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Electric Pumps, Groundwater, Agriculture and Water Buyers: Evidence from West Bengal

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ABSTRACT *Irrigation with electric pumps is cheaper than with diesel pumps in West Bengal where electricity and diesel are unsubsidised, and where pump owners typically irrigate their winter rice crop and often sell water to farmers who do not own pumps. Using purposefully selected primary data, we examine whether electric-pump owners have greater water access and rice production during the monsoon and winter seasons compared to diesel-pump owners and water buyers. We also examine whether electric pump-owners provide greater access to irrigation services through water sales. We find that electric-pump ownership increased agricultural outputs both at the extensive and intensive margins in both seasons. The number of clients served by electric-pump owners was greater than those served by diesel-pump owners, but there was only a small difference in total irrigated areas, suggesting that electric-pump owners sell water to farmers with smaller land holdings. The evidence indicates that in an environment where inadequate irrigation has been one of the factors constraining agriculture, electric pumps have the potential to support agricultural growth and generate pro-poor side effects.*

1. Introduction

How does access to a less expensive energy technology for water lifting affect agricultural outcomes in West Bengal? We examine this question in a context where surface irrigation schemes are limited, electric pump use was historically restricted by permits for connections and high fixed installation and grid-connection costs, and where a policy change was implemented in 2012 to ease permit requirements and to lower fixed costs without subsidising electricity. The alternative is for farmers to use small fuel pumps that are powered by unsubsidised diesel. Irrigating a given crop with a diesel pump, however, is more expensive than doing so with an electric pump (including fuel and other costs, see section 2).

Since 2011, farmers who reside in 'safe' administrative blocks (i.e. where groundwater has not been heavily developed and recharges significantly after the monsoons), whose tubewells discharge less than 30 m^3/hour, and who intend to use small pumps (less than 5 HP) no longer need permits from the State Water Investigation Department (SWID) to apply to the West Bengal State Electricity Distribution Company (WBSEDCL) for electric connections (Mukherji, Shah, & Banerjee, 2012). Since 2012, the Department of Agriculture has also provided farmers in 'safe' blocks with a one-time subsidy of INR 8,000 to connect their pumps to the grid (called the 'One Time Assistance for Electrification of Agricultural Pump-sets'). There are no subsidies for the purchase of pumps. In

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administrative areas identified as 'semi-critical' and 'critical', permits are still needed irrespective of the discharge of the tubewell or the size of the pump.[1] Following these changes, the number of electrified tubewells increased by 68 per cent from 2011 to 2018, to 296,405 wells.

Access to cheaper energy is likely to directly affect pump-owning farmers and their agricultural outcomes, but it may also benefit non-pump-owning farmers, who often purchase water from pump owners (Mukherji, 2007). With considerably lower energy costs, electric pumps may enable more non-pump-owning farmers to be served (extensive margin), or more of their land to be irrigated (intensive margin), or both. In this article, we test two specific hypotheses: (a) whether electric pumps affect cropping patterns, yields, value added, and irrigation practices of pump owners, and (b) whether electric pumps benefit non-pump-owners through water sales.

Estimating the effect of electric pumps on irrigated agriculture is likely to be confounded by two factors. At the block level, the relaxation of the permit system and the hydrological conditions are not random. We address this bias through our sampling strategy by selecting blocks that are just 'around' the threshold that separates 'safe' from 'semi-critical' blocks. This design controls for block-level features that may drive differences in irrigated agricultural outcomes. The second factor is selection into pump ownership, where 'better off' farmers – those who are wealthier, have larger land holdings and are better socially and politically connected – may be more likely to apply for electric pumps. To address this bias, we use propensity score matching (PSM) methods to construct a counterfactual group of diesel-pump owners and water buyers with observable characteristics that are similar to those of electric-pump owners.

We collected primary data through a survey of 1,396 farming households, where 370 households owned electric pumps, 398 owned just diesel pumps, and 628 bought their water. We find that electric-pump owners cultivate greater areas of monsoon and winter rice, and irrigate plots a greater number of times and for longer durations than diesel pump owners and water buyers. Monsoon rice yields and value added are higher for electric pump owners than diesel pump owners. Finally, electric pump owners provide irrigation water to a greater number of non-pump-owning farmers than diesel pump owners do, though there is little significant difference in the total size of irrigated areas belonging to their clients.

These results provide a justification for the permit-requirement relaxation and for the one-time fixed-cost subsidy. In an environment where agricultural growth has slowed (section 2), and access to irrigation is a limiting factor, electric pumps improve access to irrigation water for their owners and for smaller farmers who buy water from them, indicating its potential for generating pro-poor side effects.

It is worth noting that in this paper we do not directly estimate the effects of the groundwater and electrification policy changes. Rather, we indirectly examine the effects of the policy changes by studying the effects of electric pumps on agricultural outcomes, irrigation practices, and water sales. A direct examination of the policy was not possible in a context where there has been no variation in the policy across space and time since its inception. In addition, beyond lower fuel costs, electric pumps have lower maintenance costs and are more efficient. Since we cannot distinguish between fuel and other costs in our study, we consider them together as energy costs.

2. Context

State governments in the north, south and west of India have subsidised energy for agriculture (either diesel or electricity, or both; Badiani, Jessoe, & Plant, 2012), which have increased groundwater use (Badiani-Magnusson & Jessoe, 2018; Balali, Khalilian, Viaggi, Bartolini, & Ahmadian, 2011; Birner, Gupta, & Sharma, 2011; Briscoe & Malik, 2006; Janakarajan & Moench, 2006; Kimmich, 2016, Somanathan & Ravindranath, 2006)[2]; and consequently increased farm value-added (Bardhan, Mookherjee, & Kumar, 2012) and expanded cultivated area under water-intensive crops (Badiani-Magnusson & Jessoe, 2018). In West Bengal, however, diesel prices and electricity tariffs have never been subsidised (Mukherji, 2007). Farmers there pay the highest farm electricity tariff in India, which has tripled between 2009 and 2016 (Sarkar, 2020; Shah & Chowdhury, 2017). Nonetheless, electricity is still less expensive than diesel in West Bengal – the 'fuel' cost of using a five-horsepower diesel pump was around INR 41/hour in 2013, while that of a similar powered electric pump was around INR 26/hour during the day and only INR 7/hour at night.[3] In addition, electric pumps require less maintenance and are more efficient, and thus have lower overall energy costs.

West Bengal has three agricultural seasons (pre-monsoon, monsoon and winter), with the bulk of production taking place during the monsoon and winter seasons. Winter cultivation is possible only with groundwater irrigation, and monsoon cultivation is increasingly becoming dependent on supplemental irrigation due to south-west monsoon irregularities (Nandargi & Barman, 2018). It is common for farmers without pumps to purchase water from pump owners (Mukherji, 2004, reports that 48 per cent of pump owners sold water in 2003–04).

In the 2000s, growth in the agricultural sector stagnated due to a slow-down in the growth of electric pump use (Mukherji et al., 2012). In the 1980s and 1990s, a steady increase in production, areas under cultivation, and yields of winter rice (Figure 1) coincided with an increase in the number of electrified tubewells (Figure 2). As the number of electrified tubewells stagnated in the 2000s, so did these indicators (Figures 1 and 2).

