Does increased access to groundwater irrigation through electricity reforms affect agricultural and groundwater outcomes? Evidence from West Bengal, India

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LIST OF ABBREVIATIONS

ATE	Average Treatment Effect
BCKV	Bidhan Chandra Krishi Viswavidyalaya
CAGR	Compound Annual Growth Rate
CCC	Customer Care Center
CGWB	Central Ground Water Board
DiD	Difference-in-Differences
DTW	Deep Tube Well
GCA	Gross Cropped Area
GP	*Gram Panchayat*
EAP	Electrification of Agricultural Pump-sets
FGD	Focus Group Discussion
IGP	Indo-Gangetic Plains
IWMI	International Water Management Institute
LATE	Local Average Treatment Limit
NSA	Net Sown Area
OTA	One Time Assistance
RDD	Regression Discontinuity Design
SOD	Stage of Groundwater Development
STW	Shallow Tube Well
SWID	State Water Investigation Directorate
TOD	Time of Day
WBSEB	West Bengal State Electricity Board
WBSEDCL	West Bengal State Electricity Distribution Company Limited
WRI&DD	Water Resources Investigation and Development Department

EXECUTIVE SUMMARY

The Indian state of West Bengal undertook three important policy reforms related to groundwater and electricity. These were: (i) universal metering of electric-run agricultural tube wells starting in 2007; (ii) change in the groundwater law in 2011, which removed the requirement of farmers having to procure a prior permit from the groundwater department to get an electricity connection; and (iii) provision of a capital cost subsidy for the electrification of groundwater pumps in 2012. These three policy measures helped remove barriers to the electrification of agricultural wells and tube wells. This resulted in a more than threefold increase in the number of electric pumps – from 86,776 in 2007 to 303,018 by 2018. In this report, we analyze the impact of the increase in the number of electric pumps on agriculture- and groundwater-related outcomes. For this analysis, we used data from 326 administrative blocks for the period from 2008 to 2019. In addition, we substantiate our findings with qualitative data collected from 11 villages during the period from October 2019 to February 2020.

We expect that electrification of wells and tube wells will affect agricultural and groundwater outcomes through lowering the costs of irrigation. Per unit costs of pumping groundwater with electric pumps is much lower than pumping with diesel pumps. Therefore, we expect that farmers with access to electric pumps will operate their pumps for longer hours and grow more water-intensive crops.

We find that despite the positive effect of the groundwater policy reform on the immediate outcome in terms of the number of pumps electrified, its effect on agricultural outcomes (cropping pattern, cropping intensity, cropped area, production and yield) was not evident. We did find a positive effect of the policy on the summer (*boro)* paddy area and production, and a negative effect on the area under pulses. Yet, these effects were not robust to different specifications and robustness checks, and were driven by a limited number of blocks. We also found that groundwater policy changes led to slight improvements in groundwater levels in the period after 2011, as compared to the period before. The expectation was that groundwater levels would decline further, but given that cropping patterns and crop water use had not changed significantly in the post-2011 period, there was no overall acceleration in the pace of groundwater extraction either.

We are then faced with a puzzle where the addition of over 216,000 new electric pumps seems to have had only a very limited effect on agricultural outcomes. We offer two possible explanations. First, we hypothesize that a substantial number of these so-called new 'permanent' electric pumps were already operating either as 'temporary' electric pumps or as diesel pumps. Similarly, we have anecdotal evidence from our qualitative fieldwork that a fair number of erstwhile water buyers opted for electricity connections when entry barriers for electrification were lowered. Therefore, it seems that there may have been only a minimal number of new water users brought into the ambit of irrigated agriculture as a result of the groundwater policy change. The main impact may have been a reduction in the costs and increased reliability of irrigation, especially for erstwhile diesel pump owners and water buyers. Second, we show that farmers did not particularly benefit from the lower cost of irrigation due to the continuously rising electricity tariffs as well the costs of other components of production. This, coupled with the relative stagnation in *boro* paddy prices, squeezed farmers' profit margins and discouraged them from expanding the area under water-intensive *boro* paddy. The lack of economic incentives for farmers possibly explains the absence of an extensive margin effect of the groundwater policy reform.

Given our findings, and in the context of a near certain agricultural downturn following the Covid-19 pandemic and Cyclone Amphan, we suggest that the Government of West Bengal reform its tariff structure in ways that it encourages the intensive use of groundwater for irrigation. Our qualitative fieldwork also showed that farmers, especially in water-abundant villages, view *boro* paddy as a critical crop that enhances their incomes as well as food security. *Boro* paddy is also more labor intensive than other field crops. Given the immediate need for food security, and the need to absorb surplus labor in agriculture, the government should also encourage *boro* paddy cultivation. Due to Covid-19-related disruptions, many migrant youths have returned or will return to the villages in the near future. This will create a surplus labor pool in the villages. Reforming the paddy procurement system to enable small and marginal farmers to pool together their produce and sell to the government procurement camps will ensure they get a fair price for their produce. Overall, we recommend policies to improve profitability from agriculture, such as the lowering of electricity tariffs for irrigation. This could be achieved through the promotion of *boro* paddy in water-abundant parts of the state, and diversification to less water-intensive crops in western parts of the state.

1. INTRODUCTION

The Indian state of West Bengal undertook three important policy reforms related to groundwater and electricity[1]. These were: (i) universal metering of electric-run agricultural tube wells (henceforth called electric pumps for ease of understanding) starting in 2007; (ii) change in the groundwater law in 2011, and (iii) provision of a capital cost subsidy for the electrification of pumps in 2012. These three policy measures helped remove barriers to electrification of agricultural wells and tube wells in the state. This resulted in a more than threefold increase in the number of electric pumps – from 86,776 in 2007 to 303,018 by 2018 (Figure 1). In this report, we analyze the impact of the increase in the number of electric pumps on agriculture and groundwater-related outcomes. For this analysis, we use data from 326 administrative blocks[2] for a period from 2008 to 2019. In addition, we substantiate our findings with qualitative data collected from 11 villages during the period from October 2019 to February 2020.

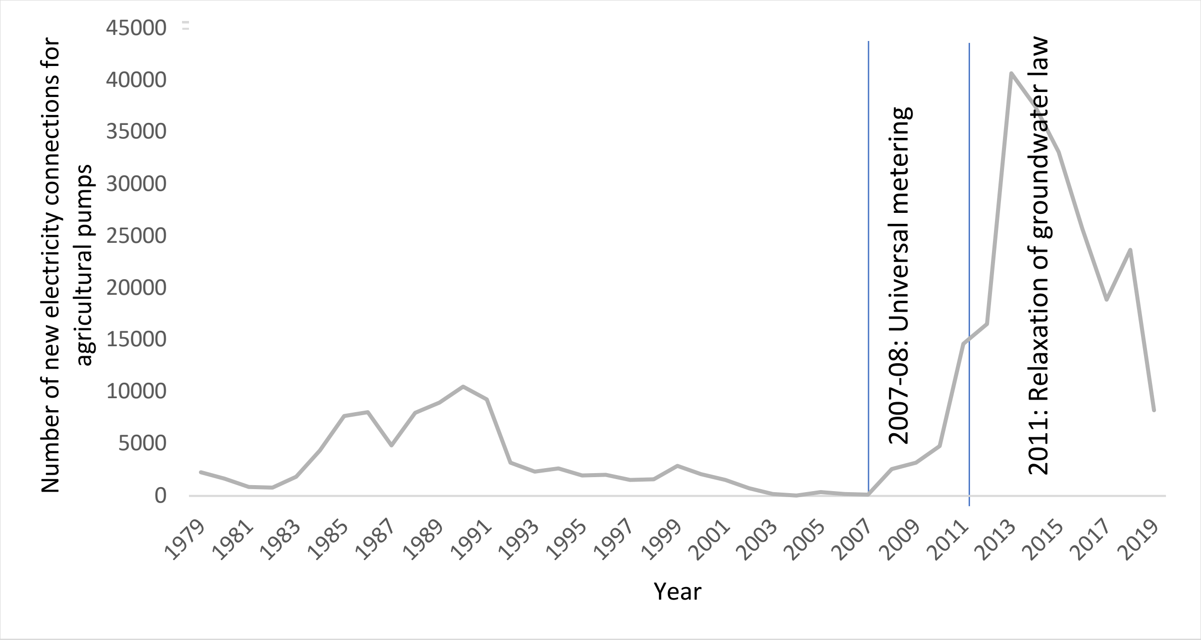

Figure 1. Year-wise addition in the number of electric agricultural pump sets in West Bengal, 1979-2019 (S*ource:* 1979-2005: Yearbook published by WBSEB, and 2006-2019 data shared by WBSEDCL).

West Bengal is a part of the eastern Indo-Gangetic Plains (IGP). The state is the largest producer of rice and vegetables in India. There are 7.1 million farm families in the state, of which 96% are small and marginal farmers with average landholdings of only 0.77 hectares (ha). The net sown area (NSA) of the state is 5.2 million hectares (Mha), of which approximately 50% is irrigated. Of the state's 27.5 billion cubic meters (Bm^3) of annual renewable groundwater resources, only 11.7 Bm^3 is extracted annually. West Bengal also

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[1] Of these three reforms, the following were made possible through policy advocacy by the International Water Management Institute (IWMI): (i) amendment of the groundwater law to allow for the electrification of wells and tube wells without the need for prior permission from the groundwater department, and (ii) the policy to provide a one-time capital cost subsidy for electrification. IWMI's researchers had presented their findings to the Chief Minister and other senior officials of the state in September 2011 (Mukherji et al. 2012).

[2] Blocks are the lowest administrative units in India.

receives high rainfall and, consequently, the predominantly alluvial aquifers of the state are well recharged (Bhanja et al. 2018).

Historically, the eastern IGP has had fertile lands, rich peasant traditions and huge groundwater potential. The region also has very high population densities, low to medium agricultural productivities and concentrated rural poverty. The issue of the eastern IGP being characterized by low agricultural productivity and backwardness has been at the heart of active academic debates on agrarian structure and rural poverty in India from the 1960s to the 1990s (Bose 1993; Boyce 1987; Palmer-Jones 1992). Three broad types of explanations for the paradox of 'scarcity amidst plenty' have been given. These relate to characteristics of agroecology, agrarian structure and public policy in the region. Following decades of agrarian stagnation, West Bengal emerged out of it and recorded one of the highest rates of growth in agricultural production in the 1980s and early 1990s. Agricultural growth rates declined again in the post-1990s period. Research conducted by the International Water Management Institute (IWMI) indicated that one of the reasons for the decline in agricultural growth rates could be the 'energy squeeze' in agriculture – while groundwater was available in plenty and at shallow depths, the cost of extracting the resource was prohibitive due to restrictions on the electrification of pumps (Mukherji 2007a; Mukherji et al. 2009). Through the groundwater policy reforms in 2011 and 2012, two of the main barriers to pump electrification, namely, that of procuring a prior permit from the state groundwater department[3], and the high costs of electrification, were removed. As mentioned earlier, this led to a more than threefold increase in the number of electric pump sets in the state.

In view of this, the main objective of this report is to understand the impact of an increase in the number of electric pump sets on agricultural and groundwater outcomes in the state. This will be done using block level secondary data. We will also use qualitative data to explain results from the quantitative analysis, and create a narrative explaining the implications of policy reforms related to groundwater and electricity on agriculture in West Bengal.

The report is divided into eight sections. After the brief introductory section, section 2 provides a historical snapshot of agricultural growth in West Bengal and a conceptual framework that underpins this work. Section 3 describes the sources of data, while section 4 provides descriptive statistics. Section 5 presents the results of the econometric analysis and section 6 presents supporting evidence from qualitative fieldwork. Section 7 discusses the results, while section 8 sums up the major policy implications of this work, including areas for future research.

2. AGRICULTURAL GROWTH IN WEST BENGAL: A HISTORICAL PERSPECTIVE

Agrarian growth or the lack of it in West Bengal has been a much-researched area. There are three distinct trends in agrarian growth in the state. The first from 1900 to 1980 tells a sad tale of "hunger in a fertile land" (Boyce 1987: 1); the second (1981 to the early 1990s) is a triumphant account of the rate of food grain production that was "highest among 17 major states of the Indian union" (Saha and Swaminathan

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[3] The state groundwater department in West Bengal is referred to as the State Water Investigation Directorate (SWID).

1994: A2); and the third phase is where the agricultural growth rate had “significantly slowed down in the 1990s” (Sarkar 2006: 342). Based on several studies, Table 1 summarizes the growth rates in the agriculture sector from 1949-2019.

Table 1. Agricultural growth rates in West Bengal (1949-2018).

Sr. No	Period	Growth rate per annum (%)	Model specification	Dependent variable	Source
1	1949-1964	1.20	Kinked exponential	Agricultural output	Boyce 1987: 68
2	1965-1980	2.27	Kinked exponential	Agricultural output	Boyce 1987: 68
3	1971-1983	0.54	Double kink linear	Food grain output	Majumdar and Basu 2005: 228
4	1982-1991	6.50	Simple exponential excluding the drought year of 1982	Index number of agricultural production	Saha and Swaminathan 1994: A2
5	1982-1991	5.10	Simple exponential including the drought year of 1982	Index number of agricultural production	Saha and Swaminathan 1994: A11
6	1984-1991	5.86	Double kink linear	Food grain output	Majumdar and Basu 2005: 228
7	1992-2000	1.96	Double kink linear	Food grain output	Majumdar and Basu 2005: 228
8	1997-2010	0.09	Exponential growth rate	Total rice output	This study
9	2011-2017	1.86	Exponential growth rate	Total rice output	This study

2.1 1900 TO 1980: HUNGER IN A FERTILE LAND

In his seminal work, Boyce captured the dynamics of the first phase when the proverbial ‘*Sonar Bangla*’[4] that once abounded “with every necessary (*sic*) of life” (Boyce 1987:4) became the home of some of the poorest people in the world. The growth rate of agriculture was merely 1.74% per annum (Boyce 1987: 68) and this was lower than the average growth rate of population during the same time. This paradox of hunger amidst plenty was explained by Boyce and other scholars in terms of the regressive agrarian structure and high rural inequality that prevented the unleashing of technological improvements in the production frontier. In particular, he recognized water control as the key input that could steer the state on a path to high agricultural growth. Bose (1993) drew attention to the role of the colonial state which, through its reluctance to invest in irrigation and drainage development as well as through exploitative means of appropriating agricultural surplus, contributed to agrarian stagnation. Palmer-Jones (1999: 145) explained the situation of low agricultural productivities, high concentration of rural poverty in a region with fertile soils and rich peasant traditions in terms of ‘floods, feudals and Fabians’, thereby pointing to the flood-prone agroecology, historically inherited regressive agrarian structure, and ineffective public

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[4] *Sonar Bangla* translates to ‘golden Bengal’. It refers to the once famed prosperity of Bengal, in general, and fields overflowing with golden ripe paddy, in particular.

policies both in the colonial as well as post-independence India. The regressive agrarian structure was kept central to the problem of 'agrarian impasse in Bengal'[5].

2.2 1980S: WAS THE HIGH GROWTH RATE DUE TO LAND REFORMS OR TECHNOLOGY?

Just as Boyce's book was published in 1987, there were signs of a quiet Green Revolution going on in rural West Bengal. An unprecedented growth in the agriculture sector at the rate of 6.5% per annum[6] was recorded during the period 1981 to 1991 (Saha and Swaminathan 1994). At the same time, as per the National Sample Survey (NSS) data, head count incidence of poverty fell by over 20 percentage points between 1977-1978 and 1987-1988, and this was one of the largest declines in poverty among Indian states. Enhanced agricultural growth and productivity in West Bengal in the 1980s was sought to be explained in terms of two very opposing arguments – that of "agrarian structure" (Banerjee et al. 2002; GoWB 1996, 2004; Lieten 1996; Saha and Swaminathan 1994), and "market and technology" (Harriss 1993; Palmer-Jones 1992).

A decade earlier, the then newly elected Communist government of West Bengal had implemented one of the most successful land reform programs in India[7]. There were two components of this reform – redistribution of vested land above the ceiling to the rural landless and registration of the rights of the sharecroppers, ensuring security of tenure and increasing the share of tenants in the output. At the same time, village *panchayats* were reconstituted and empowered, and regular democratic elections were held after every 5 years. The fact that phenomenal growth in agriculture took place just after these two effective reforms led most analysts to seek the causal relationship between the reforms. This explanation was also largely coherent with the earlier debate on reasons for agrarian stagnation in Bengal. Land reforms were suggested as a policy intervention and this found support in the influential 'inverse farm-size productivity' literature, most of which was published in successive issues of the *Economic and Political Weekly* (Chattopadhyay and Rudra 1976; Chattopadhyay and Sengupta 1999; Rudra 1968; Sen 1962).

Indeed, very few studies have tried to quantitatively model the impact of land reforms and *panchayat* reforms on agricultural production in West Bengal. Banerjee et al. (2002) adopted a "quasi-experimental approach that uses Bangladesh as a control" (2002: 258). They found that after controlling for rainfall, public irrigation and the share of high-yielding varieties, paddy yield in West Bengal was 18% higher than in Bangladesh during the post-operation *Barga* period and this they attributed to tenancy reforms.

Amidst the general consensus that agrarian growth in West Bengal was a result of land and political reforms (Harriss 1993; Palmer-Jones 1992) offered an alternative explanation. In his study villages in Bankura and Bardhaman, Harriss (1993) found that there was indeed evidence of unprecedented growth, but this could

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[5] These arguments were largely a reiteration of Daniel Thorner's thesis of built-in "depressor" (Thorner 1956: 16), which referred to the production relations where landlords could live by appropriating rent, usurious interest and speculative trading profits from the poor peasantry, and could stall productivity-enhancing technological innovations in the process (Harriss 1992) – an argument later supported by Bhaduri (1973) and Bhaduri (1986).

[6] Concerns have been raised about the reliability of data and choice of base year for growth rate calculations (for further details, see Boyce 1987; Rogaly et al. 1999; and Gazdar and Sengupta 1999).

