regime of farm electricity. Our study shows that pricing electricity at the margin not only reduces the amount of groundwater extraction but also increases the efficiency in terms of the reduction in the deadweight loss. We provide a politically feasible solution given that the objective of the government is to reduce the overextraction of groundwater resources and at the same time keep the welfare of farmers unchanged. Currently, the state electricity board bears the burden of free electricity provision to the farmers which in turn are provided compensation by the state government. Under the volumetric pricing regime, the state electricity board is able to recover the cost of provision of electricity since farmers pay for every unit of electricity consumed for groundwater extraction. However, the farmer surplus is reduced under volumetric pricing regime. We show that the government can provide lump-sum transfers to the farmers in order to keep their surplus unchanged and the average amount of lump-sum transfers are lower than the average compensation that the government gives to the state electricity board for free provision of power supply to the farmers.

References

Angrist, J. D. and J.-S. Pischke (2009). *Mostly Harmless Econometrics.* Princeton University Press, Princeton, NJ.

Auffhammer, M., V. Ramanathan, and J. R. Vincent (2012). Climate change, the monsoon, and rice yield in India. *Climatic change 111*(2), 411–424.

Badiani-Magnusson, R. and K. Jessoe (2018). Electricity Prices, Groundwater, and Agriculture: The Environmental and Agricultural Impacts of Electricity Subsidies in India. In W. Schlenker (Ed.), *Agricultural Productivity and Producer Behavior*, pp. 157–183. University of Chicago Press, Chicago.

Central Ground Water Board (2019). National Compilation on Dynamic Ground Water Resources of India, 2017. *Government of India, Ministry of Jal Shakti, Department of Water Resources, Central Ground Water Board, Faridabad.*

Deaton, A. (1995). Data and econometric tools for development analysis. *Handbook of development economics 3*, 1785–1882.

Fishman, R. (2016). More uneven distributions overturn benefits of higher precipitation for crop yields. *Environmental Research Letters 11*(2), 024004.

Fishman, R., U. Lall, V. Modi, and N. Parekh (2016). Can Electricity Pricing Save India's Groundwater? Field Evidence from a Novel Policy Mechanism in Gujarat. *Journal of the Association of Environmental and Resource Economists 3*(4), 819–855.

Gill, S. S. and K. S. Nehra (2018). Subsidy and Efficiency of Groundwater Use and Power Consumption in Haryana. *Economic and Political Weekly 53*(50).

Government of India (2015). Price Policy for Kharif Crops, The Marketing Season 2015-16. *Commission for Agricultural Costs and Prices, Department of Agriculture and Cooperation, Ministry of Agriculture.*

Griliches, Z. and J. Mairesse (1995). Production functions: the search for identification. Technical report, National Bureau of Economic Research.

Kumar, M. D. (2005). Impact of electricity prices and volumetric water allocation on energy and groundwater demand management: analysis from Western India. *Energy policy 33*(1), 39–51.

Kumar, M. D., C. A. Scott, and O. Singh (2011). Inducing the shift from flat-rate or free agricultural power to metered supply: Implications for groundwater depletion and power sector viability in India. *Journal of Hydrology 409*(1-2), 382–394.

Matsuura, K. and C. J. Willmott (2015). Terrestrial precipitation: 1900–2014 gridded monthly time series. *University of Delaware Dept. of Geography*.

Meenakshi, J., A. Banerji, A. Mukherji, and A. Gupta (2012). Does Marginal Cost Pricing of Electricity Affect Groundwater Pumping Behaviour of Farmers? *Project report submitted to International Initiative for Impact Evaluation (3ie) by International Water Management Institute (IWMI), New Delhi.*

Mitra, A., S. Balasubramanya, and R. Brouwer (2021). Can Cash Incentives Modify Groundwater Pumping Behaviours? Evidence from an Experiment in Punjab. Unpublished work.

Mukherji, A., B. Das, N. Majumdar, N. Nayak, R. Sethi, and B. R. Sharma (2009). Metering of agricultural power supply in West Bengal, India: Who gains and who loses? *Energy Policy 37*(12), 5530–5539.