The experience of neighbouring Bangladesh demonstrates the effects of easing access to cheaper energy for irrigation. The expansion of minor irrigation that followed the liberalisation of diesel-pump imports and the subsidisation of diesel in the mid-1980s, has been a major driver of long-term agricultural growth, poverty reduction, and food self-sufficiency there (Ahmed & Sampath, 1992; Palmer-Jones, 1992, 1999; Parvin & Rahman, 2009).

3. Sampling strategy and data

Our analysis is based on a sample of 1,396 farming households surveyed in six districts in West Bengal in May and June 2013. These households resided in 93 villages that were located in blocks which were purposively selected from administrative units that the Government of India categorised as 'safe' and 'semi-critical' in terms of groundwater development and recharge.

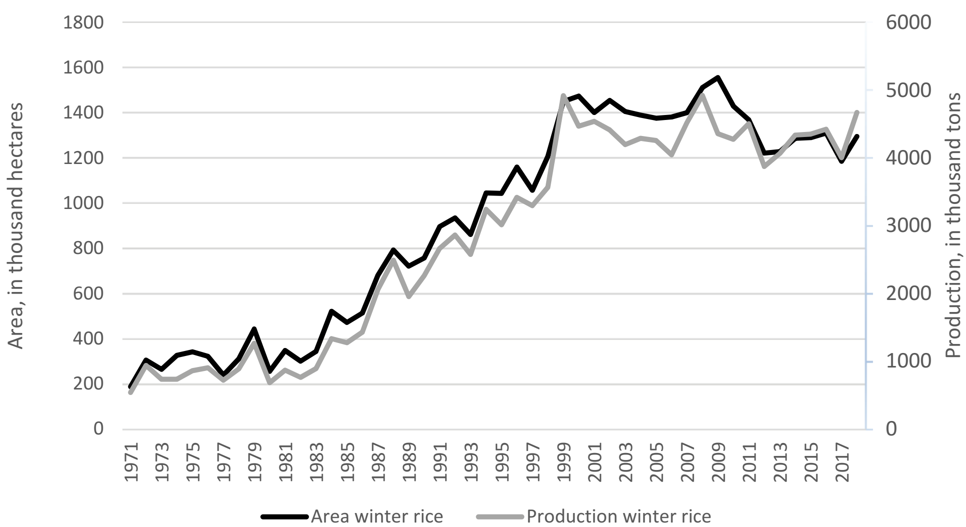

Figure 1. Area and production of winter rice produced in West Bengal.
Source: Own calculation from authors based on data published by the Bureau of Applied Economics and Statistics, Department of Statistics and Programme Implementation, Government of West Bengal.

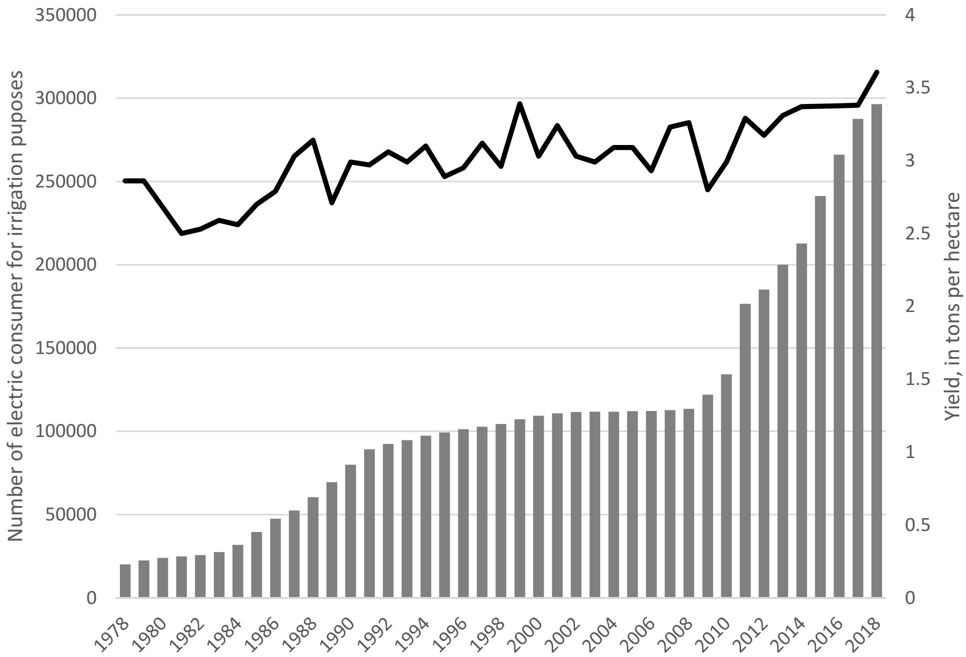

Figure 2. Number of tubewells permanently electrified and yield of winter rice in West Bengal.
Source: Own calculation from authors based on WBSEDCL Annual reports and data published by the Bureau of Applied Economics and Statistics, Department of Statistics and Programme Implementation, Government of West Bengal.

A census of pump owners was conducted in each selected village to classify them as electric or diesel pump owners. In villages where there were more than 15 electric- and diesel-pump-owning households in total, proportional numbers of these households were randomly selected. In villages where there were fewer than 15 electric- and diesel-pump-owning households in total, all of these households were selected, and water buyers were randomly selected in order to give a total of 15 households. This procedure resulted in a sample of households in which 26.5 per cent are electric-pump owners, 28.5 per cent are diesel-pump owners, and 45.0 per cent are water buyers. Although the sample is not representative of the population of rural farmers in West Bengal, it is representative of pump owners. The sample is large enough to provide adequate statistical power for comparisons of electric-pump-owning households with other farming households.

The survey instrument collected detailed information about households' agricultural production and practices over the course of the previous agricultural year. The one-year recall covered three cropping seasons. For logistical reasons, information on inputs and output quantities and costs was only collected for the plot with the easiest access to irrigation. This was usually the largest plot cultivated by the household, accounting for an average of 42.2 per cent of the total cultivated area. Information was collected on the characteristics of the wells and pumps owned by the household as well as on the associated investment and operational costs. For each season, respondents were asked how they used their pumps (frequency and duration). Water sellers provided information on their services and on the contractual arrangements they made for each of the irrigated crops. Respondents were asked about their access to agricultural electricity connections and associated costs. Finally, those using fossil fuels provided information on their fuel sources and prices, and on their procurement practices.

While 2012 was a year with a moderate deficit in monsoon rainfalls compared to the 1971–1990 mean, 2013 was a normal year (Kothawale & Rajeevan, 2017). We, therefore, do not expect our results to be driven by mitigation strategies linked to major climatic shocks (Rosenzweig & Udry, 2020).

4. Empirical strategy

The effect of electric pump ownership on on-farm outcomes is likely to be confounded by two factors: (1) permits were relaxed in 'safe' blocks, where agricultural outcomes and hydrological conditions could historically be different from those in 'semi-critical' blocks, and (2) farmers who have better outcomes are also more likely to have electric pumps. We address the former using a purposeful sampling strategy, and the latter using a propensity-score matching approach.

4.1. Non-random relaxation of permits at the block level

The Government of India uses two criteria to categorise administrative blocks as 'safe', 'semi-critical', and 'critical' in terms of groundwater: (a) the stage of groundwater development (SOD)[4]; and (b) long-term change in pre-monsoon and post-monsoon groundwater levels.[5] At the time of the survey, the categorisation for West Bengal was based on data collected in 2009, before the policy change.