[7] While it is outside the scope of this report to go into details of this ambitious and largely successful land reforms program, further information can be found in Bandyopadhyaya (1981), Bhowmick (2001), Lieten (1996) and in numerous other studies.

be better explained in terms of development of groundwater irrigation rather than agrarian reforms. Expansion in the area under *boro* cultivation, which is entirely dependent on irrigation, and the increase in the yield of all paddy crops (*aman, aus* and *boro* seasons) due to assured groundwater irrigation from tube wells resulted in high growth rates. This finding that groundwater irrigation unleashed the productive forces also partly confirms Boyce's thesis that water control was the 'leading input' (Boyce 1987). However, contrary to Boyce's claim that only public intervention or cooperative action could bring about groundwater development[8], Harriss (1993) found that expansion in groundwater irrigation was taking place through private investment. He also found that farmers were able to overcome the scale problems arising from small and fragmented landholdings, by selling water to neighboring farmers (water markets) and leasing land seasonally from their neighbors (changing agrarian relations). Palmer-Jones (1999) also noted that in the context of Bangladesh and by extension of West Bengal, "… better than expected performance has more to do with ecological factors and technical and institutional innovations (in the form of privately owned shallow tube wells [STWs] and the development of water markets) than with policies specifically designed and implemented to deal with the obstacles posed by the agrarian structure."

2.3. 1990 TO 2010: STAGNATION IN GROWTH LEADING TO 'GROUNDWATER SCARCITY' VERSUS 'ENERGY SQUEEZE' HYPOTHESIS

The period of high agricultural growth was relatively short lived. By the early 1990s, stagnation had begun once again. Total production of cereals stagnated at 12.7 to 12.9 million tonnes (Mt) during the period from 1991-1992 to 1994-1995 (Rogaly et al. 1999). Majumdar and Basu (2005) estimates the growth rate of food grain output from 1990-1991 to 1999-2000 at a mere 1.96% per annum, which is even lower than the growth rate recorded during the period from 1965 to 1980 (see Table 1). Sarkar (2006) noted that agricultural growth had significantly slowed down in the 1990s. He offered several reasons for this slowdown, i.e., constraints to further expansion of *boro* cultivation due to the unavailability of water, lack of technological breakthrough in the form of better seeds, unfavorable food grain prices due to the marketing policy of the Government of West Bengal and higher input costs due to a reduction in subsidies in the post-economic reform period.

While agreeing with the argument of unfavorable input-output price ratio, researchers from IWMI (Mukherji 2007a; Shah et al. 2009) questioned the other dominant viewpoint – that constraints to further expansion of *boro* cultivation was limited due to the unavailability of groundwater. Their research pointed to two factors: (i) high cost of diesel, which was making the already unfavorable input-output price ratios even more unfavorable due to high pumping costs for irrigation, and (ii) high administrative hurdles involved in switching from diesel to electric pumps. This high administrative hurdle was due to a provision of the state groundwater act, which required farmers to obtain a permit from the State Water Investigation Directorate (SWID) to apply for electricity connections from the state electricity utility. More often than not, such permissions were denied by the SWID, even in 'safe' blocks, without citing any reason. There were also reports of corruption in granting these permits (Mukherji et al. 2012). In addition, the state electricity utility – the West Bengal State Electricity Board (WBSEB) – and later, its unbundled successor, the West

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[8] Boyce was rather pessimistic about the possibility of the development of private groundwater markets. He wrote, "The monopoly positions of tube well owners … however, place limits on the market's scope for resolving the indivisibility problem (Boyce 1987: 242).

Bengal State Electricity Distribution Company Limited (WBSEDCL) required that farmers pay the full capital cost of electrification, including the cost of poles, wires and transformers. This made the cost of electrification prohibitively high and beyond the reach of most farmers.

In September 2011, IWMI researchers, in collaboration with the then Planning Commission, presented these research findings to the newly elected government officials in West Bengal at that time. The study team recommended that restrictions on electrification be eased. Soon thereafter, in November 2011, there was an amendment to the Groundwater Act of 2005, via a memorandum issued by the Water Resources Investigation and Development Directorate (WRI&DD). Through this change, farmers located in 'safe' groundwater blocks, and owning pumps less than 5 horsepower (HP), with discharge rates of less than 30 m^3/hour, could apply to WBSEDCL without obtaining a prior permit from the SWID. Later, in November 2012, a scheme called One Time Assistance for Electrification of Agricultural Pump-sets (OTA-EAP) was announced by the Department of Agriculture, which made available a capital cost subsidy of INR 8,000-12,000 for the electrification of pumps. Around the same time, the WBSEDCL also removed the requirement of farmers having to pay the full capital cost subsidy for electrification. These two policy reforms followed another reform that had started in 2007 – the universal metering of electric pumps. These three reforms together increased the demand for electrification of pumps. Universal metering of electric pumps changed the incentive structure for pump owners, and they were less likely to sell water as done previously (Meenakshi et al. 2013; Mukherji and Das 2014). The erstwhile water buyers could no longer purchase water at favorable terms and conditions, and this also resulted in greater demand for electrification of pumps. To meet this demand, in 2008, WBSEDCL started providing temporary connections for cultivating *boro* paddy. These temporary connections were given for 105 days (from January to April) and farmers had to pay a non-trivial lump sum amount. Later, with the lowering of restrictions for electricity connections, these temporary connections were slowly phased out (Figure 2).

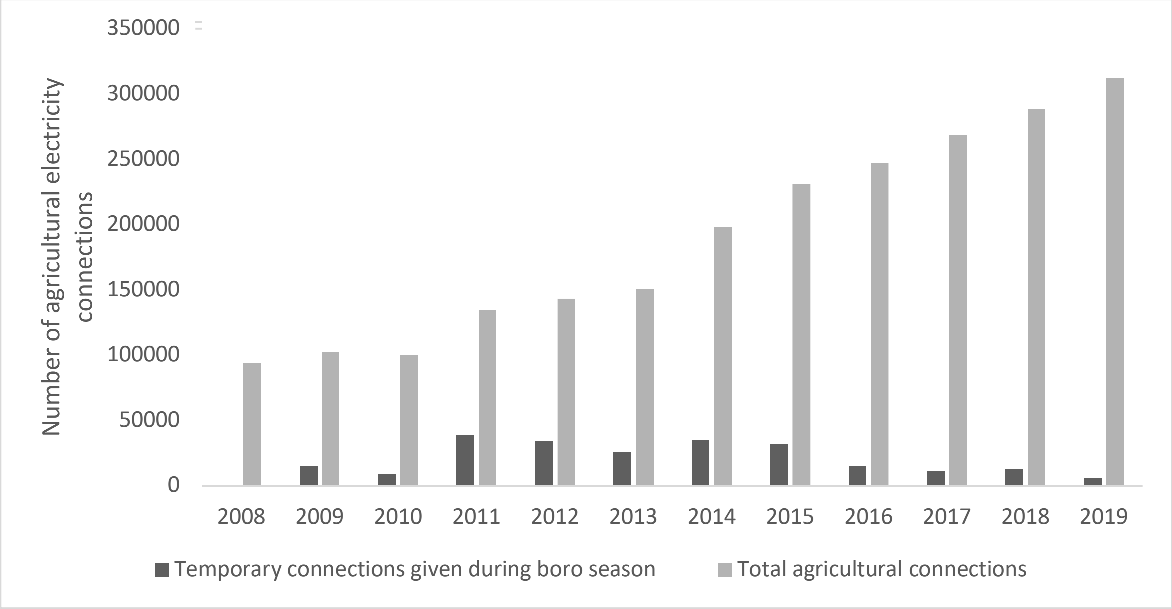

Figure 2. Temporary and total agricultural electricity connections in West Bengal, 2008–2019 (Source: Data from WBSEDCL).

2.4 HOW AND WHY WILL ELECTRIFICATION OF TUBE WELLS AFFECT AGRICULTURAL AND GROUNDWATER OUTCOMES?

There are a number of reasons why we expect the electrification of wells and tube wells to affect agricultural and groundwater impacts. First, per unit costs of pumping groundwater with electric pumps is much lower than pumping with diesel pumps. Therefore, it is expected that farmers with access to electric pumps will operate their pumps for longer hours and grow more water-intensive crops. Second, again related to lower costs, it is expected that irrigation costs will be lower for those with access to electric pumps – both through ownership and informal water markets. There is evidence that falling groundwater irrigation costs resulted in growth in per acre (1 acre = 0.404686 hectares) value added for farms in West Bengal (Bardhan and Mookherjee 2012; Buisson et al. Under Review), due to lower pumping costs per acre. Buisson et al. (Under Review) and Mukherji (2007a) show that costs of irrigation per acre were much higher for diesel pump owners when compared to electric pump owners, due to the difference in per unit costs of pumping. This also enabled electric pump owners to irrigate a bigger area and devote a larger part of their land to water-intensive *boro* paddy, leading to a higher cropping intensity among these farmers. Farmers with electric pumps and facing a high flat tariff (in the pre-2007 period) also sell water to those managing a larger area of land as compared to those farmers facing metered electricity tariffs (Meenakshi et al. 2013). Electric pump owners (irrespective of whether they pay a flat rate or are on a metered tariff) are also more likely to sell water than diesel pump owners (Mukherji 2007a).

A number of studies have looked into the agricultural benefits, and environmental and economic costs of electricity subsides in India (Badiani-Magnusson and Jessoe 2019; Badiani et al. 2012). With electrification, if more and more farmers choose to cultivate water-intensive crops, there is likely to be higher withdrawals of groundwater. However, the exact trend of the groundwater table will depend on a number of factors, including rainfall, nature of the aquifer, crop type and the cultivation season.

3. DATA

The present analysis is based on two main sources of data: (i) block level data created from different government sources; and (ii) qualitative data based on 28 focus group discussions (FGDs) held in 11 villages in eight out of 19 districts in West Bengal. Tables 2, 3 and 4 summarize the quantitative and qualitative data, used in this analysis.

Table 2. Details of block level secondary data used for the econometric analysis.

Year	Source of data	Variables
2003-2018	State Water Investigation Directorate (SWID)	Groundwater level in the pre- and post-monsoon periods
2000, 2007 and 2019	Water Resources Investigation & Development Department (WRI&DD), Government of West Bengal	Categorization of blocks as safe, semi-critical and critical Stage of groundwater development

Year	Source of data	Variables
		Groundwater trend in pre- and post-monsoon periods
		Basic statistics (drinking water, fertilizer depot, seed stores, fair price shops, Gram Panchayat (GP) offices with telephone)
2008-2013	District Statistical Handbook in West Bengal	Basic statistics (drinking water, fertilizer depot, seed stores, fair price shops, GP offices with telephone)
		Number of banks and cooperative societies
		Area, production of fisheries
		Source of irrigation and area irrigated by sources
		Persons engaged in agriculture
		Length of roads maintained by different agencies and transport facilities
2000-2001, 2006-2007 and 2013-2014	Minor Irrigation Census	Number of minor irrigation sources and energy (only district-level data for 5th Minor Irrigation Census)

Table 3. Sample power calculation of block level secondary data used for the econometric analysis.

Indicator	Area boro	Area aman
Mean (‘000 ha)	4149	7113.303
Standard deviation (‘000 ha)	4502.4	8833.303
Intra-cluster correlation	0.258	0.197
Number of clusters	326	326
Number of treated	290	290
Number of non-treated	36	36
Number of units/years per cluster i	11	11
Sample size	3586	3586
Minimum detectable effect size	1079.856	1918.85

Table 4. Details of qualitative data used in the analysis.

Date of visit	Village	Block	District	Number of FGDs	Total number of respondents	Visited in 2004 (Yes/No)
September 17, 2019	Adhata	Amdanga	North 24 Parganas	3	17	Yes
September 18, 2019	Silinda	Chakda	Nadia	3	18	Yes
September 19 and 20, 2019	Bengai	Goghat 2	Hooghly	3	19	Yes
September 21, 2019	Tajpur	Kotolpur	Bankura	3	17	No
October 19 and 20, 2019	Polsonda	Nabagram	Murshidabad	3	17	Yes
October 21, 2019	Donaipur	Sriniketan	Birbhum	3	17	Yes
October 22, 2019	Amra	Bardhaman 2	Bardhaman	3	20	Yes
February 21, 2020	Pushpadanga	Cooch Behar 1	Cooch Behar	2	10	No
February 21, 2020	Nakkati	Cooch Behar 1	Cooch Behar	1	4	No
February 22, 2020	Angerkata Khaterbari	Mathabahnga 2	Cooch Behar	2	12	Yes
February 23, 2020	Jorabari I and II	Dinhata	Cooch Behar	2	14	No
Total	**11**			**28**	**165**	**7**

Data related to agriculture were collected from the Bureau of Applied Economics and Statistics (BAES) for the period 2008-2016, and from the Department of Agriculture for the period after 2016. These data provided information on area, production and yields of major crops at block level.

WBSEDCL provided data on a number of agricultural consumers, and the number of agricultural connections each year from 2008 to 2019. Using these data, it was possible to derive the number of permanent and temporary electricity connections given on a yearly basis. WBSEDCL also shared data on electricity consumption by the agriculture sector from 2015 to 2019. However, these data are only available from 2015, i.e., after all electric pumps in the state were metered. WBSEDCL collects data at customer care center (CCC) level, and these CCCs do not always coincide with administrative block boundaries. Whenever the CCC name did not match with an administrative block, block level coverage of that CCC had to be cross-checked with individual CCC offices. In 32 instances, we found that one CCC serves two blocks. Therefore, those blocks had to be combined for this analysis (Annexure, Table A1).

Groundwater levels during pre- and post-monsoon periods are based on data from monitoring wells maintained by SWID. The data are aggregated following an inverse distance weighting method to obtain one measure per block from 2003 to 2018. Categorization of the blocks as safe, semi-critical and critical is carried out by WRI&DD, and is based on the Groundwater Estimation Committee report of 1997 published by Central Ground Water Board (CGWB) (CGWB 1998). WRI&DD also published variables – stage of groundwater development, and trends in pre- and post-monsoon seasons – used for the categorization of blocks into safe, semi-critical and critical categories.

We obtained data on a number of groundwater structures and motive power (electric versus diesel) of pumps from three rounds of the Minor Irrigation Census conducted by the Ministry of Water Resources, Government of India, in 2000-2001, 2006-2007 and 2013-2014. For the 5th Minor Irrigation Census (2013-2014), data were not available at the block level.

We obtained data for other variables (e.g., area under different sources of irrigation, land tenure, infrastructure, markets for inputs, and outputs, etc.) from the District Statistical Handbooks which are published every year by respective district administrations. These were used as control variables.

The collection and combination of these different quantitative datasets involved several challenges. First, various indicators had to be combined from different sources and this was challenging because of different geographical units. Most data were at block level, except for the information provided by WBSEDCL, which had to be mapped at block level to create comparable datasets. Second, some of these datasets were not digitalized and had to entered manually. Once merged, these different datasets provide a panel of 326 blocks for a period of 11 years from 2008 to 2019. Depending on the variable considered, the actual years differ, but the data always covered pre-reform (before 2011) and post-reform (after 2011) periods. Of these 326 blocks, 290 blocks benefited from the liberalization of norms of agricultural electrification in 2011, while 36 semi-critical and critical blocks did not, as farmers in these blocks still needed permits from SWID to apply for electrification. Sample power calculations performed with this secondary dataset indicate that the panel data analysis detects an impact of the groundwater policy reform equivalent to 23.9% of the standard deviation of the area cultivated under *boro* paddy, or equal to 21.7% of the standard deviation of the area cultivated under *aman* paddy. We, therefore, consider our analysis to be adequately powered (Table 3).

For qualitative data, we visited 11 villages in eight districts (Bankura, Birbhum, Bardhaman-2, Cooch Behar, Hooghly, Murshidabad, Nadia and North 24 Parganas). Three types of FGDs were conducted in each village with (i) pump owners; (ii) small farmers, including water buyers; and (iii) women farmers. In total, we conducted 28 FGDs and held discussions with 165 farmers of which 45 were women. We had conducted fieldwork in seven of these 11 villages in 2004. We visited three villages in Cooch Behar for the first time on the recommendation of the local CCC office, because these villages had received a large number of new electricity connections as a result of the reforms in 2011 (Table 4).

4. DESCRIPTIVE STATISTICS

4.1 INCREASE IN PUMP ELECTRIFICATION POST-2011

In West Bengal, there were 86,776 electric pump users in 2007 and this had increased to 303,018 in 11 years by 2018, registering a compound annual growth rate (CAGR) of 12.0%. The trend in the number of electric pump users was increasing even before 2011, but the growth rate picked up after 2011 when the groundwater act was amended. Between 2007 and 2011, the CAGR for the number of electric pump users was 6.4%, while this was 15.6% in the period 2012–2018 (Table 5, Figure 3).

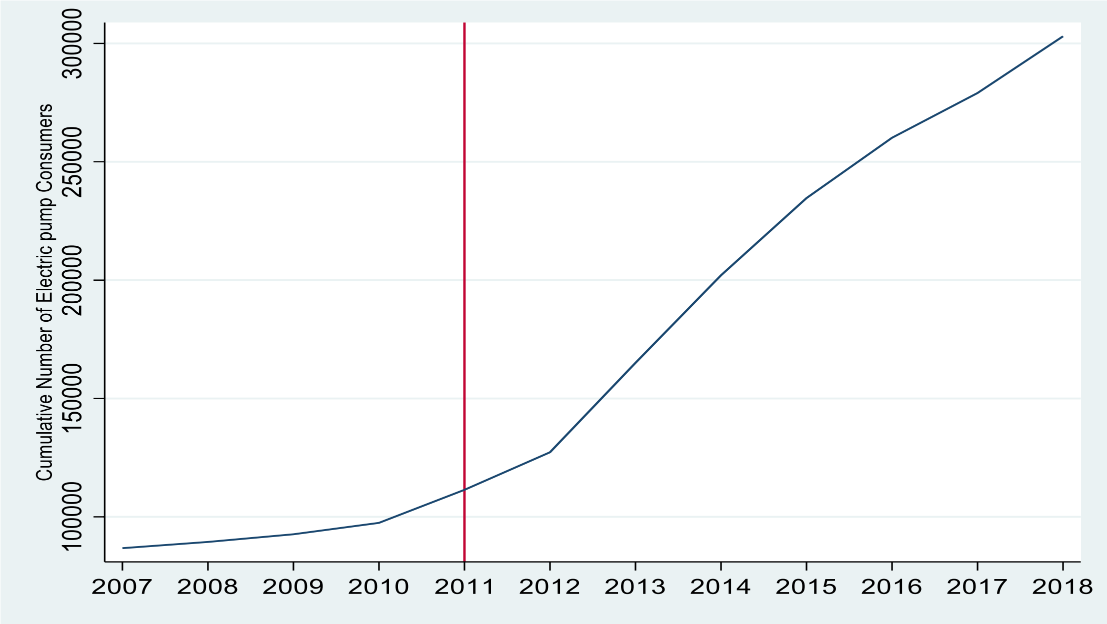

Figure 3. Cumulative number of electric pump consumers (2007-2018) in West Bengal.