Mukherji, A., T. Shah, and P. S. Banerjee (2012). Kick-starting a second green revolution in Bengal. *Economic and Political Weekly 47*(18), 27–30.

NSW Farmers Association (2013). Diesel versus electric pumps, Farm Energy Innovation - Energy & Irrigation. https://www.aginnovators.org.au/sites/default/files/Energy%20%20Irrigation%20-%20Diesel%20versus%20electric%20pumps.pdf. Last accessed on 7 January 2019.

Olley, G. S. and A. Pakes (1996). The Dynamics of Productivity in the Telecommunications Equipment Industry. *Econometrica: Journal of the Econometric Society*, 1263–1297.

Sanderson, E. and F. Windmeijer (2016). A weak instrument F-test in linear IV models with multiple endogenous variables. *Journal of Econometrics 190*(2), 212–221.

Sekhri, S. (2014). Wells, water, and welfare: the impact of access to groundwater on rural poverty and conflict. *American Economic Journal: Applied Economics 6*(3), 76–102.

Shah, T. (1993). *Groundwater Markets and Irrigation Development : Political Economy and Practical Policy.* Oxford University Press, Bombay.

Shah, T. and S. Chowdhury (2017). Farm power policies and groundwater markets contrasting Gujarat with West Bengal (1990–2015). *Economic and Political Weekly 52*(25&26), 39–47.

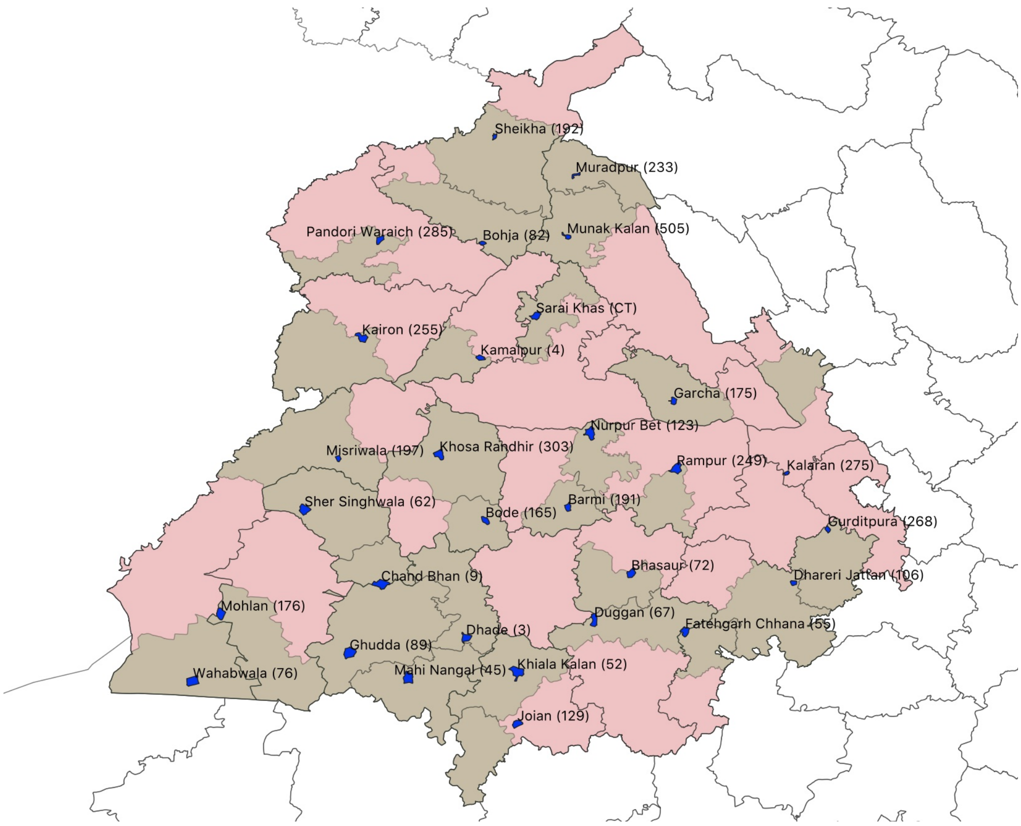
Singh, K. (2012). Electricity subsidy in Punjab agriculture: Extent and impact. *Indian Journal of Agricultural Economics 67*(4), 617–632.