Hydrological conditions that might influence agricultural outcomes such as cropping choices, yields, value-added, and irrigation decisions are likely to be quasi-random just around the threshold that separates 'safe' from 'semi-critical' blocks. There is, however, a discrete, and exogenous, difference in the transaction costs of acquiring an electricity connection between 'safe' and 'semi-critical' blocks which likely affects new electric-pump ownership but not on-farm outcomes.

Since SOD and post-monsoon groundwater-decline levels uniquely distinguish 'safe' from 'semi-critical' blocks, these were used for selecting blocks. In blocks where the SOD was less than 90 per cent, blocks within 5 cm of the 20 cm post-monsoon groundwater-decline threshold were sampled (i.e. Zone 1 in Figure 3). Similarly, blocks with post-monsoon groundwater-decline lower than 20 cm per year and within 10 percentage points of the 90 per cent SOD threshold were selected

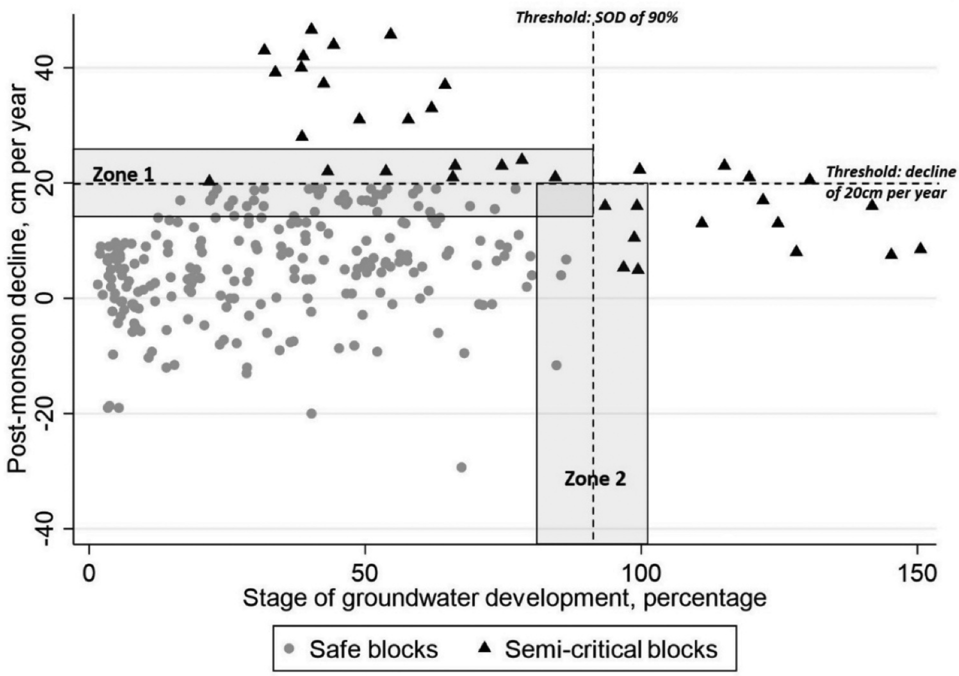

Figure 3. Stages of groundwater development and post-monsoon groundwater decline of administrative blocks in West Bengal.

(i.e. Zone 2 in Figure 3). In total, 33 blocks were purposively selected, 20 of which were ‘safe’ and 13 of which were ‘semi-critical’ (Figure 4).

4.2. Non-random selection into pump ownership

Farmers with better outcomes may be more likely to acquire electric pumps, biasing the observed relationship between electric-pump ownership and these outcomes. Acquiring an electric pump is also likely correlated with observable farmer characteristics ($\boldsymbol{X}$) that are themselves correlated with the outcome variables (Y). We thus follow Rosenbaum and Rubin (1983) and compare the average differences in outcomes for electric-pump owners (T = 1) and non-electric-pump owners (T = 0) ‘matched’ on the conditional probability of being an electric pump owner (Prob($T = 1 \mid \boldsymbol{X}$); referred to as a propensity score).

Propensity scores were estimated using a logit model in which the dependent variable is an indicator of whether the farm has an electric pump. The following observable household/farm characteristics were included as predictors: the area of land cultivated; a productive asset index constructed using principal component analysis[6]; the proportion of household members involved in agriculture; information on the household head (age, education, religion, and caste) and on the number of household members; a wealth asset index constructed using principal component analysis[7]; an indicator of whether the household has any off-farm sources of income; village level pre- and post-monsoon groundwater depth; status as a ‘semi-critical’ block (vs. being a ‘safe’ block); presence of electricity connections for domestic purposes; the difference between the blocks’ actual SOD measured in 2009 and the 90 per cent SOD threshold; and the difference between the 20 cm threshold in the decline in groundwater depth and the blocks’ actual pre- and post-monsoon measured declines, respectively. The choice of these determinants (including minor ones and those affected by electric-pump ownership) was guided by the need to minimise omitted variables bias (for example, see Heckman, Ichimura, & Todd, 1997; Smith & Todd, 2005).

Summary statistics for all the variables used in the analysis are presented in Table 1, and the results of the logit regression for the pooled sample (electric-pump owners, diesel-pump owners, and water buyers) are presented in Table 2. These regression estimates are as expected.

Coefficients from the logit model were used to estimate propensity scores for each of the households. Then, a nearest-neighbour matching was performed, where each electric-pump owner was matched with five counterfactual farmers (diesel-pump owners and water buyers[8]) that had the closest propensity scores within a 0.01 probability band from the electric-pump farmer’s propensity score. Alternate matching methods (first nearest neighbour, kernel matching, radius matching) with different calipers (from 0.01 to 0.2) yielded similar results and the sensitivity analysis is presented in Supplementary Appendix Figure A.1.

Conditional independence was tested using Durbin-Wu-Hausman tests where the outcome (Y) was regressed on the propensity score and the residuals from the logit model (Supplementary Appendix Table A.1). Unobserved heterogeneity was checked using the bounding approach (Rosenbaum, 2002; see Supplementary Appendix Table A.2), and the results suggest that for most of the outcome variables, the analysis is sensitive to the existence of unobservables (Abou-Ali, El-Azony, El-Laithy, Haughton, & Khandker, 2010; Duvendack & Palmer-Jones, 2011). As such, we are cautious about interpreting the PSM results as causal. Kernel density estimates of the propensity scores for the electric-pump owners and counterfactual farmers confirm large overlapping support (Supplementary Appendix Figure A.2; Heckman et al., 1997). Finally, t-test of differences were used to compare the observable characteristics, outcome variables and propensity scores of the electric-pump owners and counterfactual farmers before and after the matching (Supplementary Appendix Table A.3) and standardised percentage bias[9] were also plotted (Supplementary Appendix Figure A.3; Imbens & Wooldridge, 2009). The two approaches confirm minimal differences in the matched sample.

In Tables 3–6, we present mean differences in outcomes over the common support between the electric-pump owners and the non-pump owners weighted by the propensity score for each unit.