Table 5. Compound annual growth rate (CAGR) of the cumulative number of electricity connections in West Bengal.

	Pre-2011 CAGR	Post-2011 CAGR	2007-2018 CAGR
Cooch Behar	162.6%	27.6%	71.3%
South 24 Parganas	17.3%	53.4%	40.7%
Jalpaiguri	0.7%	57.9%	29.6%
Paschim Medinipur	11.7%	28.7%	22.3%
Bankura	15.4%	18.0%	17.0%
Purba Medinipur	6.5%	24.5%	15.9%
Dakshin Dinajpur	5.4%	21.4%	14.5%
Uttar Dinajpur	13.4%	13.3%	14.1%
Purulia	13.5%	13.6%	13.2%

Malda	4.3%	16.8%	11.1%
North 24 Parganas	1.2%	18.0%	10.7%
Birbhum	7.6%	10.1%	10.4%
Howrah	3.0%	7.2%	5.6%
Murshidabad	4.1%	6.5%	5.5%
Burdwan	3.5%	5.3%	4.5%
Hooghly	2.9%	5.4%	4.4%
Nadia	0.5%	4.9%	3.1%
West Bengal	6.4%	15.6%	12.0%

Source: Data from WBSEDCL

The increase in electricity connections were, however, not the same everywhere across the state. Some districts such as Cooch Behar and Paschim Medinipur have shown huge increases in the post-2011 period (Figure 4). In some other districts, the number of electricity connections remained more or less the same across the years (Table 5).

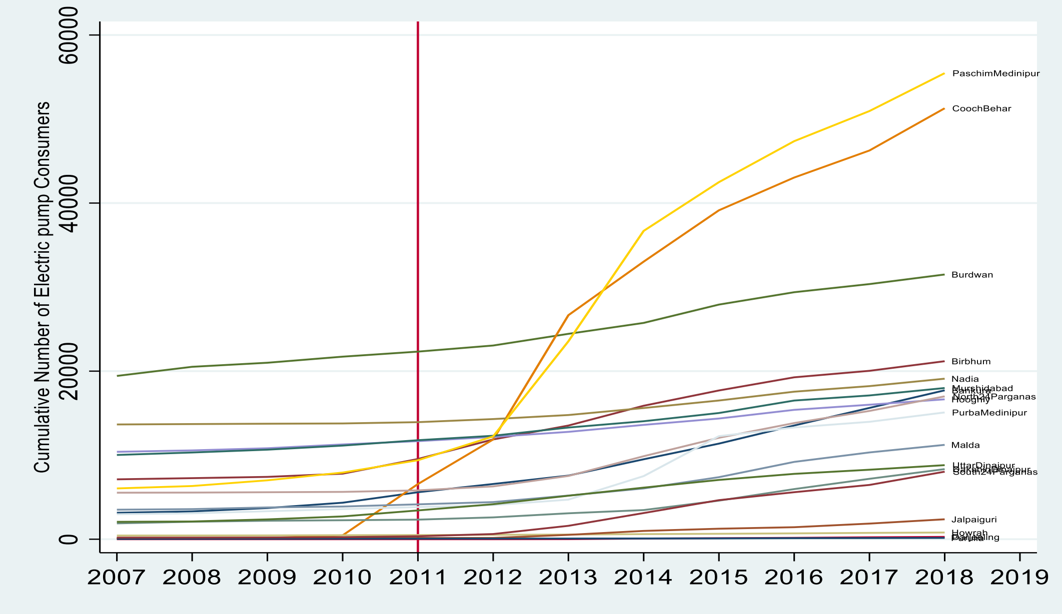

Figure 4. District-wise cumulative number of electric pump consumers (2007-2018) in West Bengal.

In Table 5, we compared the CAGR for the number of electricity connections across different districts. In all districts, except Cooch Behar and Uttar Dinajpur, the pre-2011 CAGR was lower than the post-2011 CAGR. The pre-2011 CAGR in Cooch Behar is very high because of a very low base of only 138 consumers in 2007. So, the number of electricity connections has been rising in Cooch Behar even before 2011, but this number increased further with the change in the groundwater act in 2011. For districts such as Uttar Dinajpur and Purulia, the pre-2011 and post-2011 CAGR were almost the same at around 13.5%. For all other districts, there has been a marked increase in CAGR post-2011. Overall, Cooch Behar, South 24 Parganas, Jalpaiguri and Paschim Medinipur had some of the highest CAGRs for the entire period from 2007 to 2018.

Based on the categorization of blocks by WRI&DD and CGWB as safe, semi-critical or critical, we can also see how the policy affected the electrification of pumps in safe blocks as compared to semi-critical or critical blocks. Since the policy made obtaining electricity connections easier in safe blocks and not easy in semi-critical or critical blocks, we would expect the growth in the safe blocks to be much more than that in the unsafe blocks. Based on the 2009 categorization in West Bengal, almost 90% of the blocks were safe and there were no critical blocks in the state. The growth rate in the number of consumers was already higher in safe blocks (7.5%) compared to semi-critical blocks (3.3%). However, the growth rate increased substantially in the post-2011 period in safe blocks (18%) vis-à-vis only 4.3% in semi-critical blocks (Table 6). This indicates that the amendment of the groundwater act did indeed make it much easier to obtain electricity connections in the safe blocks of West Bengal (Figure 5).

Table 6. Compound annual growth rate (CAGR) of electricity connections in safe and semi-critical blocks in West Bengal.

	Pre-2011 CAGR	Post-2011 CAGR	2007-2018 CAGR
Safe blocks	7.5%	18.0%	14.1%
Semi-critical blocks	3.3%	4.3%	3.9%

Source: Data from WBSEDCL and WRI&DD

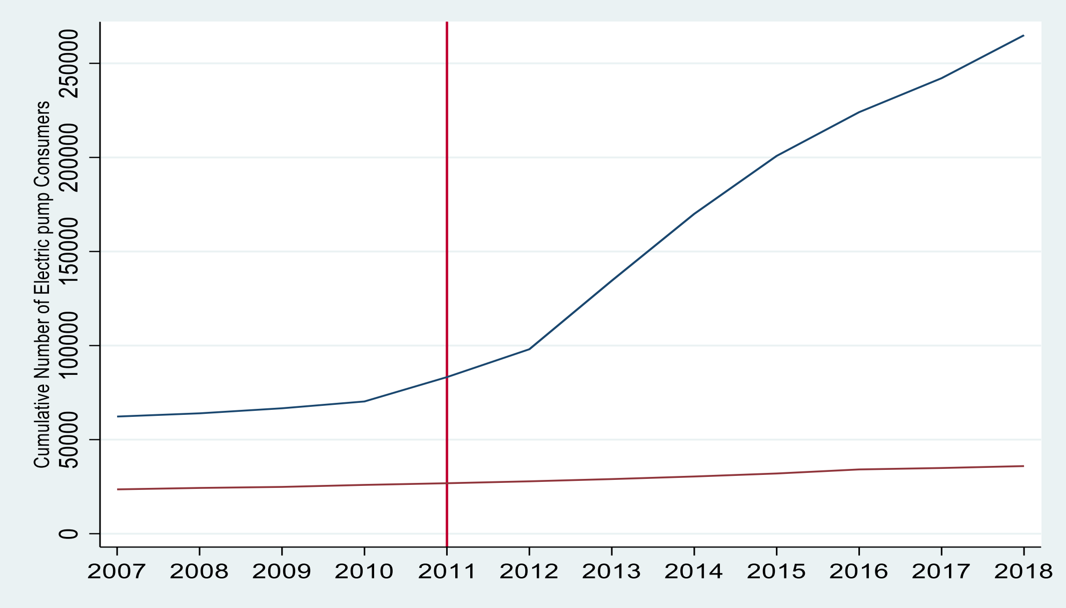

Figure 5. Cumulative number of electric pump consumers (2007-2018) in safe versus semi-critical blocks. Blue line = trend in safe blocks; brown line = trend in semi-critical blocks.

4.2 No discernible change in gross cropped area, net sown area and cropping intensity

One of our hypotheses was that due to cheaper and more affordable irrigation from electric pumps, farmers would irrigate more intensively, expand their net and gross sown area and, as a result, cropping intensity would increase (Mukherji et al. 2012).

Overall, looking at NSA and gross cropped area (GCA) in West Bengal (Figure 6), we can see that NSA has remained almost constant over the past 20 years. It was 5.4 Mha in 1998 and 5.2 Mha in 2017. Although GCA was 6% higher in 2017 (9.9 Mha) compared to 1998 (9.3 Mha), there is no substantial difference when comparison is made between the pre-2011 period (average GCA was 9.5 Mha) with the post-2011 period (average GCA was 9.7 Mha).

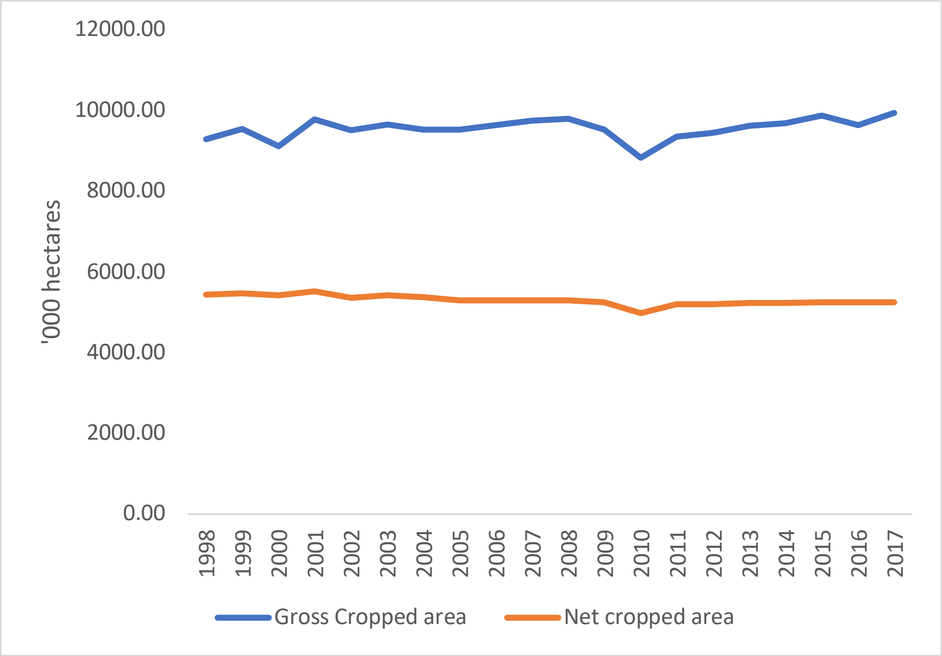

Figure 6. Gross cropped area and net sown area in West Bengal (1998-2017).

Cropping intensity (defined as GCA / NSA * 100) in West Bengal has, however, increased from 170.8% in 1998 to 189.5% in 2017, i.e., 18.7 percentage points in 20 years. This is because of the increase in GCA over the years without any increase in NSA. Overall, cropping intensity increased by 0.77 percentage points each year, and there is no indication of any substantial difference in the rate of increase in the period after 2011 (Figure 7).

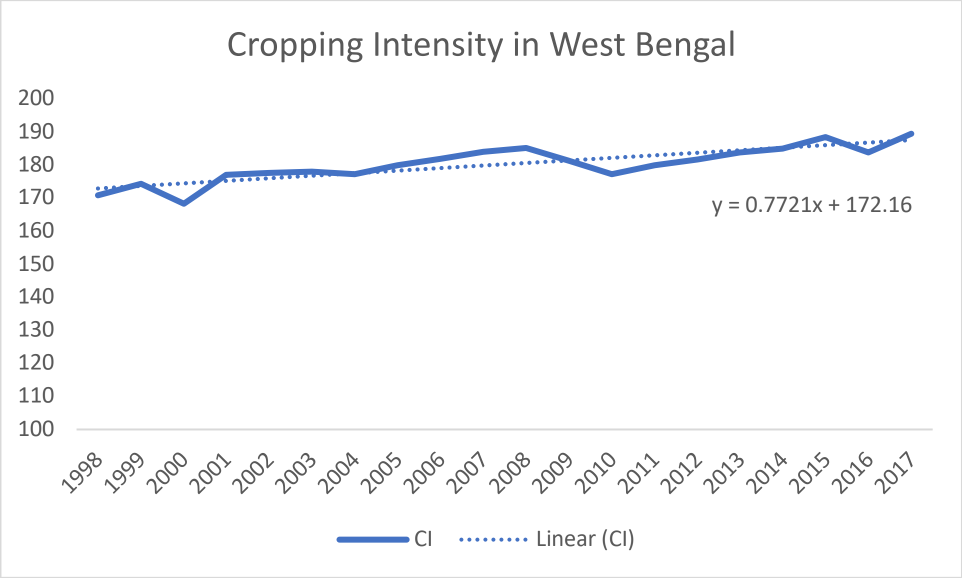

Figure 7. Trend in cropping intensity in West Bengal (1998-2017).

In Paschim Medinipur and Cooch Behar, the two districts which witnessed the maximum growth in the number of electric pumps, there were increases in NSA and GCA – more in Paschim Medinipur than in Cooch Behar. However, these trends are a continuation of the pre-2011 period and cannot be stated as a result of increased electrification alone.

4.3 SHARE OF AREA UNDER WATER-INTENSIVE *BORO* CROPS INCREASED IN DISTRICTS THAT RECORDED THE HIGHEST GROWTH IN ELECTRICITY CONNECTIONS

Although no major change in GCA or NSA were to be found in the post-2011 period, it is possible that farmers shifted away from less water-intensive crops to more water-intensive *boro* crops after 2011, because irrigation using electric pumps became more affordable than diesel pumps.

Of NSA in West Bengal, the average share of the area under *boro* crops was around 26.5% in the period before 2011 (1998-2011) and around 24.1% in the post-2011 period. In fact, except for Cooch Behar, Paschim Medinipur, Purba Medinipur, Jalpaiguri and Murshidabad, the average share of the area under *boro* crops has decreased in all other districts. So, although the overall area under *boro* crops in the state does not show any increase after the change in the groundwater act, the area under *boro* paddy as a share of total crops increased by 9.5% and 6.3% points in Paschim Medinipur and Cooch Behar, respectively, in the post-2011 period as compared to the pre-2011 period (Table 7).

Table 7. Share of *boro* area to net sown area (1998-2017).

District	Average share of *boro* area (1998-2011)	Average share of *boro* area (2012-2017)	Difference
North 24 Parganas	36.80%	29.80%	-7.00%
South 24 Parganas	19.20%	17.90%	-1.30%
Bankura	13.80%	11.90%	-1.90%

Birbhum	21.00%	19.80%	-1.20%
Cooch Behar	15.50%	21.80%	6.30%
North Dinajpur	19.80%	10.30%	-9.50%
South Dinajpur	33.20%	16.00%	-17.20%
Hooghly	45.20%	37.60%	-7.60%
Howrah	58.10%	50.40%	-7.70%
Jalpaiguri	4.70%	6.30%	1.60%
Malda	29.50%	24.70%	-4.80%
Purba Medinipur	45.10%	51.00%	5.90%
Paschim Medinipur	25.90%	35.40%	9.50%
Murshidabad	30.50%	31.60%	1.10%
Nadia	39.70%	31.40%	-8.30%
Bardhaman	46.40%	33.60%	-12.80%
Purulia	0.40%	0.10%	-0.30%
West Bengal	26.50%	24.10%	-2.40%

4.4 OVERALL CROPPING PATTERN REMAINED UNCHANGED, WITH SOME INCREASES IN THE AREA UNDER MAIZE, POTATO, OILSEEDS AND PULSES.

There were no major changes in the area under *aman* and *boro* paddy in the period from 1997 to 2017. For other crops, there has been an increasing trend in the area under potato, pulses, oilseeds and maize, with a decreasing trend in *aus* rice, wheat and jute. *Aman* paddy is the most important crop in West Bengal and this can be seen from Table 8. The share of *aman* paddy in GCA has remained practically the same at around 41% when comparing the pre-2011 period with the post-2011 period. The area under *boro* paddy has also remained almost the same, but its share in GCA has reduced from 14.9% to 13.1%. Jute and *aus* paddy have also decreased, both in terms of absolute area and as a share of GCA. During the same time, oilseeds (from 6.2 to 7.1%) and potato (from 3.7 to 4.4%) increased, both in absolute area and as a share of total area, from the pre-2011 period to the post-2011 period (Table 8).

Table 8. Changes in the share of different crops in the gross cropped area (1998-2017).

	Pre-2011 average	Post-2011 average	Difference
Aman rice	41.70%	41.40%	-0.30%
Boro rice	14.90%	13.10%	-1.80%
Jute	6.40%	5.80%	-0.60%
Oilseeds	6.20%	7.10%	0.90%
Potato	3.70%	4.40%	0.70%
Aus rice	3.30%	2.30%	-1.00%
Pulses	2.30%	2.80%	0.50%
Wheat	3.90%	3.40%	-0.50%
Maize	0.70%	1.50%	0.80%
Sugarcane	0.20%	0.20%	0.00%
Other crops	16.80%	18.00%	1.20%

The area under maize in West Bengal has been increasing since the beginning of 2000, and it has continued to grow at an accelerated pace in the post-2011 period. The maize area increased with a CAGR of 7.3% from 1997 to 2010, while the CAGR was 16.6% from 2011 to 2017. Maize production almost tripled from 130.4 thousand tonnes in 1997 to 352.3 thousand tonnes in 2010 (i.e., a CAGR of 7.9% in 13 years), but it increased four times in the next 6 years at a CAGR of 25.5% (364.1 thousand tonnes in 2011 to 142.3 thousand tonnes in 2017). Although the maize area increased in West Bengal, the share of maize area is less than 5% of the net sown area of the state. However, there has been definite improvements in maize yield in the post-2011 period, where maize production has shown impressive gains. Most of the major maize-growing districts are in North Bengal. The highest growth in area and production was in North Dinajpur district, where the maize area almost tripled from 2011 to 2017, and production increased by 4.7 times. However, these increases in area and production of maize do not seem to be correlated with an increase in the use of electric pumps.