Somanathan, E. and R. Ravindranath (2006). Measuring the marginal value of water and elasticity of demand for water in agriculture. *Economic and Political Weekly 41*(26), 2712–2715.

Stock, J. and M. Yogo (2005). Testing for weak instruments in linear iv regression. In D. W. K. Andrews and J. H. Stock (Eds.), *Identification and Inference for Econometric Models: Essays in Honor of Thomas Rothenberg*, pp. 80–108. New York: Cambridge University Press.

Appendix Figures

Figure A1: Villages sampled from Punjab in the cost of cultivation surveys



Source: Based on the cost of cultivation data for the period 2011-12 to 2013-14 from Directorate of Economics & Statistics, Ministry of Agriculture and Farmers Welfare, Government of India.

Appendix Tables

Table B1: Translog Production Function

Dependent variable: log (yield) in quintals per hectare			
	Coefficient	Robust std. error	p-value
log (human labour)	-5.404	6.227	0.385
log (machine labour)	-1.602	4.276	0.708
log (water use)	-3.564	2.479	0.151
log (human labour)-squared	-0.050	0.661	0.940
log (machine labour)-squared	0.122	0.38	0.748
log (water use)-squared	0.030	0.089	0.736
log (human labour)×log (machine labour)	0.232	0.731	0.751
log (human labour)×log (water use)	0.535	0.526	0.309
log (machine labour)×log (water use)	-0.031	0.293	0.915
Variance of monthly rainfall	-0.000012**	0.0000049	0.015
Year 2012 dummy	-0.071**	0.042	0.094
Year 2013 dummy	0.039	0.039	0.323
Parcel fixed-effects	Yes		
Observations	1,131		
Number of parcels	410		

Notes: i. All inputs are taken in per hectare terms; ii. The higher order terms, i.e. the squared and interaction terms are jointly insignificant with $\chi^2_{(6)} = 5.14$ (p-value = 0.525); iii. Cluster-robust standard errors are reported in the parentheses with clustering at the parcel-level; iv. Asterisks denote the significance levels: *** p<0.01, ** p<0.05, * p<0.1.
Source: Based on the cost of cultivation data from Directorate of Economics & Statistics, Ministry of Agriculture and Farmers Welfare, Government of India; rainfall data from Matsuura and Willmott (2015); groundwater depth data from Central Ground Water Board.

Table B2: Output Production Function [Constant Returns to Scale]

Dependent variable: log (output) in quintals							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
log (crop area) in ha	0.980***	1.024***	1.015***	0.941***	0.949***	0.979***	0.575**
	(0.037)	(0.050)	(0.049)	(0.064)	(0.067)	(0.076)	(0.236)
log (human labour) in hours		-0.088**	-0.073*	-0.069*	-0.067*	-0.063	0.386*
		(0.043)	(0.041)	(0.040)	(0.040)	(0.040)	(0.218)
log (machine labour) in hours		0.028	0.025	0.024	0.024	0.025	-0.041
		(0.023)	(0.023)	(0.023)	(0.023)	(0.023)	(0.085)
log (water) in cu m	0.053*	0.062**	0.059**	0.054**	0.054**	0.052**	0.159***
	(0.028)	(0.029)	(0.026)	(0.025)	(0.025)	(0.025)	(0.048)
log (fertilizer) in kilograms				0.078**	0.079**	0.082**	
				(0.031)	(0.031)	(0.033)	
log (insecticides) in ₹					-0.011	-0.012	
					(0.017)	(0.016)	
log (seeds) in ₹						-0.035	
						(0.067)	
Variance of monthly rainfall			-0.000014***	-0.000014***	-0.000014***	-0.000014***	-0.000015***
			(0.000003)	(0.000003)	(0.000003)	(0.000003)	(0.000003)
Method	Fixed-effects	Fixed-effects	Fixed-effects	Fixed-effects	Fixed-effects	Fixed-effects	FE – IV
Parcel fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Returns to scale	1.033 {CRS}	0.997 {CRS}	1.002 {CRS}	1.004 {CRS}	1.015 {CRS}	1.049 {CRS}	1.119 {CRS}
p-value [H_0: sum of coeff.= 1]	0.212	0.943	0.962	0.908	0.705	0.494	0.169
Observations	1,225	1,225	1,225	1,225	1,225	1,222	1,131
R-squared	0.760	0.762	0.775	0.776	0.777	0.777	0.716
Number of parcels	504	504	504	504	504	503	410