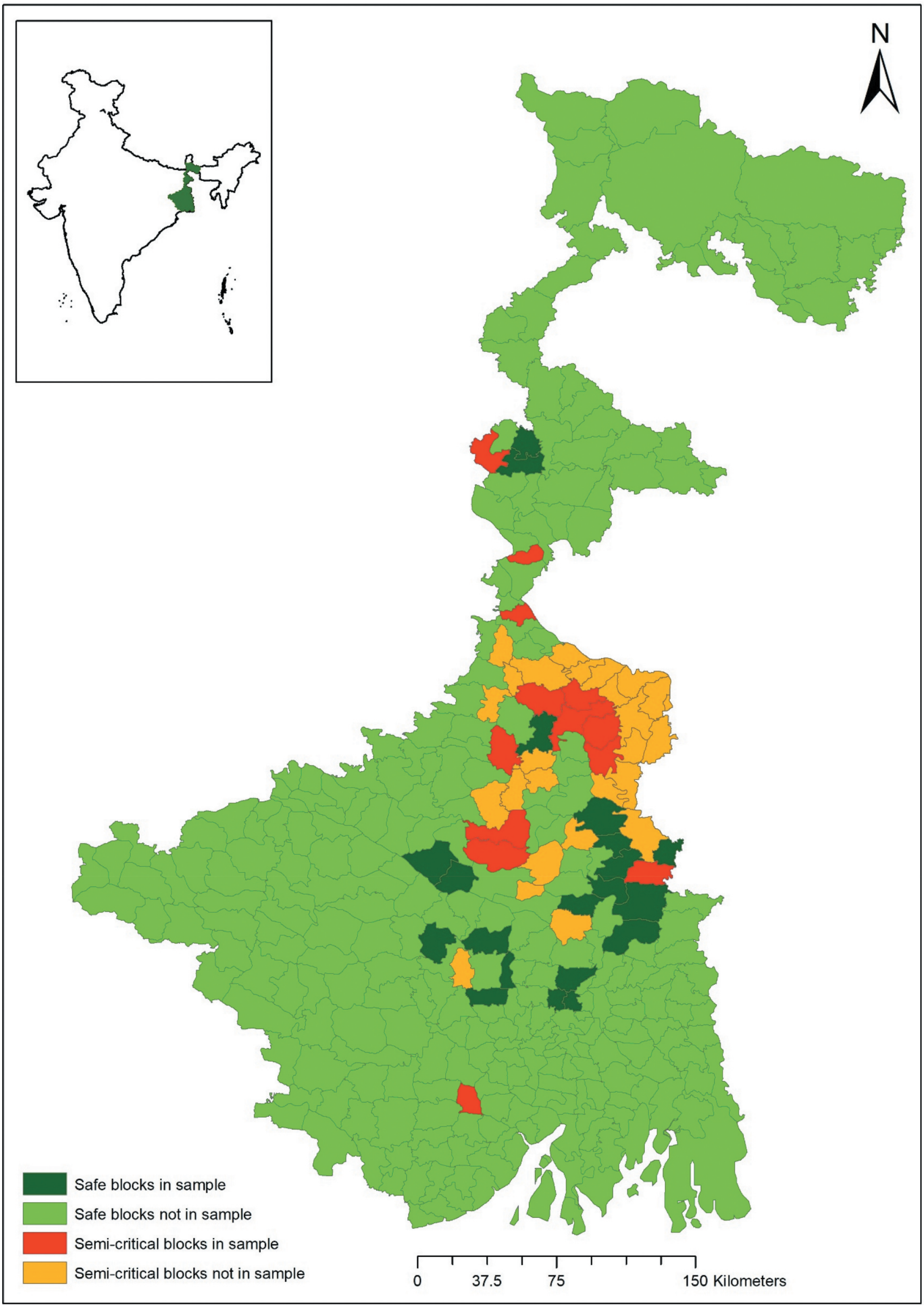

Figure 4. Map of blocks categorisation in 2009 and sample selection.

Table 1. Summary statistics

Variables		Obs	Mean	Standard deviation	Minimum	Maximum
	Electric-pump owner, dummy	1,396	0.27	0.44	0.00	1.00
Need for electrification	Net cultivated area, in acres	1,396	2.0	2.4	0.00	20
	Productive assets index	1,396	0.00	0.73	−1.23	1.42
	Proportion of the members in agriculture	1,396	0.47	0.25	0.00	1.00
Social capital	Age head of household	1,396	53.4	11.8	17.0	95.0
	No education (=1, 0 otherwise)	1,396	0.01	0.08	0.00	1.00
	Primary level of education (=1, 0 otherwise)	1,396	0.49	0.50	0.00	1.00
	Hindu (=1, 0 otherwise)	1,396	0.68	0.47	0.00	1.00
	Number of household members	1,396	5.7	2.8	1.00	17.0
Economic capacity	Domestic assets index	1,396	0.00	0.86	−1.81	1.52
	Sources of income apart from agriculture (=1, 0 otherwise)	1,396	0.75	0.44	0.00	1.00
Environmental and technical suitability	Domestic electric connection (=1, 0 otherwise)	1,387	0.92	0.27	0.00	1.00
	Pre-monsoon depth of groundwater (GW)	1,396	71.7	32.0	25.0	170.0
	(Pre-monsoon depth of GW)^2	1,396	6,164.8	5630.1	625.0	28,900.0
	Post-monsoon depth of GW	1,396	47.8	21.9	10.0	100.0
	(Post-monsoon depth of GW)^2	1,396	2,763.1	2295.8	100.0	10,000.0
	Semi-critical block (=1, 0 otherwise)	1,396	0.46	0.50	0.00	1.00
Distance from threshold	Distance from SOD 90% cut-off	1,396	34.6	21.9	−9.7	69.4
	Distance from 20 cm GW depth threshold (pre-monsoon)	1,396	11.0	13.1	−9.0	58.0
	Distance from 20 cm GW depth threshold (post-monsoon)	1,396	1.43	5.70	−17.3	17.0
Dependent variables	Crop intensity	1,396	195.1	76.6	0.0	300.0
	Winter rice					
	Share of net cultivated area	1,396	0.43	0.44	0.00	1.00
	Yield (kg/acre)	645	1,763.4	604.3	50.5	4,848.5
	Value added (INR/acre)	644	2,992.2	12,417.1	−174,248.9	54,012.1
	Number of irrigations	649	34.1	23.1	0.00	99.0
	Duration of irrigation (hours/acre)	665	203.0	202.9	0.00	2,400.0
	Number of buyers	766	2.8	7.5	0.00	50.0
	Area served (acre)	767	0.19	0.91	0.00	9.9
	Monsoon rice					
	Share of net cultivated area	1,396	0.73	0.40	0.00	1.00
	Yield (kg/acre)	1,093	1,418.4	494.2	30.3	4,242.4
	Value added (INR/acre)	1,092	987.4	6,414.0	−20,046.3	28,363.6
	Number of irrigations	1,074	8.7	13.2	0.00	90.0
	Duration of irrigation (hours/acre)	1,104	57.3	91.9	0.00	1,212.1
	Number of buyers	759	3.9	8.5	0.00	50.0
	Area served (acre)	766	0.37	1.5	0.00	16.5