4.5 RATE OF GROUNDWATER DECLINE DECREASED MARGINALLY AFTER 2011

To study the trend in groundwater level in West Bengal from 1997 to 2016, we have used the inverse distance weighting method to aggregate the measurements from CGWB wells. Figures 8 and 9 indicate that the groundwater level (both pre- and post-monsoon) had been declining in the state even before 2011. The fitted trend line on the post-2011 groundwater data indicates two interesting factors. First, there is a positive shock in 'depth to groundwater' in 2011 when the policy is introduced. Second, the slope of the trend line is 'flatter' in the post-2011 period. This implies that the groundwater level was still declining post-2011, but the rate of decline was slower than pre-2011 period.

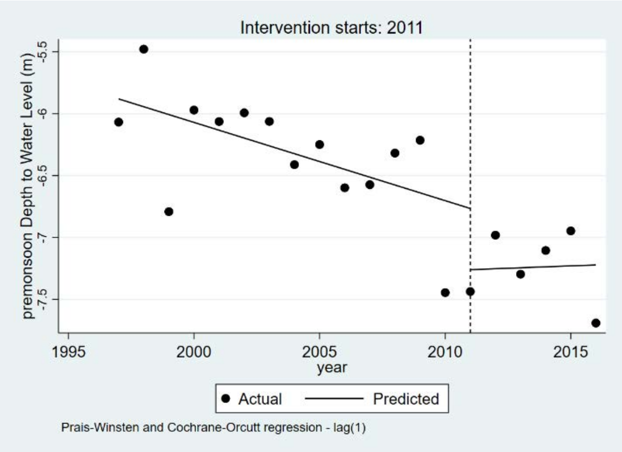

Figure 8. Trend in pre-monsoon groundwater level in West Bengal (breakpoint = 2011).

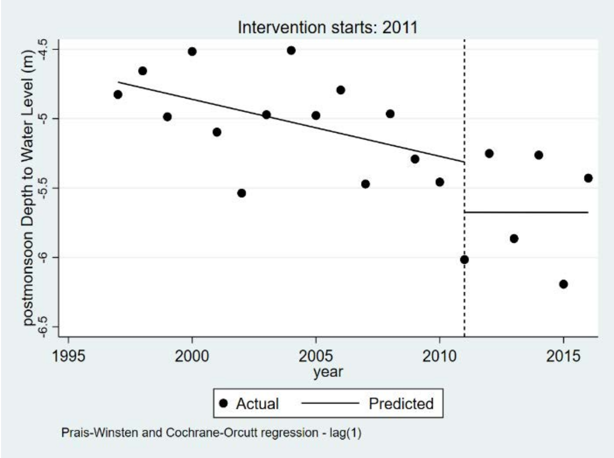

Figure 9. Trend in post-monsoon groundwater level in West Bengal (breakpoint = 2011).

However, are the changes that were observed post-2011, in the above figures, statistically significant? Also, is 2011 the actual breakpoint?

For the purpose of answering these questions, the interrupted time series analysis was used to estimate the equation below:

$$G_t = \alpha_0 + \alpha_1 T + \alpha_2 I + \alpha_3 (I \times T) + \beta X + \varepsilon$$

Where: G_t is the groundwater level at time t, T is the time variable, I is a dummy variable indicating the intervention period (i.e., 0 pre-2011 and 1 post-2011), $I \times T$ is the interaction term and X is other control variables. Here $\alpha_0$is the constant, $\alpha_1$is the slope of the trend line in the pre-intervention period, while α_3 is the change in the slope of the trend line in the post-intervention period. α_2 gives the change in the level of groundwater in the post-2011 period. β is a vector of estimated coefficients for the control variables and ε is the terms of errors. So, if $\alpha_3 = 0 \; and \; \alpha_2 > 0$, it means that the trend line shifted up in the post-intervention period, but the slope has remained the same. The generalized least squares method was used to estimate the coefficients assuming the error term to follow the first-order autoregressive process. We check the robustness of our estimates assuming multiple lagged auto-regressive process, but the findings do not change substantially.

Results from Table 9 indicate that the pre-intervention trend is significant and positive, i.e., the groundwater level was declining before 2011 at around 6 centimeters (cm) per year for the pre-monsoon level and 4 cm per year for the post-monsoon level. Also, α_2 is positive and α_3 is negative, but none of the coefficients are significant. Therefore, we could not reject the hypothesis that the trend in groundwater remained the same both in level and slope in the post-2011 period. So, these results indicate that, at the state level, there is no indication that groundwater started declining more rapidly after the policy change in 2011. In fact, there is an indication that the decline slowed down post-2011, but the decline in trend is not significant at the state level.

Table 9. Coefficient estimates of interrupted time series analysis at the state level

	Pre-monsoon groundwater level		Post-monsoon groundwater level	
Pre-intervention trend (α_1)	-0.063**	-0.062**	-0.041***	-0.040***
	(0.025)	(0.027)	(0.010)	(0.014)
Level change after 2011 (α_2)	-0.494	-0.470	-0.362	-0.353
	(0.298)	(0.348)	(0.216)	(0.235)
Trend change after 2011 (α_3)	0.071	0.0642	0.0409	0.0366
	(0.081)	(0.094)	(0.063)	(0.071)
Rainfall		0.00007		0.00004
		(0.0005)		(0.0003)
Constant	-5.881***	-6.020***	-4.737***	-4.819***
	(0.172)	(0.949)	(0.100)	(0.661)
N	20	20	20	20
Adjusted R^2	0.878	0.866	0.837	0.831

Notes: Robust standard errors in parentheses. *** significant at the 1% level, ** significant at the 5% level, * significant at the 10% level. We excluded groundwater level data for 2017 from our data, because the depth to groundwater level for both pre- and post-monsoon periods was very low. This was due to either some data error or some external shock such as rainfall or change in cropping intensity. Including 2017 in our sample makes the 'trend change post-2011' significantly negative. In fact, post-2011, the depth to groundwater level starts falling, i.e., groundwater level is rising. See Annexure, Table A2 for the estimated coefficients as a counterpart of Table 9.

However, after the policy change, not all districts could capitalize on the easy availability of electric pumps due to varied reasons. So, although we did not find any significance at the state level, it is interesting to look at those districts where the number of electricity connections grew at a very high rate in the post-2011 period, i.e., Cooch Behar and Paschim Medinipur. The above analysis was carried out for these two districts to identify whether groundwater level trends changed in the post-2011 period (Figures 10 and 11).

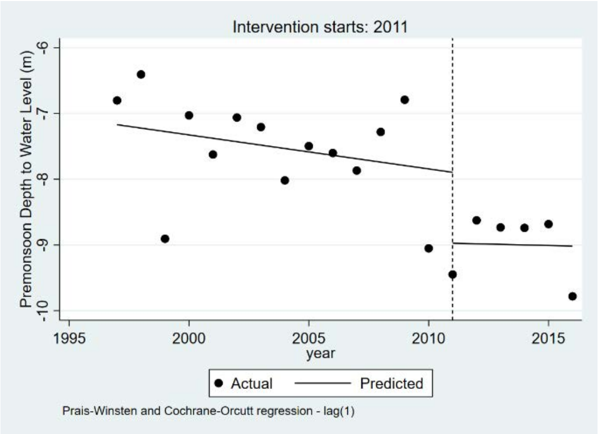

Figure 10. Trend in pre-monsoon groundwater level in Cooch Behar (breakpoint = 2011).

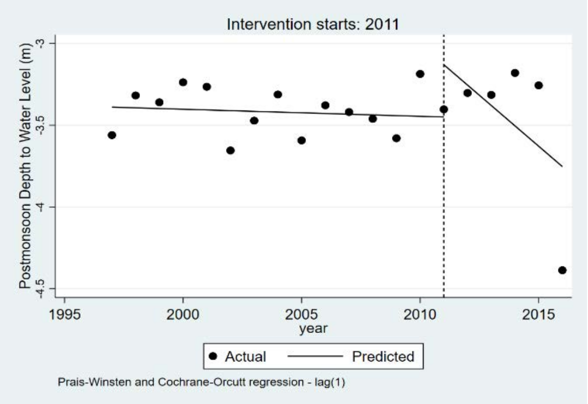

Figure 11. Trend in post-monsoon groundwater level in Cooch Behar (breakpoint = 2011).

In Cooch Behar, the groundwater level was already quite high and there was no declining trend before 2011. We also could not find any significant change in pre-monsoon groundwater trends in the post-intervention period. Visually, it looked as though post-monsoon groundwater trends started falling post-2011. However, our regression estimate indicates no significant change in either level or slope of the almost flat trend line of the pre-2011 period. So, in spite of a rapid increase in number of electric agricultural connections, there is no evidence of decline in groundwater levels (Table 10). This is partly because Cooch Behar has one of the highest average annual rainfall amounts among all the districts in the state. So, the recharge in this area is also likely to be very high.

Table 10. Coefficient estimates of interrupted time series analysis in Cooch Behar

	Pre-monsoon groundwater level		Post-monsoon groundwater level	
Pre-intervention trend (α_1)	-0.000931	-0.00716	-0.00434	0.0000249
	(0.013)	(0.017)	(0.009)	(0.009)
Level change after 2011 (α_2)	-0.125	-0.119	0.320*	0.287
	(0.151)	(0.143)	(0.181)	(0.191)
Trend change after 2011 (α_3)	0.00329	0.0296	-0.120	-0.134
	(0.053)	(0.052)	(0.094)	(0.100)
Rainfall		-0.00026		0.000142
		(0.0001)		(0.0001)
Constant	-3.602***	-2.738***	-3.389***	-3.863***
	(0.125)	(0.582)	(0.066)	(0.370)
N	20	20	20	20
Adjusted R^2	-0.162	-0.030	0.358	0.185

Notes: Robust standard errors in parentheses. *** significant at the 1% level, ** significant at the 5% level, * significant at the 10% level.

Similarly, as above, we did not find any significant effect of the policy change on the groundwater level (either post-monsoon or pre-monsoon) in Paschim Medinipur (Figures 12 and 13; Table 11). The groundwater level has been declining in the pre-intervention period, but no change in the trend can be observed in the pre-monsoon water level. However, the post-monsoon trend shows that the decline in groundwater level increased after 2011. The coefficient α_3 is 0.4 and the p-value is below 0.15. Given the small sample size, the power of our test is low, but it does indicate that there is some weak evidence that the rate of groundwater decline was somewhat faster in the post-2011 period when compared to the pre-2011 period. In fact, the average annual rainfall was also slightly less in Paschim Medinipur in the post-2011 period when compared to the pre-2011 period.

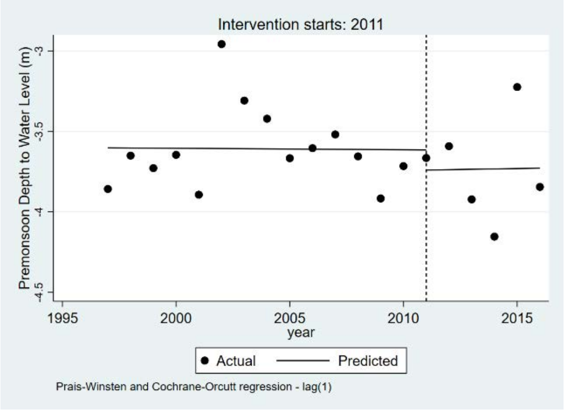

Figure 12. Trend in pre-monsoon groundwater level in Paschim Medinipur (breakpoint = 2011).

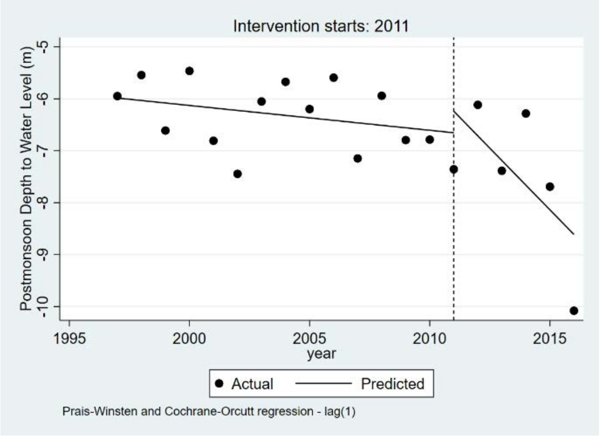

Figure 13. Post-monsoon groundwater level in Paschim Medinipur (breakpoint = 2011).

Table 11. Coefficient estimates of interrupted time series analysis in Paschim Medinipur

	Pre-monsoon groundwater level		Post-monsoon groundwater level	
Pre-intervention trend (α_1)	-0.0517	-0.0721*	-0.0478*	-0.0491*
	(0.051)	(0.035)	(0.027)	(0.027)
Level- change after 2011 (α_2)	-1.079*	-0.362	0.414	0.470
	(0.573)	(0.288)	(0.668)	(0.667)
Trend change after 2011 (α_3)	0.0431	-0.0268	-0.427	-0.424
	(0.150)	(0.096)	(0.267)	(0.268)
Rainfall		0.00151***		0.000217
		(0.0004)		(0.0005)

Constant	-7.171*** (0.378)	-9.553*** (0.797)	-5.985*** (0.253)	-6.333*** (0.793)
N	20	20	20	20
Adjusted R^2	0.744	0.865	0.540	0.554

Notes: Robust standard errors in parentheses. *** significant at the 1% level, ** significant at the 5% level, * significant at the 10% level.

5. ECONOMETRIC ANALYSIS

5.1 EMPIRICAL MODEL

Based on the conceptual framework and the descriptive findings, the econometric analysis aims to assess the effect of the groundwater policy reforms on agricultural and environmental outcomes.

The empirical model to be estimated is the following:

$$Y_{it} = \alpha T_{it} + \beta X_{it} + \gamma_i + \delta_t + \varepsilon_{it} \qquad (1)$$

Where: Y_{it} is the dependant variable and three types of outcomes are measured. First, we consider the number of permanent electric pumps added in year t in block i. With this dependent variable, we measure the immediate effect of the policy. Second, we consider agricultural outputs with Y_{it} defined as the area cultivated, production and yields of major crops. Third, the dependant variable is the depth of groundwater in the pre- and post-monsoon periods in year t in block i and will, therefore, measure the environmental effect of the policy.

T_{it} is the treatment variable; it takes the value 0 (zero) before 2012 for all the blocks, 0 from 2012 in the semi-critical blocks, and 1 from 2012 in the safe blocks where the policy is applied. α is, therefore, the coefficient of interest and measures the effect of the groundwater reform on the different outputs. The treatment variable here is the policy. We, accordingly, estimate the Intention-to-Treat effect of the groundwater reform.

X_{it} is a vector of control variables including the supply of inputs (number of fertilizer depots and seed stores), land tenure (number of sharecroppers, and marginal and small farmers), supply of labor (number of agricultural laborers), access to market (road length) and the alternative sources of irrigation water (areas irrigated with a canal and with STWs), and finally the groundwater depth in year t or year t^{-1}.

γ_i and δ_t are the block level and time fixed effects, respectively, while ε_{it} is the term of error.

Equation (1) is estimated with two-way fixed effects. This method is widely used to estimate the causal effects from panel data and adjust for unobserved block-specific and time-specific confounders at the same time. Considering that some variables such as the area and population of the block or the rainfall are missing, this fixed effect approach allows controlling for unobserved heterogeneity between the blocks and within a block across the time period. In the present case, the two-way fixed effect is equivalent to a difference-in-differences (DiD) estimator with more than two periods and under specific hypotheses (Imai and Kim 2019a).

Most of the control variables are available on a subset of the panel. Tables 13 to 17, therefore, present the regressions without the control variables for the entire panel, and the results with the inclusion of the control variables for a reduced time period.

5.2. ROBUSTNESS CHECKS

As the two-way fixed effect validity is also dependent on the modeling assumptions and can be challenging to interpret (Imai and Kim 2019b), we also run several robustness checks to confirm our results.

First, regression discontinuity design (RDD) estimates the Local Average Treatment Effect (LATE). The reform is applied in safe blocks, while farmers in semi-critical blocks still need a permit from SWID to apply for an electricity connection. The Government of India uses two criteria to categorize administrative blocks as 'safe,' 'semi-critical' and 'critical' in terms of groundwater potential for development: (i) stage of groundwater development (SOD), and (ii) long-term changes in pre- and post-monsoon groundwater levels. SOD is the extraction of water as a percentage of the net renewable recharge. Following guidelines developed by CGWB (1998), the government classifies administrative blocks according to the assignment rule illustrated in Table 12, which includes combinations of SOD and significant long-term declines in groundwater levels pre- and post-monsoon.

Table 12. Criteria adopted for the categorization of blocks as safe, critical and semi-critical.

Stage of groundwater development	Significant long-term decline in groundwater level		Categorization
	Pre-monsoon	Post-monsoon	
≤ 70%	No	No	Safe
≤ 70%	Yes	No	Safe
≤ 70%	No	Yes	Semi-critical
≤ 70%	Yes	Yes	Semi-critical
> 70% and ≤ 90%	No	No	Safe
> 70% and ≤ 90%	Yes	No	Semi-critical
> 70% and ≤ 90%	No	Yes	Semi-critical
> 70% and ≤ 90%	Yes	Yes	Critical
> 90% and ≤ 100%	No	No	Semi-critical
> 90% and ≤ 100%	Yes	No	Semi-critical
> 90% and ≤ 100%	No	Yes	Semi-critical
> 90% and ≤ 100%	Yes	Yes	Critical
> 100%	No	No	Semi-critical
> 100%	Yes	No	Overexploited
> 100%	No	Yes	Overexploited
> 100%	Yes	Yes	Overexploited

Source: CGWB 1998.

A long-term decline means that groundwater levels fall by at least 20 cm per year, on average, over the previous 10 years. This assignment rule is used to categorize administrative blocks all over India and cannot be manipulated. The categorization used in 2011 was based on data collected by WRI&DD and CGWB in 2009, which was before the change in groundwater policy. For the RDD, we restrict our sample to blocks with a SOD lower than 90%, which allows us to consider a single variable to explain the treatment. The assignment variable is the decline in the groundwater levels in the post-monsoon period, and we use a sharp cut-off at 20 cm. In this subsample, all the blocks with a decrease of more than 20 cm are semi-critical and all those with a drop less than 20 cm are safe (Figure 14).