Notes: i. Cluster-robust standard errors are reported in the parentheses with clustering at the parcel-level; ii. Asterisks denote the significance levels: *** p<0.01, ** p<0.05, * p<0.1.
Source: Based on the cost of cultivation data from the Directorate of Economics & Statistics, Ministry of Agriculture and Farmers Welfare, Government of India; rainfall data from Matsuura and Willmott (2015); groundwater depth data from the Central Ground Water Board.

Table B3: OLS regression with log (fertilizer) in kilograms per hectare as the dependent variable

	Coefficient	Robust std. error	p-value
log (human labour) in hours/ha	-0.035	0.027	0.192
log (machine labour) in hours/ha	0.020	0.022	0.343
log (water use) in cu m/ha	0.007	0.012	0.508
Variance of monthly rainfall	-0.000006***	0.000001	0.000
Year 2012 dummy	-0.046**	0.018	0.011
Year 2013 dummy	-0.050***	0.016	0.003
Observations	1,225		
Number of parcels	504		

Note: Asterisks denote the significance levels: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.
Source: Based on the cost of cultivation data from the Directorate of Economics & Statistics, Ministry of Agriculture and Farmers Welfare, Government of India; rainfall data from Matsuura and Willmott (2015); groundwater depth data from the Central Ground Water Board.

Table B4: Yield Production Function at various pump efficiencies

Dependent variable: log (yield) in quintals/ha				
	(1)	(2)	(3)	(4)
log (human labour) in hours/ha	0.313	0.323*	0.310	0.312
	(0.197)	(0.196)	(0.198)	(0.198)
log (machine labour) in hours/ha	-0.055	-0.038	-0.061	-0.058
	(0.086)	(0.085)	(0.086)	(0.085)
log (water) in cu m/ha	0.161***	0.166***	0.163***	0.163***
	(0.050)	(0.051)	(0.050)	(0.050)
Variance of monthly rainfall	-0.000015***	-0.000015***	-0.000015***	-0.000015***
	(0.000003)	(0.000003)	(0.000003)	(0.000003)
Year 2012 dummy	-0.084***	-0.080***	-0.085***	-0.085***
	(0.030)	(0.029)	(0.030)	(0.030)
Year 2013 dummy	0.037*	0.039*	0.036*	0.037*
	(0.021)	(0.021)	(0.021)	(0.021)
Pump Efficiency				
Diesel	35%	40%	25%	25%
Electric centrifigal	40%	40%	40%	40%
Electric submersible	75%	40%	85%	75%
Average water use (cu m/ha)	42,136	32,430	43,798	40,840
Estimated Marginal Product of Water (qtls./'000 cu m)	0.37	0.48	0.37	0.39
Parcel fixed-effects	Yes	Yes	Yes	Yes
Observations	1,131	1,131	1,131	1,131
Number of parcels	410	410	410	410

Notes: i. Cluster-robust standard errors are reported in the parentheses with clustering at the parcel-level; ii. Asterisks denote the significance levels: *** p<0.01, ** p<0.05, * p<0.1.
Source: Based on the cost of cultivation data from Directorate of Economics & Statistics, Ministry of Agriculture and Farmers Welfare, Government of India; rainfall data from Matsuura and Willmott (2015); groundwater depth data from Central Ground Water Board.