Table 2. Logit model of electric-pump ownership

	Variables		Logit Electric pump owner
Need for electrification	Net cultivated area		0.136***
			(0.0389)
	Productive assets index		0.662***
			(0.126)
	Proportion of the members in agriculture		−0.364
			(0.305)
Social capital	Age head of household		−0.00447
			(0.00656)
	No education		0.602
			(0.865)
	Primary level of education		0.106
			(0.147)
	Hindu		−0.543**
			(0.212)
	Number of household members		−0.0221
			(0.0293)
Economic capacity	Domestic assets index		0.403***
			(0.109)
	Sources of income apart from agriculture		−0.291*
			(0.163)
Environmental and technical suitability	Domestic electric connection		0.194
			(0.328)
	Pre-monsoon depth of groundwater (GW)		0.0811***
			(0.0201)
	(Pre-monsoon depth of GW)^2		−0.000392***
			(0.000103)
	Post-monsoon depth of GW		−0.0499*
			(0.0263)
	(Post-monsoon depth of GW)^2		0.000325
			(0.000220)
	Semi-critical block, dummy		0.921***
			(0.216)
Distance from threshold	Distance to SOD 90% cut-off		−0.00419
			(0.00574)
	Distance to 20 cm decline in GW depth in pre-monsoon		−0.00180
			(0.00737)
	Distance to 20 cm decline in GW depth in post-monsoon		−0.00254
			(0.0164)
	Constant		−1.718**
			(0.863)
	Caste dummies	Wald test	3.78
		P-value	(0.436)
	District dummies	Wald test	31.40
		P-value	(0.000)
	Observations		1387
	Pseudo R^2		0.223

Note: Standard errors in parentheses. *** stands for 1 per cent of significance, ** for 5 per cent and * for 10 per cent.

Table 3. Effects of electric-pump ownership on cropping patterns

		Crop intensity		Share of net cultivated area allocated to . . . Monsoon rice		Winter rice	
		Mean difference	Weighted OLS	Mean difference	Weighted OLS	Mean difference	Weighted OLS
A. Sample = electric, diesel & water buyers							
Electric pump owner		17.2***	33.078***	0.077***	0.054***	0.21***	0.33***
		(5.41)	(5.2)	(0.026)	(0.018)	(0.033)	(0.027)
Common support sample	*Non-pump owners*	1,010		1,010		1,010	
	Electric-pump owners	353		353		353	
Sample size		1,363	1,387	1,363	1,387	1,363	1,387
Adjusted R^2			0.12		0.27		0.33
B. Sample = electric & diesel							
Electric pump owner		13.5*	20.84***	0.13***	0.089***	0.25***	0.38***
		(8.7)	(4.7)	(0.047)	(0.019)	(0.049)	(0.023)
Common support sample	*Diesel-pump owners*	384		384		384	
	Electric-pump owners	307		307		307	
Sample size		691	765	691	765	691	765
Adjusted R^2			0.26		0.43		0.52
C. Sample = electric & water buyers							
Electric pump owner		26.9***	40.9***	0.012	−0.0015	0.21***	0.36***
		(10.6)	(3.8)	(0.056)	(0.015)	(0.037)	(0.022)
Common support sample	*Water buyers*	538		538		538	
	Electric-pump owners	327		327		327	
Sample size		865	990	865	990	865	990
Adjusted R^2			0.18		0.28		0.43

Notes: Mean difference = Mean difference in outcome between the electric pump owners and the counterfactual group over the common support, weighted by the propensity score for each unit. Figures in parentheses are analytical standard errors for the mean differences and standard errors for the weighted OLS. Control variables are included in the weighted OLS regressions but results are omitted here. *** stands for 1 per cent of significance, ** for 5 per cent and * for 10 per cent.

Table 4. Effects of electric-pump ownership on rice yields and value-added

		Monsoon Rice				Winter Rice			
		Yield (kg/acre)		Value Added (INR/acre)		Yield (kg/acre)		Value added (INR/acre)	
		Mean difference	Weighted OLS	Mean difference	Weighted OLS	Mean difference	Weighted OLS	Mean difference	Weighted OLS
A. Sample* = *electric, diesel & water buyers									
Electric pump owner		82.4	85.3*	1,273.0**	587.9	179.3*	141.4*	2,659.0**	1,381.7
		(55.9)	(47.01)	(622.5)	(540.5)	(101.0)	(79.03)	(1,344.3)	(1,461.7)
Common support sample	*Non-pump owners*	751		750		387		386	
	Electric-pump owners	320		320		255		255	
Sample size		1,071	1,090	1,070	1,089	642	642	641	641
Adjusted R^2			0.90		0.20		0.89		0.14
B. Sample* = *electric & diesel									
Electric pump owner		126.8	153.7***	2,044.3**	1,749.4***	56.7	97.7	2,744.5	3,870.4**
		(93.3)	(40.1)	(1004.1)	(531.3)	(312.6)	(81.7)	(2104.2)	(1,879.7)
Common support sample	*Diesel-pump owners*	264		264		108		107	
	Electric-pump owners	277		277		255		136	
Sample size		541	609	541	609	383	383	243	382
Adjusted R^2			0.91		0.13		0.091		0.017
C. Sample* = *electric & water buyers									
Electric pump owner		47.9	40.5	932.4	337.8	143.5	−81.8	1,074.0	−693.6
		(78.2)	(37.1)	(650.5)	(419.3)	(154.7)	(53.3)	(1,501.1)	(1,238.7)
Common support sample	*Water buyers*	421		421		209		209	
	Electric-pump owners	296		296		176		176	
Sample size		717	816	717	815	385	514	385	514
Adjusted R^2			0.89		0.24		0.12		0.039

Notes: Mean difference = Mean difference in outcome between the electric pump owners and the counterfactual group over the common support, weighted by the propensity score for each unit. Figures in parentheses are analytical standard errors for the mean differences and standard errors for the weighted OLS. Control variables are included in the weighted OLS regressions but results are omitted here. *** stands for 1 per cent of significance, ** for 5 per cent and * for 10 per cent.

Table 5. Effects of electric-pump ownership on water use

		Monsoon Rice				Winter rice			
		Total irrigations (number/crop)		Hours (hours/acre/crop)		Total irrigations (number/crop)		Hours (hours/acre/crop)	
		Mean difference	Weighted OLS	Mean difference	Weighted OLS	Mean difference	Weighted OLS	Mean difference	Weighted OLS
A. Sample = electric, diesel & water buyers									
Electric pump owner		4.8***	3.8***	33.8***	30.8***	7.7***	9.6***	45.8**	58.4**
		(1.5)	(1.03)	(10.8)	(7.04)	(3.4)	(2.2)	(23.5)	(23.9)
Common support sample	*Non-pump owners*	734		760		364		377	
	Electric-pump owners	319		322		223		228	
Sample size		1,053	1,071	1,082	1,101	587	646	605	662
Adjusted R^2			0.479		0.431		0.746		0.53
B. Sample = electric & diesel									
Electric pump owner		3.7*	2.2*	39.1***	33.7***	−1.2	4.2	45.4	38.4
		(2.1)	(1.5)	(14.0)	(7.2)	(8.6)	(3.05)	(40.4)	(29.9)
Common support sample	*Diesel-pump owners*	248		268		108		112	
	Electric-pump owners	269		279		142		148	
Sample size		517	602	547	615	250	389	260	397
R^2			0.48		0.45		0.78		0.51
C. Sample = electric & water buyers									
Electric pump owner		4.6***	4.9***	27.4***	20.2***	10.9***	11.1***	41.1	11.8
		(1.2)	(0.88)	(10.5)	(6.4)	(3.5)	(1.9)	(28.6)	(18.9)
Common support sample	*Water buyers*	409		426		209		214	
	Electric-pump owners	288		298		180		183	
Sample size		697	803	724	823	389	520	397	529
Adjusted R^2			0.47		0.40		0.76		0.55

Notes: Mean difference = Mean difference in outcome between the electric pump owners and the counterfactual group over the common support, weighted by the propensity score for each unit. Figures in parentheses are analytical standard errors for the mean differences and standard errors for the weighted OLS. Control variables are included in the weighted OLS regressions but results are omitted here. *** stands for 1 per cent of significance, ** for 5 per cent and * for 10 per cent.