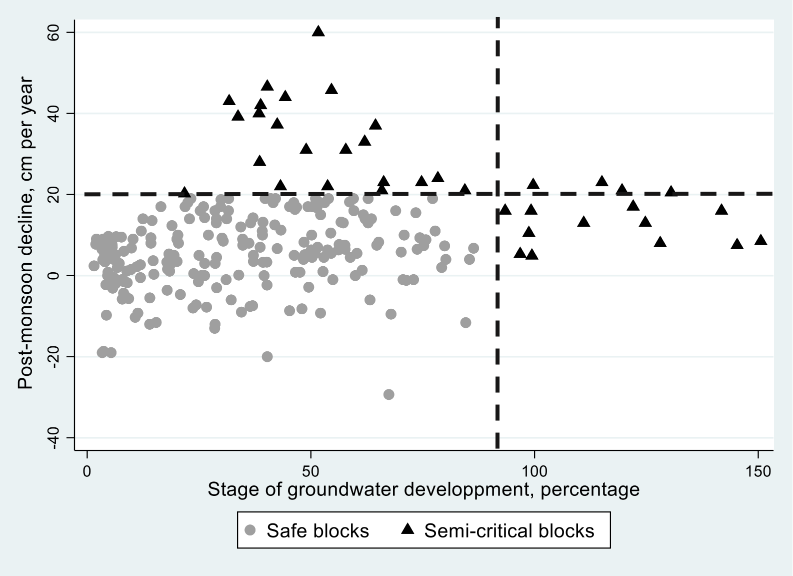

Figure 14. Stages of groundwater development and pre-monsoon decline in groundwater levels of administrative blocks in West Bengal.

Near the cut-off, we consider the treatment to be random. The estimations follow Calonico et al. (2014, 2017) and present local linear regression discontinuity point estimators with robust bias-corrected confidence intervals. The bandwidth selection procedure is based on minimal mean squared errors and uses two different bandwidth selectors below and above the cut-off. Finally, the regression discontinuity estimator is run with robust standard errors and clustering at the block level with year dummy variables as covariates to consider the panel nature of our dataset.

Second, we also estimate the Average Treatment Effect (ATE) by replacing the treatment variable by the actual number of permanent electric pumps added in each block in the previous year.

Finally, sub-sample regressions check the heterogeneity of the treatment. Different sub-samples are built based on the number of electric pumps installed in 2011, number of pumps newly electrified, and the geographical proximity of safe blocks to semi-critical blocks. The results of these regressions do not highlight any heterogeneity in the treatment effects. The tables presenting these results are, therefore, omitted[9].

5.3 TESTS OF PARALLEL TRENDS

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[9] The additional tables are available upon request.

The availability of data for several years before the groundwater policy reform for each of the outcomes allows testing the parallel trend assumption. This assumption usually supports the DiD estimates by checking with pre-treatment information whether the control units are an appropriate counterfactual and whether the treated observations would have followed the same trends in the absence of the treatment. The parallel trends are tested graphically for safe and semi-critical blocks and presented in Figures 15, 16 and 17. These tests confirm that before the treatment and the new policy, safe and semi-critical blocks were following similar paths in terms of pump electrification, and agricultural and environmental outcomes. These paths were parallel even if the levels were different.

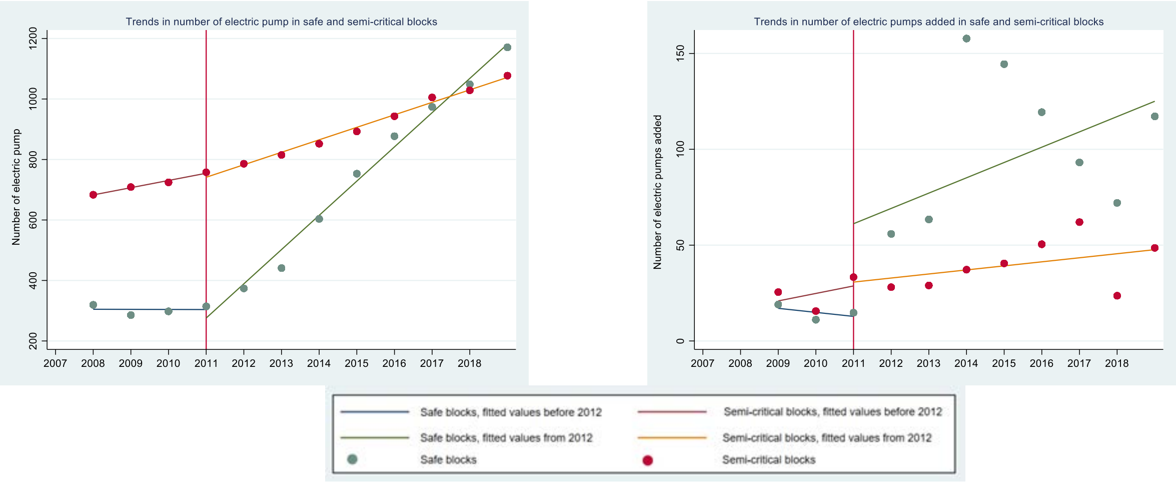
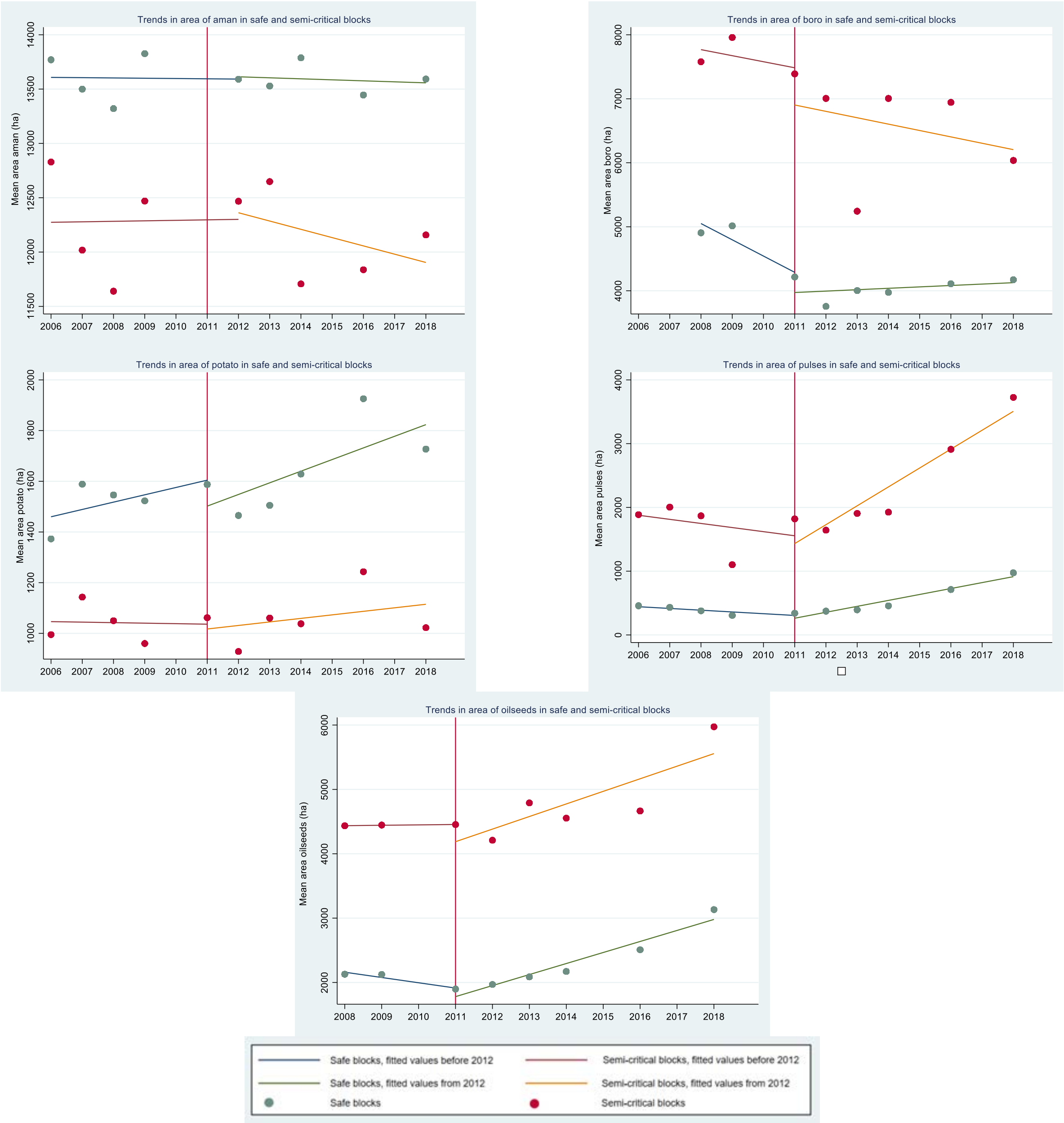


Figure 15. Parallel trend test - number of electric pumps.


Trends in area of aman in safe and semi-critical blocks

Trends in area of boro in safe and semi-critical blocks

Trends in area of potato in safe and semi-critical blocks

Trends in area of pulses in safe and semi-critical blocks

Trends in area of oilseeds in safe and semi-critical blocks

Figure 16. Parallel trend test - area cultivated with major crops.

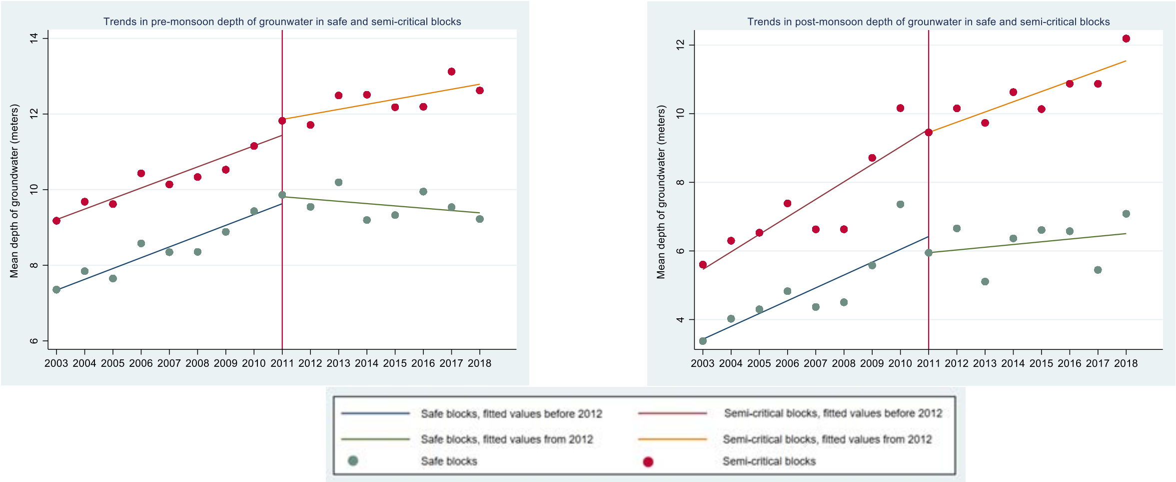


Figure 17. Parallel trend test - depth of groundwater.

In Figure 15, we note that the average number of electric pumps per block was higher in semi-critical blocks when compared to safe blocks, and that the number of pumps newly electrified each year was also higher. This observation justified the change in the legislation and the removal of the permit requirement. The permit was a constraint in safe blocks while it did not prevent groundwater over-abstraction in semi-critical blocks. In Figure 16, parallel trends are visually confirmed for five crops. Before 2011, the areas cultivated with different types of crops were evolving simultaneously in safe and semi-critical blocks. Finally, Figure 17 underlines that in the pre-reform period, the depth of groundwater was increasing over the years but at a parallel trend between safe and semi-critical blocks in the pre-monsoon season. However, in the post-monsoon season, the trend of depletion was slightly higher in semi-critical blocks when compared to safe blocks.

5.4 IMPACT ON THE NUMBER OF ELECTRIC PUMP CONNECTIONS

The first outcome of the policy reform is the immediate effect it had on the number of pumps permanently electrified. The results are presented in Table 13. As expected from the descriptive statistic, the reform had a positive and significant effect on the number of permanent electric pumps added annually in each block. The policy change explains an addition of, on average, 69 electricity connections per year and per block. Multiplied by 290 safe blocks and by 8 years after the reform, 75% of the 211,808 pumps electrified from 2012 to 2019 was due to the reform.

Table 13. Two-way fixed effect estimates on the number of electric pumps added.

Variables	(1) Number of permanent electric pumps added	(2) Number of permanent electric pumps added
Treated	68.99*** (13.03)	50.89*** (12.52)

Sharecroppers (number)		-0.00103
		(0.000840)
Patta holders (number)		0.00138
		(0.00184)
Small farmers (number)		-0.00196
		(0.00191)
Marginal farmers (number)		0.000156
		(0.000123)
Agricultural laborers (number)		0.00214**
		(0.000949)
Road length (km)		0.0733
		(0.0609)
Canal area (km)		-0.00183
		(0.00164)
Area irrigated by shallow tube well (ha)		-0.00709**
		(0.00341)
Observations	3,586	1,304
R-squared	0.079	0.062
Number of blocks	326	326
Years	2009-2019	2008-2013

Notes: Robust standard errors in parentheses. *** significant at the 1% level, ** significant at the 5% level, * significant at the 10% level.

The result is consistent with the addition of control variables on a smaller sample, even if the coefficient is slightly reduced. As expected, we note that the areas irrigated by alternative sources of irrigation water (canal and STW) are negatively correlated with the number of electric pumps added.

5.5 IMPACT ON CROPPING PATTERNS

For the cropping patterns, we consider the effect of the policy on three types of indicators: area under cultivation, production, and yields of *boro* and *aman* paddy, potatoes, pulses and oilseeds.

First, with the effect on the areas cultivated with different crops in Table 14, we identify a positive and significant impact of the treatment on the area planted with *boro* paddy. The coefficient is equivalent to 27% of the mean area in 2011. This result is expected as *boro* paddy is a water-intensive crop that requires multiple irrigation applications during the dry season. The result is also consistent with the slight decline of *boro* areas in semi-critical blocks observed after 2011, while it remains constant in safe blocks. Therefore, the groundwater reform slowed down the decline in *boro* areas in locations that benefit from increases in the number of electric pumps. Nonetheless, this result is not robust when control variables are added. Second, the effect of the treatment is positive on the area cultivated with oilseeds, but the result is not robust to the addition of control variables. Finally, we note a negative and significant effect of the groundwater reform on the area cultivated with pulses. The impact measured here is equivalent to 51% of the mean area planted with pulses per block in 2011. This result confirms the observation from the descriptive statistics and the increase in the area under pulses in semi-critical blocks after 2011. Pulses are an alternative crop to *boro* paddy in the dry season that does not require irrigation. Consequently, it is expected that the area under pulses will increase in blocks where there are constraints to irrigation, as in semi-critical blocks. This result is robust to the inclusion of control variable.

The results presented in Tables 15 and 16 for the production and yields, respectively, of these major crops confirm the effects measured on the area under cultivation. There is no significant effect of the reform on the production and yields of *boro* paddy. The treatment has a negative impact on the production of pulses (Table 15) and a negative effect on the yield of potatoes (Table 16). However, in these two cases, the significance of the coefficients is not consistent in the specifications with and without control variables. We, therefore, consider that these estimates are not robust and should be interpreted with precaution.

Table 14. Two-way fixed effect estimates on the area cultivated with major crops.

Variable	(1) Area *boro*	(2) Area *boro*	(3) Area *aman*	(4) Area *aman*	(5) Area potatoes	(6) Area potatoes	(7) Area pulses	(8) Area pulses	(9) Area oilseeds	(10) Area oilseeds
Treated	656.8**	721.9	-70.17	-158.8	88.60	-30.83	-456.8***	-293.7***	921.1***	101.9
	(305.1)	(560.2)	(540.5)	(357.6)	(93.78)	(131.4)	(166.3)	(110.9)	(315.1)	(174.5)
Fertilizer depots (number)		0.256		-4.864**		-1.203*		1.499***		-1.821
		(2.475)		(2.250)		(0.614)		(0.538)		(1.694)
Seeds store (number)		-6.589		3.267		1.925*		-4.227***		0.807
		(5.456)		(3.401)		(0.999)		(1.106)		(2.487)
Sharecroppers (number)		0.0821		-0.142		-0.00230		-0.00265		-0.0470
		(0.0615)		(0.111)		(0.0120)		(0.0103)		(0.0426)
Patta holders (number)		0.0530		0.123		-0.00376		0.0117		0.0695
		(0.0340)		(0.0987)		(0.00863)		(0.00754)		(0.0428)
Small farmers (number)		-0.0156		0.0341**		-0.0249***		-0.000987		-0.0173**
		(0.0199)		(0.0148)		(0.00416)		(0.00261)		(0.00701)
Marginal farmers (number)		-0.00631		0.00116		0.000302		0.00166*		-0.00101
		(0.00418)		(0.00415)		(0.000908)		(0.000997)		(0.00207)
Agricultural laborers (number)		-0.0639**		-0.0139		-0.00103		-0.00857**		-0.00517
		(0.0263)		(0.0204)		(0.00400)		(0.00343)		(0.00818)
Road length (km)		-0.200		-0.126		-0.0779		0.185**		0.235
		(0.379)		(0.776)		(0.0935)		(0.0864)		(0.198)
Area irrigated by canal (ha)		-0.00550		0.0324		-0.0150		3.70e-05		-0.000608
		(0.0291)		(0.0263)		(0.0239)		(0.00173)		(0.00697)
Area irrigated by shallow tube well (ha)		0.0629		-0.0318		-0.00528		2.01e-05		-0.0163
		(0.0492)		(0.0206)		(0.00602)		(0.00686)		(0.0168)
Groundwater depth post-monsoon (m) [Y-1]		-39.40				13.63		-2.652		-5.955
		(38.83)				(9.772)		(4.966)		(13.04)
Groundwater depth pre-monsoon (m) [Y]				26.39						
				(67.52)						
Observations	3,260	1,357	3,260	1,342	3,260	1,357	3,260	1,357	3,260	1,357
R-squared	0.033	0.080	0.022	0.125	0.020	0.030	0.171	0.059	0.119	0.018
Number of blocks	326	292	326	291	326	292	326	292	326	292
Years	2006-2018	2008-2013	2006-2018	2008-2013	2006-2018	2008-2013	2006-2018	2008-2013	2006-2018	2008-2013

Notes: Robust standard errors in parentheses. *** significant at the 1% level, ** significant at the 5% level, * significant at the 10% level.