Table 6. Effects of electric-pump ownership on water sales

		Monsoon season				Winter season			
		Number of buyers		Area served (acre)		Number of buyers		Area served (acre)	
Sample = electric & diesel		Mean difference	Weighted OLS	Mean difference	Weighted OLS	Mean difference	Weighted OLS	Mean difference	Weighted OLS
Electric pump owner		5.6***	6.9***	0.48***	0.56***	3.8***	5.0***	0.22***	0.22***
		(0.68)	(0.58)	(0.14)	(0.11)	(0.57)	(0.52)	(0.12)	(0.061)
Common support sample	*Diesel-pump owners*	384		384		384		384	
	Electric-pump owners	300		305		305		306	
Sample size		684	756	689	763	689	763	690	764
Adjusted R^2			0.19		0.056		0.19		0.057

Notes: Mean difference = Mean difference in outcome between the electric pump owners and the counterfactual group over the common support, weighted by the propensity score for each unit. Figures in parentheses are analytical standard errors for the mean differences and standard errors for the weighted OLS. Control variables are included in the weighted OLS regressions but results are omitted here. *** stands for 1 per cent of significance, ** for 5 per cent and * for 10 per cent.

Because the standard confidence intervals computed for matching estimators are likely to be biased, analytical standard errors are presented (Abadie & Imbens, 2008).

As bias due to unobservable characteristics can never be entirely ruled out with matching estimators (Abadie & Imbens, 2016; Duvendack & Palmer-Jones, 2012; Smith & Todd, 2005), results from propensity-score weighted OLS regressions are also presented as a check for the propensity-score matching (Lechner, 2008). These estimates are based on the following model:

$$Y_i = \alpha + \beta T_i + \gamma X_i + \varepsilon_i,$$

where Y, T and X are the outcome variable, the pump-ownership variable, and control variables, respectively, as defined above. Weights of 1 for electric pump owners and $P(T = 1 \mid \boldsymbol{X})/(1 - P(T = 1 \mid \boldsymbol{X}))$ for the control observations are used (Chen, Mu, & Ravallion, 2009; Hirano, Imbens, & Ridder, 2003). The weighted OLS estimator was applied to the entire sample, not just to the sample with common support from the PSM. The set of covariates used in the weighted OLS include only those unlikely to be affected by pump ownership: age, education and cast of the household's head, number of household members, sources of income apart from agriculture, domestic electric connection, block category, and distance to categorisation thresholds.

5. Results

The estimated effects of electric-pump ownership on cropping patterns, rice yields, and value-added, irrigation for rice production, and water sales are presented in Tables 3–6, respectively. The results are replicated for three different samples. The first is the pooled sample of electric-pump owners, diesel-pump owners, and water buyers. The second is a truncated sample that includes only electric- and diesel-pump owners (that is excludes water buyers); and the third sample includes only electric-pump owners and water buyers (that is excludes diesel-pump owners).[10] For the effects of electric-pump ownership on water sales, we exclude water buyers and estimate the models on just the second sample of electric- and diesel-pump owners.

Since multiple outcomes are tested (the probability of committing a Type I error – falsely rejecting the null hypothesis – increases with the number of outcomes being tested), the family-wise error rate (FEW; that is the probability of one or more false rejections) is used to adjust the p-values. Different methods were used to calculate the adjusted p-values (Supplementary Appendix Table A.4). The classical method developed by Bonferroni (1935) adjusts the p-values for the number of outcomes considered; Holm (1979) orders the tests based on the p-value; and List, Shaikh, and Xu (2019) incorporate information about the joint dependence structure for a more restrictive test. All statistically significant estimates discussed below are also statistically significant when using the multiple adjusted p-values to determine significance.

5.1. Electric pumps and cropping patterns

Electric-pump owners used their land more intensively than both diesel-pump owners and water buyers. While the average cropping intensity (gross cropped area/net sown area) of 195.1 per cent in the pooled sample (Table 1) indicates that farmers in West Bengal generally used their plots twice a year for production, electric-pump owners used their land 13 percentage points more than diesel-pump owners, and 27 percentage points more than water buyers (Table 3).

In addition, electric pump owners also allocated more land to rice production, especially in the dry winter season; 25 percentage points more than diesel-pump owners, and 21 percentage points more than water buyers (Table 3). Considering that only 43 per cent of the land is used to produce rice in this season (Table 1), these large differences suggest that the lack of access to less expensive energy for water lifting has hindered rice production in the winter.

While there is no statistically significant difference compared to water buyers in the monsoon season, electric-pump owners also allocated 13 per cent more of their land to monsoon rice compared to diesel-pump owners (Table 3). This is a season where farmers in West Bengal allocate 73 per cent of their land to rice production (Table 1). In recent years, farmers in West Bengal tend to need supplemental irrigation for monsoon rice at the end of the growing period due to the vagaries of the monsoon. With a less-expensive source of energy than diesel-pump owners, electric-pump owners can allocate more land to rice during the monsoon period in the presence of rainfall uncertainty.

5.2. Electric pumps and rice yields and value-added

While access to electric pumps for irrigation did not significantly affects rice yields and value-added in the winter season, electric-pump owners had higher rice yields and values added than diesel-pump owners in the monsoon season. Monsoon season rice yields of electric-pump owners were 127 kg per acre greater than that of diesel-pump owners, and their value added was INR 2,044 per acre greater (Table 4). This is consistent with increasing need for supplemental irrigation at the end of the monsoon-season due to the vagaries of the monsoon.

5.3. Electric pumps and irrigation practices

Electric-pump owners irrigated their rice plots more frequently and for longer durations than both diesel-pump owners and water buyers. This was the case for the winter season, and more so for the monsoon season. Electric-pump owners conducted 3.7 more irrigations on their monsoon rice plots than diesel-pump owners, and 4.6 more than water buyers (Table 5). In doing so, they also irrigated their rice plots for a total of 39 more hours per acre than diesel-pump owners, and 27 more hours per acre than water buyers during the monsoon season. These differences are especially large; in the monsoon season, the average number of irrigations on rice plots is 8.7, and the average total duration is 57 hours per acre (Table 1).

During the winter season, electric-pump owners conducted 7.7 more irrigations on their rice plots and irrigated for 46 more hours per acre compared to the pooled group of diesel-pump owners and water buyers (Table 5). These differences were not as economically significant as during the monsoon season; farmers conducted substantially more irrigations (34.1) for longer durations (203 hours/acre) during the dry winter season than during the monsoons (Table 1). Disaggregating the counterfactual sample, a significant effect on the number of irrigations for winter rice plots was found when comparing electric pump owners to water buyers; electric-pump owners conducted 11 more irrigations on their rice plots than water buyers in the winter season (Table 5).

It is likely that electric-pump owners used more water, but without information on volumes of water (there is no metering of water), it is not possible to confirm this.

5.4. Electric pumps and water sales

Electric-pump owners sold water to more buyers than diesel-pump owners did, but the difference in the size of the land area served by their irrigation services was small both in the winter and in the monsoon season. Compared to diesel-pump owners, electric-pump owners sold water to an average of 5.6 more water buyers in the monsoon season, and 3.8 more buyers in the winter season (Table 6). They also provided irrigation services to 0.5 more acres of land on average in the monsoon season and 0.2 more acres in the winter season. As the average water buyer cultivated less area, owned fewer plots, and irrigated a smaller share of land compared to pump owners (Table 7), electric-pump owners sold water to more farmers with smaller holdings than diesel-pump owners did. The explanation of this finding may lay with the pumps' technical characteristics and the tariff structure. Diesel pumps can be moved around easily, and are often rented out to non-pump owners for a fixed fee. Electric pumps, on the other hand, are in fixed locations and can only irrigate plots in their vicinities.

Table 7. Average land and plot characteristics

	Electric-pump owners	Diesel-pump owners	Water buyers
Net cultivated area	3.39	2.10	1.17
	(2.95)	(2.40)	(1.48)
Area of irrigated plots	0.61	0.59	0.37
	(0.60)	(0.51)	(0.32)
Number of agricultural plots owned	9.98	6.20	4.68
	(7.79)	(5.72)	(5.46)

Note: Figures in parentheses are standard deviation.

6. Conclusion

This paper examines how access to electric pumps affects the short-run agricultural outcomes of owners, and of water buyers in West Bengal. Using primary data, we test two specific hypotheses: (a) whether electric pumps affect cropping patterns, yields, value added, and irrigation practices of pump owners, and (b) whether electric pumps benefit non-pump-owners through water sales. The results show that electric-pump owners cultivated larger areas of monsoon and winter rice, and irrigated plots a greater number of times and for longer durations than diesel pump owners and water buyers in 2013. Monsoon rice yields and value added were higher for electric pump owners than diesel pump owners. Moreover, electric pump owners provided irrigation water to a greater number of non-pump-owning farmers than diesel pump owners did, though there was little difference in the size of the total irrigated areas, suggesting that electric-pump owners sold water to farmers with smaller land holdings than diesel-pump owners did.

Using back-of-the-envelope calculations, electric-pump owners accrued an additional value-added of INR 1,273 per acre for monsoon rice, and INR 2,659 per acre for winter rice. Using the average farm size in the sample of about 2 acres, additional value-added for electric-pump owners was INR 7,970 per year, which is roughly the magnitude of the one-time fixed cost subsidy provided by the government to reduce the connection costs. This calculation does not account for the additional income electric pump owners received from water selling (~INR 12,000 more as compared to diesel-pump owners).

To put these results in context, we consider Badiani-Magnusson and Jessoe (2018) who exploited the variation in tariffs across administrative divisions and over time to estimate the effects of electricity tariff subsidies (that is variable-cost subsidies) on agricultural outcomes in India. Their study found positive impacts on agricultural output and shifts in the composition of crops towards more water-intensive ones that increased farmers' incomes. Unlike variable-cost subsidies that are perpetual and a major financial burden on governments, however, West Bengal's permit relaxation and the one-time fixed cost subsidy similarly leveraged significant incomes for the farmers at a relatively low cost to the government.

Our results suggest that relaxing the permit-requirement and providing a one-time fixed-cost subsidy in West Bengal were justified on a welfare basis. Moreover, our analysis suggests that in environments where agricultural growth has slowed and access to irrigation is a limiting factor, electric pumps can improve access to irrigation water for their owners and for smaller farmers who buy water from them. Policies such as those pursued by the West Bengal government thus also have pro-poor side effects[11] which are important for reviving the agricultural sector in the short term. They may also provide an alternative to energy tariff subsidies that are applied in most Indian states. In the long term, fixed cost subsidies may also mediate the risk of depleting groundwater resources, which energy tariff subsidies are less likely to do.

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Notes

1. This is a noticeable departure from the electricity subsidies provided by state governments in north and west India (Badiani et al., 2012). Prior to 2011, a high flat tariff was levied (Meenakshi, Banerhi, Mukherji, & Gupta, 2013).
2. While groundwater use likely needs to increase in West Bengal, its abstraction needs to be rationalised in the western parts of India where groundwater levels are rapidly falling. Non-price measures to encourage reductions in power and groundwater use, such as compensation to farmers for every unit of electricity they 'save' from an entitlement are being experimented with in Gujarat (Fishman, Lall, Modi, & Parekh, 2016). An increase in energy prices could reduce extraction of groundwater (Pfeiffer & Lin, 2014); but are likely to be contentious in a context where small and marginal farmers dominate the agricultural sector.
3. In West Bengal, the West Bengal State Electricity Department Corporation Limited (WBSED) applies three different tariffs over 24 hours for agricultural connections. Nights rates are much lower and are supposed to incentive farmers to irrigate during the nights to balance the power consumption.
4. The SOD is defined as the extraction of water as a per cent of the net renewable recharge. A SOD that is greater than 100 per cent, for example, means that more water is being extracted from the stock of groundwater than is flowing in, and thus the groundwater level is likely to fall.
5. A long-term decline is defined as groundwater levels falling by at least 20 cm per year on average over the previous 10 years.
6. The productive assets in this index include ploughs, power tillers/tractors, spay machine, husking machine, treadle pump, manual pumps, bullocks, cows, calves, buffalos, goats, sheep, chickens, ducks, and geese.
7. The wealth assets in this index include beds, chairs, tables, sofas, cupboards, wooden or steel boxes, radios, televisions, sewing machines, stoves, mobile phones, bicycles, motorcycles, solar panels, batteries, and water storage tanks.
8. We describe the PSM procedure here for the full sample. We also conducted the analysis separately for two subsamples with (1) electric-pump owners and diesel-pump owners, and (2) electric-pump owners and water buyers.
9. The standardised percentage bias is the difference of the sample means in the electric-pump owners and counterfactual sub-samples as a percentage of the square root of the average of the sample variances in the two groups (Rosenbaum & Rubin, 1985).
10. We conduct propensity score matching separately for the separate sub-samples (electric- and diesel-pump owners, and electric-pump owners and water buyers). Results of the logit prediction models and tests of conditional independence, common support, and balancing for these sub-samples are similar to those for the pooled sample and are available from the authors upon request.
11. Unpublished work conducted subsequently by the authors demonstrates that the majority of farmers who acquired electric pumps after the policy change were previously water buyers, suggesting that the early pro-poor side effect may have become a direct pro-poor effect over time.

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References

Abadie, A., & Imbens, G. (2008). On the failure of the bootstrap for matching estimators. *Econometrica*, *76*(6), 1537–1557.

Abadie, A., & Imbens, G. W. (2016). Matching on the estimated propensity score. *Econometrica*, *84*(2), 781–807.

Abou-Ali, H., El-Azony, H., El-Laithy, H., Haughton, J., & Khandker, S. (2010). Evaluating the impact of Egyptian social fund for development programmes. *Journal of Development Effectiveness*, *2*(4), 521–555.

Ahmed, A. U., & Sampath, R. K. (1992). Effects of irrigation-induced technological change in Bangladesh rice production. *American Journal of Agricultural Economics*, *74*(1), 144–157.

Badiani, R., Jessoe, K. K., & Plant, S. (2012). Development and the environment: The implications of agricultural electricity subsidies in India. *The Journal of Environment and Development*, *21*(2), 244–262.