Table 15. Two-way fixed effect estimates on the production of major crops

Variables	(1) Production *boro*	(2) Production *boro*	(3) Production *aman*	(4) Production *aman*	(5) Production potatoes	(6) Production potatoes	(7) Production pulses	(8) Production pulses	(9) Production oilseeds	(10) Production oilseeds
Treated	1.226	1.503	-35.04	0.340	2.642	2.817	-13.68	-0.223**	14.70	1.527
	(0.943)	(2.239)	(30.01)	(1.591)	(2.903)	(4.958)	(13.18)	(0.0967)	(13.57)	(1.536)
Fertilizer depots (number)		0.00233		-0.00666		-0.0404*		0.00188***		0.00221
		(0.0110)		(0.00959)		(0.0237)		(0.000705)		(0.00350)
Seeds store (number)		-0.0228		0.00111		0.113		-0.00428***		-0.00785
		(0.0203)		(0.0133)		(0.0807)		(0.00144)		(0.00627)
Sharecroppers (number)		0.000212		-0.000516		-0.000584		-1.45e-05		7.15e-05
		(0.000222)		(0.000368)		(0.000625)		(1.41e-05)		(0.000128)
Patta holders (number)		0.000130		0.000315		0.000991		1.23e-05		-5.04e-05
		(0.000111)		(0.000247)		(0.000716)		(1.20e-05)		(0.000181)
Small farmers (number)		-5.25e-05		9.64e-05		0.000379		-2.55e-06		-6.50e-06
		(6.16e-05)		(6.36e-05)		(0.000314)		(2.79e-06)		(1.77e-05)
Marginal farmers (number)		-1.42e-05		2.99e-05*		4.38e-07		3.36e-07		1.04e-05
		(1.69e-05)		(1.54e-05)		(3.66e-05)		(8.94e-07)		(1.26e-05)
Agricultural laborers (number)		-0.000197**		-4.93e-05		-0.000134		-6.21e-06**		-4.84e-05
		(8.06e-05)		(9.06e-05)		(0.000217)		(2.52e-06)		(4.23e-05)
Road length (km)		-0.00112		-0.00184		-0.00119		0.000191*		0.00633
		(0.00138)		(0.00251)		(0.00629)		(0.000108)		(0.00623)
Area irrigated by canal (ha)		-1.61e-05		0.000196**		-0.00111		3.83e-06*		1.07e-06
		(0.000106)		(8.88e-05)		(0.000823)		(2.08e-06)		(1.42e-05)
Area irrigated by shallow tube well (ha)		0.000146		7.62e-05		0.000221		1.62e-06		-8.87e-05
		(0.000150)		(8.45e-05)		(0.000288)		(6.99e-06)		(5.99e-05)
Groundwater depth post-monsoon (m) (Y^{-1})		-0.119				2.994***		-0.00128		0.0384
		(0.151)				(0.678)		(0.00454)		(0.0335)
Observations	3,260	1,357	3,260	1,342	3,260	1,357	3,260	1,357	3,260	1,357
R-squared	0.020	0.052	0.004	0.098	0.077	0.156	0.003	0.087	0.007	0.024
Number of blocks	326	292	326	291	326	292	326	292	326	292
Years	2006-2018	2008-2013	2006-2018	2008-2013	2006-2018	2008-2013	2006-2018	2008-2013	2006-2018	2008-2013

Notes: Robust standard errors in parentheses. *** significant at the 1% level, ** significant at the 5% level, * significant at the 10% level.

Table 16. Two-way fixed effect estimates on the yields of major crops.

Variables	(1) Yield *boro*	(2) Yield *boro*	(3) Yield *aman*	(4) Yield *aman*	(5) Yield potatoes	(6) Yield potatoes	(7) Yield pulses	(8) Yield pulses	(9) Yield oilseeds	(10) Yield oilseeds
Treated	45.40	11.71	-17.30	50.80	-2,677***	-1,018	747.0	245.9	13,090	36.31
	(56.13)	(90.52)	(48.27)	(79.84)	(734.4)	(1,146)	(584.3)	(261.6)	(13,554)	(35.95)
Fertilizer depots (number)		-0.0362		-0.300		-2.948		0.280		-0.327
		(0.463)		(0.473)		(7.161)		(0.363)		(0.223)
Seeds store (number)		-0.221		-0.100		-1.390		-1.209		0.136
		(0.639)		(0.638)		(12.12)		(1.025)		(0.325)
Sharecroppers (number)		0.00112		-0.0141		-0.117		0.00796		0.0230
		(0.0144)		(0.0159)		(0.323)		(0.00955)		(0.0203)
Patta holders (number)		0.00643		0.00188		-0.115		0.0131		0.00400
		(0.00906)		(0.00901)		(0.241)		(0.0177)		(0.00516)
Small farmers (number)		0.00121		0.00142		0.130**		-0.0387		-0.00237*
		(0.00249)		(0.00242)		(0.0517)		(0.0432)		(0.00140)
Marginal farmers (number)		0.000508		0.00233***		-0.00521		0.000436		0.000339
		(0.000854)		(0.000696)		(0.00834)		(0.00135)		(0.000278)
Agricultural laborers (number)		-0.00277		-0.00133		-0.0647		0.00142		0.00127
		(0.00382)		(0.00356)		(0.0604)		(0.00585)		(0.00159)
Road length (km)		-0.127		-0.0611		2.132		0.0118		-0.0506
		(0.0890)		(0.112)		(1.695)		(0.110)		(0.0565)
Area irrigated by canal (ha)		-0.00576		0.00573		-0.175*		0.000128		0.00192
		(0.00511)		(0.00359)		(0.0909)		(0.00689)		(0.00185)
Area irrigated by shallow tube well (ha)		-0.000569		0.00744*		-0.0242		-0.0109		-0.000807
		(0.00428)		(0.00398)		(0.110)		(0.0107)		(0.00205)
Groundwater depth post-monsoon (m) (Y^{-1})		-0.136				335.5***		13.99		-7.290*
		(5.162)				(125.9)		(10.23)		(4.063)
Observations	2,889	1,216	3,231	1,337	2,775	1,152	2,455	907	2,871	1,173
R-squared	0.91	0.141	0.116	0.082	0.450	0.525	0.038	0.023	0.007	0.151
Number of blocks	326	282	325	291	319	274	326	242	324	276
Years	2006-2018	2008-2013	2006-2018	2008-2013	2006-2018	2008-2013	2006-2018	2008-2013	2006-2018	2008-2013

Notes: Robust standard errors in parentheses. *** significant at the 1% level, ** significant at the 5% level, * significant at the 10% level.

5.6 IMPACTS ON GROUNDWATER LEVELS

After the agricultural outcomes, the effect of the groundwater policy reform is assessed on the environmental outcomes. The dependent variables are the depth of groundwater in the pre- and post-monsoon seasons. While the effect of the treatment is not significant in the pre-monsoon depth of groundwater, we notice a negative and significant impact on the post-monsoon depth of groundwater. Water tables in blocks where the groundwater policy reform was applied were 1.5 meters (m) higher, on average, compared to control blocks. The mean depth of groundwater was 6.5 m in 2011; this effect is equivalent to a reduction of 23% of the mean. Groundwater over-extraction by electric pump owners due to lower pumping costs is often hypothesized to cause depletion of the resource. However, our result highlights that the groundwater policy reform did not jeopardize groundwater resources. On the contrary, treatment is associated with a slight improvement in groundwater levels as compared to the pre-2011 period and in comparison with semi-critical blocks (Table 17).

Table 17. Two-way fixed effect estimates on groundwater depth.

Variables	(1) Groundwater depth Pre-monsoon	(2) Groundwater depth Pre-monsoon	(3) Groundwater depth Post-monsoon	(4) Groundwater depth Post-monsoon
Treated	-0.494	-0.323	-1.585***	-1.188***
	(0.400)	(0.265)	(0.460)	(0.298)
Road length (km)		8.14e-05		0.000616**
		(0.000422)		(0.000286)
Canal area (km)		-1.55e-05		-3.10e-05
		(1.96e-05)		(1.93e-05)
Area irrigated by shallow tube well (ha)		3.95e-05***		-1.41e-05
		(1.31e-05)		(1.96e-05)
Observations	4,466	1,342	4,419	1,376
R-squared	0.240	0.261	0.350	0.298
Number of blocks	314	291	314	291
Year	2004-2018	2004-2018	2004-2018	2004-2018

Notes: Robust standard errors in parentheses. *** significant at the 1% level, ** significant at the 5% level, * significant at the 10% level.

5.7 RESULTS FROM ROBUSTNESS CHECKS

Results of the regression discontinuity estimates are presented in Annexure Tables A3 and A4. For the *boro* crop, the LATE is positive and significant on the area cultivated, production and yield. The coefficient for the area and production are quite large, indicating that this effect might be led by a limited number of blocks that benefitted from the electrification policy. This result is substantiated by the descriptive statistics presented in Figure 18 and highlights the heterogeneity in the effects of the treatment. While there are no or limited effects for most of the blocks, this positive effect with the regression discontinuity estimate is driven by a small number of blocks located near the cut-off of 20 cm decline in post-monsoon groundwater depth. Beyond the significant and positive effect of the treatment on *boro* paddy areas, production and yields, the other coefficients for agricultural outcomes are either insignificant or non-robust in the different specifications (Annexure, Table A3). The LATE of the groundwater policy reform is similarly insignificant on the groundwater depth, both in the pre- and post-monsoon seasons (Annexure, Table A4). The placement of the blocks in the safe and semi-critical blocks is random near the cut-off of 20 cm and explains the application of the policy and ease of access to electrified irrigation, but is not a significant determinant of the groundwater depth.

The average treatment effects are estimated by including the number of permanent electric pumps added per year in each block as treatment variable and presented in Annexure Tables A5 and A6. The findings are consistent with the previous results from the two-way fixed effects. Additional permanent connections may have a small significant impact on the areas cultivated with and production of *boro* paddy, but the coefficients are very small and not robust to the inclusion of control variables on a reduced sample. In general, the ATE estimates confirm the overall insignificant effect of the additional electric pumps on agricultural and environmental outcomes.

6. INSIGHTS FROM QUALITATIVE DATA

We conducted FGDs with 165 farmers (including 45 women) in 11 villages spread over eight districts in West Bengal. In these FGDs, we enquired about the extent of pump electrification in the post-2011 period, and the current cropping patterns and how these had changed in the last 10-15 years. We also discussed changes in the nature and extent of informal water markets; changes in land leasing and sharecropping arrangements; and overall economic opportunities in and beyond the villages. For women respondents, we also asked them about their level of participation in agriculture and how that had changed over the last 10-15 years. We wanted our respondents to reflect on how the policy changes in electricity and groundwater sectors after 2011 affected agricultural and groundwater outcomes in their villages. We conducted fieldwork in seven of these 11 villages in 2004 (see Table 4).

6.1 ELECTRIFICATION OF PUMPS AFTER 2011

Majority of the new electric pumps were reported from villages in Cooch Behar: Pushpadanga, Nakkati, Angerkata Khaterbari, and Jarabari I and II. Except for Angerkata Khaterbari, where we had conducted fieldwork in 2004, these villages were selected purposively in consultation with the New Town Sector CCC and Dinhata CCC. These were villages which had received a large number of electricity connections. We were interested in understanding changes in cropping pattern and agricultural dynamics as a result of massive electrification in the post-2011 period.

In the 350-household strong Pushpadanga village, approximately 50 new electric pumps were installed in the last 7-8 years. The village received an electricity connection only in 2010. In Nakkati village, there are currently 100 or so electric pumps that irrigate the entire village of 1,200 *bighas* (1 *bigha* = 0.1338 hectares). This village was electrified in 2010 and, thereafter, electric pumps were installed from 2014 onwards. This is similar to Jarabari I and II villages, where 95 new pumps were electrified after 2011. During our fieldwork in 2004, the village of Angerkata Khaterbari did not have electricity. There were only 25 or so diesel pumps at that time. Now, approximately 450 households in the village own 350 electric pumps – almost everyone has an electric pump – albeit these are small pumps, ranging from 0.5 to 2.0 HP. One villager stated:

> *"In 2016, our village got connected to the grid. Thereafter, once electric pumps were introduced and we started growing three crops in a year, days of hunger have disappeared. Every family now has enough food for the entire year."*

The picture from other districts is rather mixed. In Adhata village in North 24 Parganas, only one of approximately 100 electric pumps got a connection after 2011. The other pumps were electrified long ago in the mid-1990s and early 2000s. At present, 30 of these approximately 100 electric pumps have been disconnected due to non-payment of electricity bill. In Amra village in Bardhaman 1 block, none of the diesel pumps have received an electricity connection, and this village continues to rely solely on diesel shallow pumps. While not officially a part of critical or semi-critical blocks, the villagers told us that the electricity department had refused their applications for new connections due to the low water table in the village. In Silinda village of Nadia district, only 10 of the 46 electric pumps have received their electricity connection after 2011, others were electrified as early as in the mid-1980s, as a part of a World Bank cluster STW program.

In Bengai village in Hooghly district, of the current 50 electric pumps, 30 got their electricity connection after 2011. These were previously diesel STWs or those that had temporary electricity connections, which were then converted to permanent connections. As one resident told us:

> *"I came to know from a newspaper article in 2012 that SWID certificates were no longer required for permanent electricity connections. I enquired at our local electricity office, but they said that the policy had not been implemented in our area. So, I decided to continue applying for a temporary connection every year as before. Then, I applied for a permanent connection in 2016 and got the connection at a subsidized rate. I didn't have to pay for poles or wires."*

While electrification of pumps was seen as a major progress in these villages, there were complaints about poor quality and duration of electricity supply in Polsonda village in Murshidabad, and about arbitrarily high electricity bills in villages in North 24 Parganas (Adhata), Hooghly (Bengai), and Bankura (Tajpur).

6.2 CHANGES IN CROPPING PATTERN: DECLINE IN THE AREA UNDER *BORO* CROPS IN SOME VILLAGES AND AN INCREASE IN OTHERS

Two broad types of changes in cropping pattern were identified in the post-2011 period. First, replacement of water-intensive *boro* paddy with less water-intensive crops such as potatoes, oilseeds and vegetables in villages where there was no substantial increase in the number of electric pumps after 2011. Second, an increase in the area under *boro* paddy. This was found in almost all villages with large increases in the number of electric pumps after 2011.

In all villages in Cooch Behar, for instance, *boro* paddy cultivation started on a large scale after 2011 with the electrification of pumps. In Pushpadanga village, the irrigated area increased from 100 *bighas* to 400 *bighas* during the period from 2010 to 2019. Of these 400 *bighas*, *boro* paddy was cultivated on 250 *bighas*. The area under vegetables (potato, cabbage, cauliflower, tomato) and tobacco also increased, and maize was introduced as a new crop. In Nakkati village, before the electrification of pumps, most of the village land remained fallow during the summer. Now, after growing *aman* rice on the entire 1,200 *bighas* of land, *boro* paddy is grown on 800 *bighas*, and tobacco, jute, mustard, potato and vegetables are grown on the remaining area. The situation is similar in Angerkata Khaterbari, where the area under *boro* paddy increased from less than 50 *bighas* in 2004 to more than 500 *bighas* in 2019. In addition, on approximately 600 *bighas*, a number of crops such as maize, mustard, potato, brinjal, chili, jute and other vegetables are cultivated. In all these villages, farmers have made a transition from growing rice in just one season to cultivating three crops a year. This has had a huge positive impact on their food security and nutrition. A farmer with 2 *bighas* of land in Angerkata Khaterbari highlighted this when he stated:

> *"I grow two crops of paddy (aman and boro) and vegetables. I can meet the rice requirement for my family of 5 members for the entire year. An electric pump is like a cow. A cow gives milk for my family. An electric pump provides water, which I can use to provide food throughout the year for my children."*

The area under *boro* paddy also increased in villages such as Bengai in Hooghly district, Donaipur in Birbhum district and Polsonda in Murshidabad district. All these villages had received a substantial number of new electricity connections after 2011. In Bengai village, double-cropped land (*aman-boro* crop cycle) increased from 10% of the cultivated land to 30%, and triple-cropped land (aman-potato-sesame crop cycle) increased from 40% of the cultivated land to 70% in the last 10 years. Overall, cropping intensity increased from 150% to 200% during this time. In this village, FGD respondents also reported an increase in the yields of *boro* paddy and potato by 20-30%, as a result of better and assured irrigation using electric pumps. Donaipur village also reported an increase in the area under *boro* paddy. Before 2011, the village had only one electric pump, which was jointly owned by nine families. Based on fieldwork conducted in 2004, Mukherji (2007b) had documented the rather unique water sharing arrangement in this village. Since then, this jointly owned electric pump had been replaced by four electric pumps and, for the first time, farmers who did not own pumps could buy water and grow *boro* paddy. Villagers in Polsonda village underlined the importance of electric pumps for growing *boro* paddy when they stated:

> *"We take two harvests of paddy because we have access to electric pumps. We have heard some rumors that the government wants us to stop growing boro paddy because it needs a lot of water. But, if we stop growing boro paddy, we will face a food crisis like our fathers used to face in the 1970s and 1980s."*

A majority of the farmers who grew *boro* paddy underlined its role in household food security. However, increasing costs of production and the difficulty in getting the government-declared procurement price were squeezing farmers' profit margins. As some farmers from Bengai noted:

> *"We do not get a chance to sell our paddy at government camps at government-fixed rate. We went there to sell paddy in the month of April. They said they will purchase paddy in August and September. They are supposed to send us text messages via cell phone. But, it is October now and we have not received any text from them. Moreover, those camps pay for paddy by cheque and not by cash. Therefore, after selling paddy, farmers do not get money immediately to spend on cultivation or for household expenses."*

The area under *boro* paddy declined in villages that did not experience a massive electrification of pumps after 2011, in general. For example, most farmers in Adhata village in North 24 Parganas stopped growing *boro* paddy around 2009-2010 – a couple of years after the metering of agricultural tube wells. The reason cited was very high electricity bills. Up to around 2007, farmers used to pay a fixed electricity bill of INR 10,800 per year, irrespective of the actual hours of pumping. In 2007, the metering of agricultural pumps was introduced, and a time of day (TOD) meter was introduced. Though evidence shows that shifting from a flat tariff to metered tariff was beneficial to most pump owners (Meenakshi et al. 2013; Mukherji et al. 2009), this was not the case in some villages such as Adhata, where pump owners perceived otherwise and stopped cultivating water-intensive *boro* crops. This may have been due to successive and steep increases in TOD tariffs in the later years (Table 18).