Badiani-Magnusson, R., & Jessoe, K. (2018). Electricity prices, groundwater and agriculture: The environmental and agricultural impacts of electricity subsidies in India. In W. Schlenker (Ed.), *Agricultural productivity and producer behaviors*. National Bureau of Economic Research. Retrieved from https://www.nber.org/chapters/c13948.pdf

Balali, H., Khalilian, S., Viaggi, D., Bartolini, F., & Ahmadian, M. (2011). Groundwater balance and conservation under different water pricing and agricultural policy scenarios: A case study of the Hamadan-Bahar plain. *Ecological Economics*, *70*(5), 863–872.

Bardhan, P., Mookherjee, D., & Kumar, N. (2012). State-led or market-led green revolution? Role of private irrigation investment vis-a-vis local government programs in West Bengal's farm productivity growth. *Journal of Development Economics*, *99*(2), 222–235.

Birner, R., Gupta, S., & Sharma, N. (2011). *The political economy of agricultural policy reform in India: Fertilizers and electricity for irrigation*. Washington, DC: IFPRI Research Monograph, International Food Policy Research Institute. doi:10.2499/9780896291720

Bonferroni, C. E. (1935). Il calcolo delle assicurazioni su gruppi di teste. In Tipografia del Senato (Ed.), *Studi in onore del professore Salvatore Ortu Carboni* (pp. 13–60). Rome: Bardi.

Briscoe, J., & Malik, R. P. S. (2006). *India's water economy: Bracing for a turbulent future*. New Delhi, India: Oxford University Press. Retrieved from https://openknowledge.worldbank.org/handle/10986/7238

Chen, S., Mu, R., & Ravallion, M. (2009). Are there lasting impacts of aid to poor areas? *Journal of Public Economics*, *93*(3), 512–528.

Duvendack, M., & Palmer-Jones, R. (2011). Comment on: Abou-Ali, H., El-Azony, H., El-Laithy, H., Haughton, J. and Khandker, S., 2010. Evaluating the impact of Egyptian social fund for development programmes. *Journal of Development Effectiveness*, 2(4), 521–555. *Journal of Development Effectiveness*, *3*(2), 297–299.

Duvendack, M., & Palmer-Jones, R. (2012). High noon for microfinance impact evaluations: Re-investigating the evidence from Bangladesh. *The Journal of Development Studies*, *48*(12), 1864–1880.

Fishman, R., Lall, U., Modi, V., & Parekh, N. (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.

Heckman, J. J., Ichimura, H., & Todd, P. E. (1997). Matching as an econometric evaluation estimator: Evidence from evaluating a job training programme. *The Review of Economic Studies*, *64*(4), 605–654.

Hirano, K., Imbens, G. W., & Ridder, G. (2003). Efficient estimation of average treatment effects using the estimated propensity score. *Econometrica*, *71*(4), 1161–1189.

Holm, S. (1979). A simple sequential rejective multiple test procedure. *Scandinavian Journal of Statistics*, *6*(2), 65–70.

Imbens, G. W., & Wooldridge, J. M. (2009). Recent developments in the econometrics of program evaluation. *Journal of Economic Literature*, *47*(1), 5–86.

Janakarajan, S., & Moench, M. (2006). Are wells a potential threat to farmers well-being? Case of deteriorating groundwater irrigation in Tamil Nadu. *Economic and Political Weekly*, *41*(37), 3977–3987.

Kimmich, C. (2016). Can analytic narrative inform policy change? The political economy of the Indian electricity–irrigation nexus. *The Journal of Development Studies*, *52*(2), 269–285.

Kothawale, D. R., & Rajeevan, M. (2017). *Monthly, seasonal and annual rainfall time series for All-India, homogeneous regions and meteorological subdivisions: 1871-2016* (Research Report No. RR-138). Pune, India: Indian Institute of Tropical Meteorology.

Lechner, M. (2008). A note on the common support problem in applied evaluation studies. *Annales d'Économie et de Statistique*, (91/92), 217–235. doi:10.2307/27917246

List, J. A., Shaikh, A. M., & Xu, Y. (2019). Multiple hypothesis testing in experimental economics. *Experimental Economics*, *22*(4), 773–793.

Meenakshi, J. V., Banerhi, A., Mukherji, A., & Gupta, A. (2013). *Does marginal cost pricing of electricity affect groundwater pumping behavior of farmers? Evidence from India* (3ie Impact Evaluation Report. 4). New Delhi: International Initiative for Impact Evaluation (3ie). Retrieved from https://www.3ieimpact.org/evidence-hub/publications/impact-evaluations/does-marginal-cost-pricing-electricity-affect

Mukherji, A. (2004). Groundwater markets in Ganga-Meghna-Brahmaputra basin: Theory and evidence. *Economic and Political Weekly*, *39*(31), 3514–3520.

Mukherji, A. (2007). The energy-irrigation nexus and its impact on groundwater markets in eastern Indo-Gangetic basin: Evidence from West Bengal, India. *Energy Policy*, *35*(12), 6413–6430.

Mukherji, A., Shah, T., & Banerjee, P. S. (2012). Kick-starting a second green revolution in Bengal. *Economic and Political Weekly*, *47*(18), 27–30. Retrieved from https://hdl.handle.net/10568/34534

Nandargi, S. S., & Barman, K. (2018). Evaluation of climate change impact on rainfall variation in West Bengal. *Acta Scientific Agriculture*, *2*(7), 74–82.

Palmer-Jones, R. (1999). Slowdown in agricultural growth in Bangladesh: Neither a good description nor a description good to give. In B. Rogaly, B. Harriss-White, & S. Bose (Eds.), *Sonar Bangla? Agrarian structure and agricultural growth in Bengal* (pp. 92–136). Thousand Oaks: Sage.

Palmer-Jones, R. W. (1992). Sustaining serendipity? Groundwater irrigation, growth of agricultural production, and poverty in Bangladesh. *Economic and Political Weekly*, *27*(39), A128–A140.

Parvin, L., & Rahman, M. W. (2009). Impact of irrigation on food security in Bangladesh for the past three decades. *Journal of Water Resource and Protection*, *3*, 216–225.

Pfeiffer, L., & Lin, C. Y. C. (2014). The effects of energy prices on agricultural groundwater extraction from the high plains aquifer. *American Journal of Agricultural Economics*, *96*(5), 1349–1362.

Rosenbaum, P. R. (2002). Sensitivity to hidden bias. In *Observational studies* (pp. 105–170). New York, NY: Springer. doi:10.1007/978-1-4757-3692-2_4

Rosenbaum, P. R., & Rubin, D. B. (1983). The central role of the propensity score in observational studies for causal effects. *Biometrika*, *70*(1), 41–55.

Rosenbaum, P. R., & Rubin, D. B. (1985). Constructing a control group using multivariate matched sampling methods that incorporate the propensity score. *The American Statistician*, *39*(1), 33–38.

Rosenzweig, M. R., & Udry, C. (2020). External validity in a stochastic world: Evidence from low-income countries. *The Review of Economic Studies*, *87*(1), 343–381.

Sarkar, A. (2020). Groundwater irrigation and farm power policies in Punjab and West Bengal: Challenges and opportunities. *Energy Policy*, *140*, 111437.

Shah, T., & Chowdhury, S. D. (2017). Farm power policies and groundwater markets contrasting Gujarat with West Bengal (1990–2015). *Economic and Political Weekly*, *52*(32), 47–57.

Smith, J. A., & Todd, P. E. (2005). Does matching overcome LaLonde's critique of non-experimental estimators? *Journal of Econometrics*, *125*(1–2), 305–353.

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