Table 18. Increase in electricity tariffs for agricultural electric pumps.

	Energy cost (INR/Kwh)	
Time of Day (TOD)	2007-2008	2017-2018
6 am - 5 pm	1.37	3.78
5 pm - 11 pm	4.75	7.48
11 pm - 6 am	0.75	2.42
Average price INR/unit	**1.49**	**4.30**

In this village, cropping patterns changed from an *aman-boro* cycle before 2010 to *aman*-jute-sesame and *aman*-mustard-pulses after 2010. At the same time, one-third of the village land was converted to tree plantations. Currently, *boro* paddy is cultivated on only 250 *bighas* of land (out of a total area of 2,500 *bighas* in the village), which receives cheap irrigation from government-owned deep tube wells. In the words of an electric pump owner in the village:

> *"After installation of meters, we cultivated boro paddy for two years. Then, we started receiving electricity bills of around INR 12,000 for just three months during the boro season. So, I stopped growing boro paddy. From the next year, many others followed. We started growing less water-intensive crops like wheat, pulses, sesame and vegetables."*

In Amra village in Bardhaman, farmers have not grown *boro* paddy for the last 20-25 years. This village receives some canal water in the *aman* season and is entirely dependent on diesel STWs for the remainder of the year. In Silinda village in Nadia, there is a change in cropping pattern away from *boro* paddy to vegetables. Reasons for this shift included: low overall profits from *boro* paddy, and less water requirement for growing vegetables. Availability of labor is another factor. Many young men in the village have started migrating to other cities in India during the last 10-15 years. Increasingly, women's participation in agriculture has increased. Women from landed families work in vegetable fields, but they find the work in paddy fields to be too onerous.

6.3 INFORMAL WATER MARKETS

Overall, from our qualitative evidence, it seems that incidence of water selling, and depth and breadth of these water markets have reduced post-2011. Terms and contracts in water markets also seem to have become more uniform than before, and there is anecdotal evidence about collusion among pump owners in setting water prices and dividing command areas among themselves. This is in line with findings by Meenakshi et al. (2013), which showed that the metering of electric pumps reduced incentives among pump owners to sell water. Ease of ownership of electric pumps also meant that many of the erstwhile water buyers bought their own electric pumps and were, therefore, no longer reliant on informal water markets for their water needs. In some villages, pump density is now high, and ownership is so ubiquitous that there is no scope for emergence of informal water markets. This is especially true in some of the smaller villages in Cooch Behar.

In most villages, incidence of water selling has reduced drastically after metering. In Adhata village, up to around 2009-2010, almost every electric pump owner used to sell water for the cultivation of *boro* paddy on 20-30 *bighas* of land. Now, only one pump owner provides water to 10-12 *bighas* of land for the cultivation of *boro* paddy, and the remaining 70 electric pump owners do not get involved in water selling for boro cultivation. They run their pumps for only 100-150 hours a year – down from 800-1,200 hours a year previously in the pre-metering period. Currently, the water rate is INR 2,500/*bigha*/season for *boro* paddy, and INR 100/hour for other crops.

Within each of the villages, the water price seems to be more or less fixed across the village by pump owners, and the command area of each electric pump is also clearly earmarked. During our earlier study of informal water markets in the state (Mukherji 2007a), we found that water prices were a subject of negotiation among pump owners and water buyers, and there was substantial variation in water prices within the same village, which depended on the density of electric pumps and availability of other alternative sources of irrigation. As mentioned earlier, the metering of electric pumps removed the earlier incentive for selling water and provided higher bargaining power to water sellers. Possibly in response, and as a result of reforms after 2011, a large number of erstwhile water buyers became pump owners and informal transactions in water markets dwindled.

Overall, water prices for *boro* paddy ranges from INR 1,200-1,500/*bigha*/season in villages in Cooch Behar, where water tables are shallow and rainfall is high, to INR 2,000-2,500/*bigha*/season in other districts. The water price for *aman* paddy is half that of *boro* paddy, and that of potato is 60-70% of *boro* paddy – reflecting different water requirements of these crops. For most vegetables and *rabi* crops such as oilseeds and pulses, water prices are fixed on an hourly rate and ranges from INR 80-120/hour.

While there are two studies that document the ex-ante (Mukherji et al. 2009) and ex-post (Meenakshi et al. 2013) impact of metering on informal groundwater markets, we do not have studies that look at the post-2011 reforms, namely, ease of obtaining electricity connections and rising electricity tariffs on these markets. This should be an area of future research. The only exception is a study by Shah et al. 2019, which concludes that high electricity tariffs and resultant high electricity bills have dampened water markets.

6.4 SHARECROPPING AND LAND LEASE ARRANGEMENTS: INCREASED IN VILLAGES WITH ADDITIONAL IRRIGATION FACILITIES AND DECLINED IN OTHERS

In villages that have seen an overall decline in the area under *boro* paddy, and conversion of cultivated land to tree plantations or human habitations (e.g., Adhata in North 24 Parganas and Polsonda in Murshidabad), the incidence of land leasing has declined substantially since the last 10-15 years. In Silinda village in Nadia, the lease rate for vegetable crops has increased, and that of *boro* paddy has decreased – indicating declining profits in *boro* paddy cultivation. In all these villages, previously, there was a tendency among larger pump-owning farmers to lease land from smaller farmers at a fixed seasonal rate for the cultivation of *boro* paddy. This practice has stopped since the last 10-15 years because these villages started growing less and less *boro* paddy.

However, in villages where the area under *boro* paddy has increased and much of the village land is triple-cropped, e.g., villages in Cooch Behar, Birbhum and Murshidabad, two types of tenancy systems have emerged. In one system, larger landowners are leasing land from smaller non-pump-owning farmers against a fixed yearly contract of INR 8,000-12,000/year provided they also have plenty of family labor to work on those lands. More common, however, is a practice of reverse tenancy, where small farmers (with 1-2 *bighas* of land), who own an electric pump and have a large enough family size, leases land from larger farmers against a fixed annual rent. In Pushpadanga village in Cooch Behar, even landless farmers are known to lease land for the cultivation of *boro* paddy. In Jorabari I and II villages in Cooch Behar, some 8-10 landless families lease land from pump owners at INR 3,500/*bigha*. They also pay another INR 1,500-1,800 for buying water during the *boro* season. This is done mainly to ensure food self-sufficiency for their households.

There was a plethora of studies on sharecropping and land-leasing arrangements in West Bengal from the 1960s to the mid-1990s (Bhaduri 1973, 1986; Harriss 1992). These studies were influential in affecting land reforms in the state, and studies thereafter looked at changes in tenancy due to land reforms. However, not many studies have looked at the impacts of groundwater irrigation on changing agrarian relations since the early 2000s. This is an area of future research and can help inform pathways through which poor people are emerging from (or getting trapped in) poverty.

6.5 GROUNDWATER LEVELS

We asked farmers about their perception on groundwater levels in their villages after 2011. In majority of the villages, farmers felt that there were no perceptible changes in groundwater level, but a decline in water levels was reported in some villages. In Amra village in Bardhaman district, it was reported that many diesel STWs had dried up especially after the installation of electric submersible pumps in an adjoining village. It must be noted that, in Amra village, applications for electricity connections in the agricultural fields were turned down by the electricity department on the grounds of depleting water layer. In a few other villages such as Polsonda in Murshidabad, and Silinda in Nadia, new electricity connections have been held back in recent years due to the same reasons. There were 36 semi-critical and one critical block in West Bengal in 2009 as per data from WRI&DD. Since then, WRI&DD has proposed a revised list of 30 critical and 42 semi-critical blocks based on CGWB's groundwater assessment of 2017, but an updated list is yet to be approved by the Government of West Bengal. However, it seems that the list has been communicated to WBSEDCL and local administration, and they are using it for approving new electricity connections.

6.6 INCREASED MIGRATION, INCREASED WOMEN'S PARTICIPATION IN AGRICULTURE AND IMPROVED SOCIOECONOMIC CONDITIONS

During the course of our discussions, a number of coherent themes emerged. First, the improved financial condition of most villagers, including better food security. This, the respondents felt, was due to three interrelated developments. One was the introduction of electric pumps, especially in villages in Cooch Behar that were not electrified before 2010, which enabled farmers to grow *boro* paddy and assure food security of their households. Second, the increased trend of participation in non-agricultural labor by men in the village, including a relatively new trend of migrating to other cities in India for construction-related work. Third, increased female participation in the agricultural labor force, partly in response to male out-migration but also in response to better wage rates in agriculture.

In all villages, respondents reported improved financial conditions and better food security. In Adhata village, we were told about 20 years ago that 50% of families in the village would face food insecurity at least in some parts of the year. This is now an event of the past. This situation was the same in Polsonda, where villagers attributed better food security to an increased area under *boro* paddy, and to increased out-migration from the village to other states in India. In Angerkata Khaterbari village in Cooch Behar, migration of entire families to Bhutan for road construction work was very common until about 10 years ago. Now, almost no one migrates for such laborious work. This is because of better food availability. In these newly irrigated villages, yield of both *aman* and *boro* paddy has almost tripled since the introduction of electric pumps in 2016.

Both agricultural and non-agricultural wage rates have improved. Better non-agricultural wages are taking men away from their villages and agricultural work, and women are filling in that gap. Better wage-earning opportunities, along with memberships in self-help groups helped in improving the financial condition of women. Due to a number of government schemes such as Kanyashree[10], girls were more likely to complete their high school education, and in some schools, the number of girl students outnumbered the boys. Out-migration of men, however, has changed after the Covid-19 pandemic. In most villages, where we carried out phone interviews after the Covid-19 lockdown had started, it was reported that migrant youths had either returned to the village or were planning to return.

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[10] It is a scheme by the Government of West Bengal, where girls are paid an annual stipend of INR 750/year between the ages of 13 and 18, provided she is enrolled in a school and not married. Once the girl turns 18, she is paid another INR 25,000, provided she is still engaged in academic or occupational pursuit and is not married.

7. DISCUSSIONS: INTERPRETING THE RESULTS OF THE ECONOMETRIC ANALYSIS USING QUALITATIVE INSIGHTS

Results from our econometric analysis presented in section 5 is summed up in this section. Despite the positive effect of the groundwater policy reform on the immediate outcome of pump electrification, its effect on agricultural outcomes (cropping pattern, cropping intensity, cropped area, production and yield) was not evident. We acknowledge a positive effect of the policy on the *boro* paddy area and production, and a negative effect on the area under pulses. Yet, these effects were not robust to different specifications and robustness checks, and were driven by a limited number of blocks. The treatment (i.e., groundwater policy changes) led to slight improvements in groundwater levels when compared to the pre-2011 period, and this was particularly the case in semi-critical blocks. The expectation was that groundwater levels would decline further. However, given that cropping patterns and crop water use had not changed significantly in the post-2011 period, there was no overall acceleration in the pace of groundwater use and extraction either.

We are then faced with a puzzle. What explains the largely limited or unobserved effect on agricultural outcomes, even after the addition of over 216,000 electric pump connections between the years 2011 and 2019? We present a few hypotheses to explain this puzzle and try to substantiate it with our qualitative field evidence.

7.1 POOR QUALITY ELECTRICITY SUPPLY

Our first hypothesis is that, even though the number of electric pumps has increased manifold, the quality of electricity supply has been poor, with a limited number of hours of availability of electricity and hence very little actual change in the net electricity available for irrigation. The large number of new connections provided in the northern districts, especially Cooch Behar, and very low use of electricity per pump pointed us to this hypothesis (Figure 18).

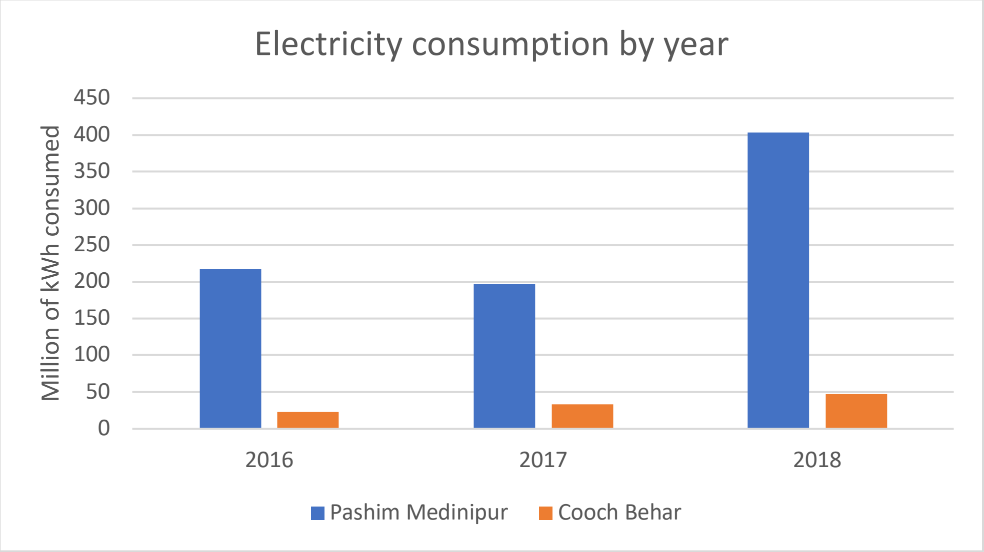

Figure 18. Electricity consumption in agriculture in Pashim Medinipur and Cooch Behar districts.

Field visits conducted in 2014 had indicated that the supply of electricity was a major constraint, with a limited number of hours of power supply in a day. The situation has improved in Cooch Behar since then, as highlighted during our field visits to four villages in February 2020. New transformers have been added and the capacity of older transformers have been improved. Low use of electricity per pump is explained by smaller pump sizes. Farmers did not complain about the quality of supply anymore, at least in the four villages we visited. However, we heard about the poor quality of electricity supply and prolonged periods of load shedding from other districts such as Murshidabad and Bankura. Electricity consumption data from 2015 to 2018 provided by WBSEDCL shows a steady increase in electricity consumption in agriculture (Figure 19). Overall, service performance of WBSEDCL has also improved over the years (Chatterjee 2018), and this hypothesis about poor quality of electricity supply is unlikely to hold true for the entire state.

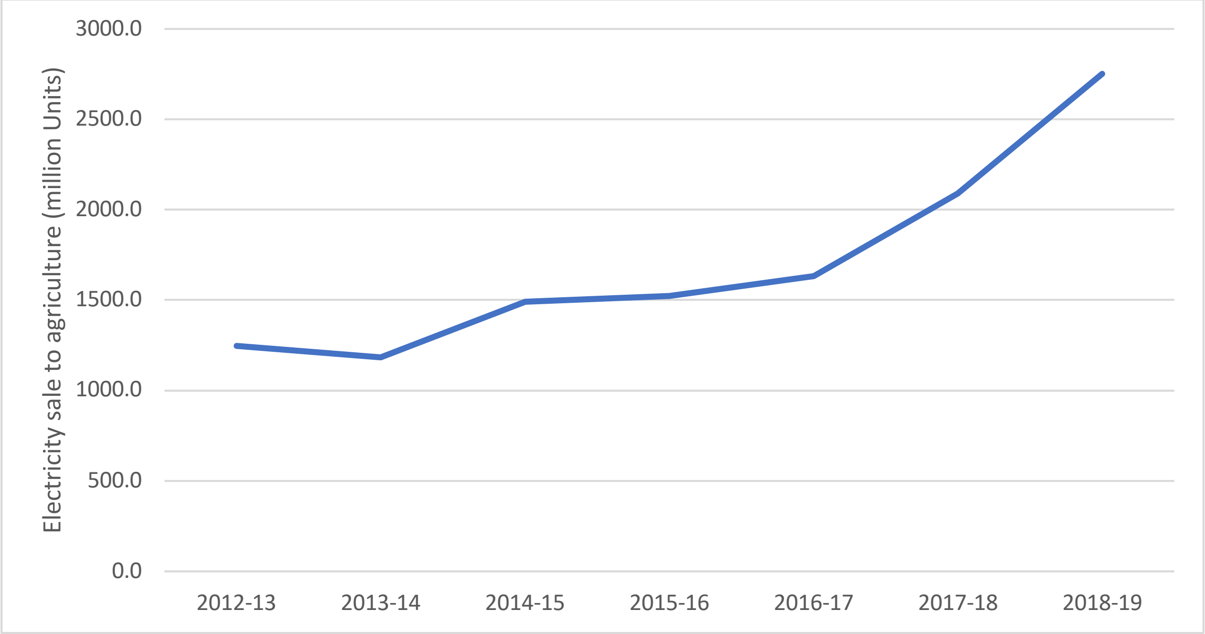

Figure 19. Sale of electricity to agricultural consumers from 2012-2013 to 2018-2019 (Source: WBSEDCL).

7.2 NEW ELECTRIC PUMPS DID NOT REALLY ADD TO THE EXISTING STOCK OF PUMPS AS THEY MERELY REPLACED TEMPORARY CONNECTIONS AND DIESEL PUMPS

We hypothesize that these new electric pumps have not really added to the total stock of agricultural pump sets in the state. Rather, a large number of them were already operating as 'temporary' connections or were diesel pumps. In other words, permanent electric pumps have merely replaced temporary electric pumps and diesel pumps which were already operational.

First, we examine the shift from temporary to permanent electricity connections in the state. WBSEDCL started giving temporary electricity connections in 2008. Through this scheme, they provided electricity connections to farmers for 105 days during the *boro* season against a fixed electricity tariff. The number of temporary electricity connections started declining after 2011 in safe blocks. It is also decreasing in semi-critical blocks, but at a lower rate (Figure 20). We also tested the effect of the treatment on the number of temporary connections. We note a significant and negative impact of the groundwater policy reform on the number of temporary electric pumps granted each year (Table 19, column 1).

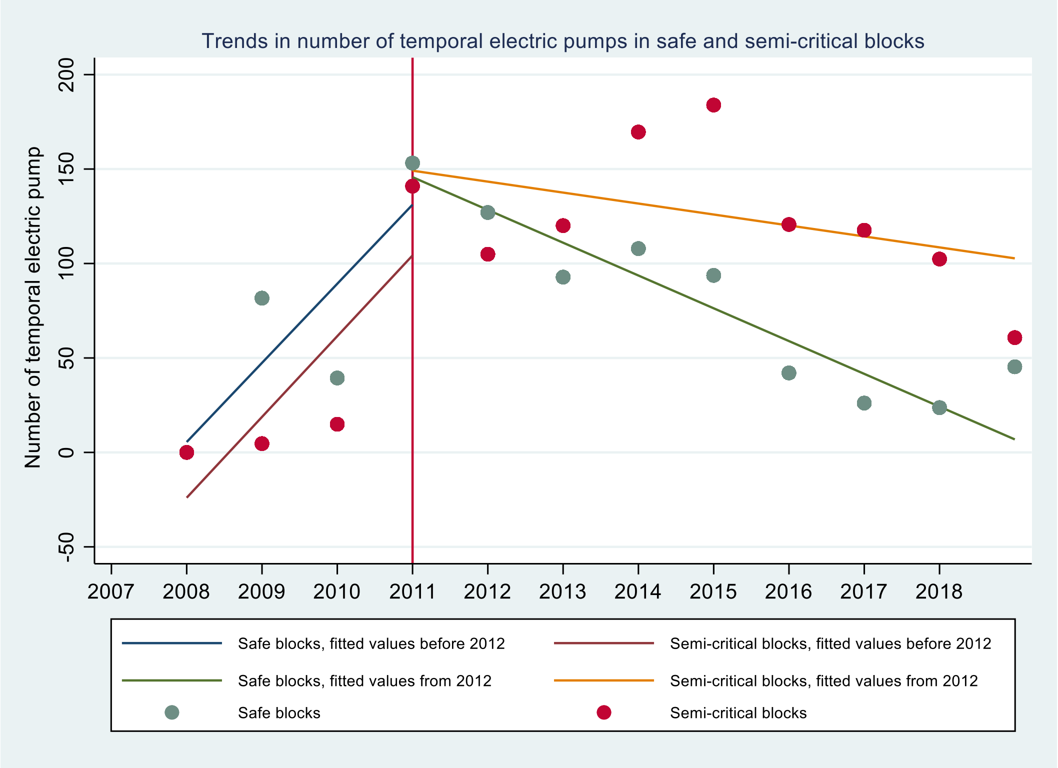

Figure 20. Trends in the number of temporary connections by block.

Table 19. Impact of the treatment on the area irrigated using deep tube wells (DTWs).

Variables	(1) Number of temporary electric pumps added	(2) Area irrigated	(3) Area irrigated per DTW
Treated	-69.73**	283.0256	-6.737***
	(30.50)	(780.292)	(2.357)
Observations	3,912	1956	1421
R-squared	0.056	0.0464	0.0258
Number of blocks	326	326	252
Years	2009-2019	2009-2014	2009-2014

Notes: Robust standard errors in parentheses. *** significant at the 1% level, ** significant at the 5% level, * significant at the 10% level.

Farmers who were getting temporary electricity connections every year and who already had the equipment (transformers, wires, poles, electric pump) were the first to benefit from the revocation of the permit requirement and were able to convert their temporary connections to permanent year-round connections. We also found evidence of this during our qualitative fieldwork in several villages. These farmers were already irrigating their *boro* crops at the same cost and under the same conditions as they would do with a permanent electricity connection. The shift from temporary to permanent electricity connections reduced their transaction cost by preventing the need to repeat the application process each year. However, the potential effects on agricultural and environmental outcomes are limited to the non-*boro* season effect, i.e., when irrigation needs are limited anyway.

It is also possible that erstwhile diesel pump owners replaced their pumps after they got new electricity connections. These farmers certainly benefited from irrigation at a lower cost; nevertheless, the effect can be limited in a context where the cropping intensity is already high and if farmers continued growing the same crops as before. The source of energy is not provided in the District Statistical Yearbooks. However, by using the Minor Irrigation Census data for 2013-2014, we know that 77% of the STWs are energized by diesel. We, consequently, consider the number of STWs as a rough estimate of the number of diesel pumps. The number of STWs per block declined since 2012 in the safe blocks while it is constant in the semi-critical blocks (Figure 21). This observation confirms a possible shift from diesel to electric pumps[11]. Our anecdotal evidence from all 11 villages confirms this hypothesis that many erstwhile diesel pump owners opted for permanent electricity connections.

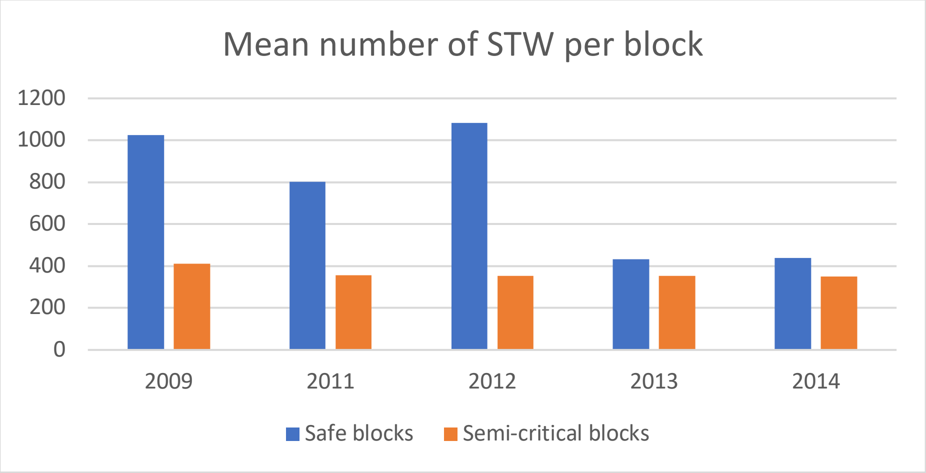

Figure 21. Mean number of shallow tube wells per block.

7.3 ERSTWHILE WATER BUYERS BECAME ELECTRIC PUMP OWNERS, SO NOT MUCH NEW LAND WAS BROUGHT UNDER IRRIGATION

Many water buyers are likely to have become electric pump owners after the groundwater policy reform. These reforms drastically reduced the transaction cost of getting an electricity connection for smaller farmers. Studies on the impact of metering of electricity on water markets showed that pump owners were less likely to sell water, and this particularly affected irrigation of *boro* paddy for water buyers (Meenakshi et al. 2013). Previous studies also showed that metering had changed the incentive structure for water sellers, and terms and conditions of water selling had become less favorable for the water buyers after the metering of electricity (Mukherji et al. 2009). It is, therefore, likely that many of these erstwhile water

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[11] Nevertheless, electrification alone cannot explain the decline in the number of STWs. From our data, 147,373 STWs went missing from 2012 to 2013, while 15,008 permanent electricity connections have been added in the meantime.

buyers applied for electricity connections soon after policy reforms in 2011. While the only way to confirm this is through a large-scale representative survey of farmers in West Bengal, our qualitative fieldwork in 11 villages does provide some confirmation of this hypothesis. For these farmers, access to a permanent electricity connection may have slightly reduced the costs of irrigation; however, it has not drastically changed their cropping pattern and agricultural practices.

When we combine the explanations given in sections 7.2 and 7.3, it seems that there may have been only a minimal number of new water users brought into irrigated agriculture as a result of the groundwater policy change. The main impact may have been the reduced costs and increased reliability of irrigation due to the electrification of pumps, especially for erstwhile diesel pump owners and water buyers. However, it is not possible to capture this impact through secondary block level analysis.

7.4 LIMITED SCOPE FOR EXPANDING THE IRRIGATED AREA, NET SOWN AREA AND CROPPING INTENSITY

The net sown area in West Bengal has been almost constant since the late 1990s. In a context of increased urbanization and pressure on farmland in some blocks, NSA is unlikely to increase even with improved access to irrigation. Similarly, cropping intensity in the state is already high, reaching almost 190% in 2017. Finally, the net irrigated area has also been more or less stagnant. The effect of the treatment on the irrigated areas tested is not significant (Table 19, column 2). These statistics indicate that easing access to and reducing costs of irrigation has not brought new areas under cultivation or irrigation, and has also not further intensified agricultural practices.

With an increased number of electric pumps added in the safe blocks, this also means that the area irrigated by each electric pump may have reduced. In the absence of information on the energy used for lifting water, we rely on the Minor Irrigation Census data from 2013 to 2014, which indicates that 82% of the deep tube wells (DTWs) are electrified. We use the area irrigated per DTW as a rough proxy for the area irrigated by an electric pump. As presented in Table 19 (column 3), the groundwater policy reform is negatively and significantly correlated with the area irrigated per DTW[12]. In safe groundwater blocks, it seems that farmers used their electric pumps less intensively, perhaps due to saturation of the number of electricity connections in some of these blocks. Again, this indicates that the main impact of policy change could be in terms of reduction in costs and improvement in the reliability of irrigation.

7.5 DWINDLING PROFITS AND EXTENSIVE MARGIN EFFECT

It is possible that the only impact of these policy reforms was in the form of a price effect, through a reduction in the costs of irrigation, especially for those who were previously dependent on diesel pumps or were water buyers. However, even this price effect may have been dampened due to two reasons.

First, the continuous increase in TOD tariffs (Table 18). To put this in perspective, let us assume that a 5 HP pump runs for 24 hours continuously. In 2017-2018, this would have cost the pump owner INR 310/day, whereas it would have cost INR 146/day in 2007-2008 when the tariff came into effect. Electricity tariffs have roughly doubled in the last 10 years, while paddy prices (in real terms) have remained more or less

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[12] This interpretation could be somewhat problematic, because DTW referred to in the Minor Irrigation Census often means government-owned DTW, and these have been in decline for several years now due to poor management.

the same over this 10-year period. At the same time, the costs of other inputs such as fertilizer, machines, seeds and fertilizers have also increased, further squeezing profit margins. Table 20 compares the costs of *boro* paddy cultivation by electric pump owners in 2004 and 2019, and this shows that profit margins have reduced significantly over the years. Annexure Table A7 provides an estimate of the cost of cultivation (CoC) of *boro* paddy as collected by *Bidhan Chandra Krishi Viswavidyalaya* (BCKV)—the nodal agency responsible for collecting CoC data for West Bengal on behalf of the Government of India.

Table 20. Cost of *boro* paddy cultivation for electric pump owners in 2004 and 2019.

Components of cost of cultivation	2004 (N=111)	2019 (N=11)	2019 (estimate from BCKV)
Fertilizer (INR/ha)	3,391	13,770	15,000
Labor (INR/ha)	7,938	44,851	45,000
Irrigation (INR/ha)	2,035	11,139	15,000
Others (INR/ha)	3,233	17,399	24,100
Total cost of cultivation (CoC) (INR/ha)	16,597	87,158	99,100
Productivity (t/ha)	5.9	6.4	6.3
Price of paddy (INR/t)	5,680	15,000	17,000
Gross revenue (INR/ha)	33,461	96,000	107,100
Net profit (INR/ha)	16,865	8,842	8,000
Net profit to total CoC ratio	1.02	0.10	0.08

Sources: Mukherji 2007a for cost estimates of 2004; Fieldwork and FGDs were conducted in 11 villages (one estimate/village) for 2019; Estimate from *Bidhan Chandra Krishi Viswavidyalaya* (BCKV) (also see Annexure, Table A7). BCKV estimate is for all farmers, while our primary estimate for 2004 and 2019 is only for farmers with electric pumps.

While it is possible, and highly probable, that the addition of approximately 216,000 electric pumps has reduced the costs of irrigation to some extent, several other factors have discouraged farmers from expanding their area under water-intensive *boro* paddy or to expand their cropped area, in general. These factors include the continuously rising electricity tariffs as well as costs of other components of production, and the relative stagnation of *boro* paddy prices. The lack of economic incentives for farmers explains the absence of an extensive margin effect of the groundwater policy reform.

7.6 FURTHER IMPACTS OF COVID-19 AND AMPHAN SUPER CYCLONE

Two new developments are likely to have severe impacts on agriculture in West Bengal. These are the Covid-19 pandemic and the super cyclone Amphan that struck southern West Bengal on May 20, 2020. The extended lockdown due to Covid-19 affected farmers quite badly, especially those growing vegetables in villages such as Silinda, as they were unable to take their crops to the market in a timely manner. Most of the villages we visited had reported migration of village youth to other states. Given Covid-19-related disruptions, many of these migrant youths have returned or will return to the villages in the near future. This will create a surplus labor pool in the villages, and wage rates are likely to be depressed in the near future. Cyclone Amphan destroyed all standing crops in South Bengal, and there are some isolated damages to crops in districts in North Bengal as well. Both these events are likely to threaten food production and food security in the near future. In this context, the intensive use of groundwater to ensure year-round irrigation can be one of the effective adaptation strategies.

8. POLICY IMPLICATIONS AND THE WAY FORWARD

Our quantitative analysis showed that the addition of over 200,000 electric pumps failed to have the kind of agricultural impacts that were initially expected when this policy reform was announced (Shah et al. 2012). While we have offered various possible explanations for this apparent puzzle (in section 7), the most likely explanation seems to be the high cost of cultivation *vis-à-vis* the market price at which farmers can sell their produce. This is particularly true for water-intensive crops such as *boro* paddy. This hypothesis, along with others, needs to be tested rigorously through a large representative survey of pump owners and water buyers in West Bengal. IWMI researchers have conducted such surveys in 2004, 2007, 2010 and 2013.

In the meantime, and in the context of a near certain agricultural downturn following Covid-19 and Cyclone Amphan, we suggest that the Government of West Bengal rethink its agricultural electricity tariff policy and provide relief to farmers, at least for 3 to 5 years. They may think either in terms of reducing TOD tariff rates or opt for a mixed tariff, which combines a part flat tariff set at relatively high level and a part metered tariff set at a nominal level (Sidhu et al. 2020). Such a tariff structure may encourage proactive water selling at a cheaper price and more intensive use of groundwater for irrigation. Our qualitative fieldwork also showed that farmers, especially in water-abundant villages, view *boro* paddy as a critical crop that enhances their income as well as food security. It is also a relatively more labor-intensive crop compared to other crops such as potato, maize or oilseeds. Given the immediate need for food security, and absorbing surplus labor in agriculture, the government may also want to encourage *boro* paddy cultivation. At the same time, reforming a paddy procurement system to enable small and marginal farmers to pool their produce together and sell to the government procurement camps will ensure they get a fair price for their produce. Overall, a twin focus on encouraging and improving the profitability of *boro* paddy, coupled with the lowering of electricity tariffs for irrigation will help as farmers struggle to overcome the unprecedented challenges they currently face.

Finally, we propose another study based on primary farmer-level data, where we will build on several years of panel data that already exists at IWMI, and in the process, understand agrarian change in West Bengal as a result of climate shocks such as Cyclone Amphan and unanticipated shocks such as Covid-19.

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10. REFERENCES

Badiani, R.; Jessoe, K.K.; Plant, S. 2012. Development and the environment: The implications of agricultural electricity subsidies in India. *Journal of Environment and Development* 21(2): 244–262. https://doi.org/10.1177/1070496512442507

Badiani-Magnusson, R.; Jessoe, K. 2019. Electricity prices, groundwater, and agriculture: The environmental and agricultural impacts of electricity subsidies in India. In: Schlenker, W. (ed.) *Agricultural productivity and producer behavior*. Chicago, Illinois, USA: University of Chicago Press. pp. 157–183.

Bandyopadhyaya, N. 1981. 'Operation Barga' and land reforms perspective in West Bengal: A discursive review. *Economic and Political Weekly* 16(25–26): A38–A42. https://www.jstor.org/stable/4369965

Banerjee, A.V.; Gertler, P.J.; Ghatak, M. 2002. Empowerment and efficiency: Tenancy reform in West Bengal. *Journal of Political Economy* 110(2): 239–280. https://doi.org/10.1086/338744

Bardhan, P.; Mookherjee, D. 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. https://doi.org/10.1016/j.jdeveco.2012.06.003

Bhaduri, A. 1973. A study in agricultural backwardness under semi-feudalism. *Economic Journal* 83(329): 120–137. https://www.jstor.org/stable/2231104

Bhaduri, A. 1986. Forced commerce and agrarian growth. *World Development* 14(2): 267–272. https://doi.org/10.1016/0305-750X(86)90058-6

Bhanja, S.N.; Mukherjee, A.; Ramaswamy, R.; Scanlon, B.R.; Malakar, P.; Verma, S. 2018. Long-term groundwater recharge rates across India by in situ measurements. *Hydrology and Earth System Sciences Discussions* 1–19. https://doi.org/10.5194/hess-2018-313

Bhowmick, P.K. 2001. *Land reforms and rural development in the state of West Bengal*. Kolkata, India: R. N. Bhattacharya Publishers.

Bose, S. 1993. *Peasant labour and colonial capital: Rural Bengal since 1770*. Cambridge, UK: Cambridge University Press.

Boyce, J. 1987. *Agrarian impasse in Bengal: Agricultural growth in Bangladesh and West Bengal, 1949-1980*. Oxford, UK: Oxford University Press.

Buisson, M.C.; Balasubramanya, S.; Stifel, D. Under Review. Effects of electric pumps on farm-level agricultural production and groundwater use in West Bengal. *Ecological Economics.* Submitted.

Calonico, S.; Cattaneo, M.D.; Farrell, M.H.; Titiunik, R. 2017. Rdrobust: Software for regression-discontinuity designs. *Stata Journal* 17(2): 372–404. https://doi.org/10.1177/1536867x1701700208

Calonico, S.; Cattaneo, M.D.; Titiunik, R. 2014. Robust nonparametric confidence intervals for regression-discontinuity designs. *Econometrica* 82(6): 2295–2326. https://doi.org/10.3982/ecta11757

CGWB (Central Ground Water Board). 1998. *Detailed guidelines for implementing groundwater estimation methdology - 1997*. New Delhi, India: Central Ground Water Board.

Chatterjee, E. 2018. The politics of electricity reform: Evidence from West Bengal, India. *World Development* 104: 128–139. https://doi.org/10.1016/j.worlddev.2017.11.003

Chattopadhyay, M.; Rudra, A. 1976. Size-productivity revisited. *Economic and Political Weekly* 11(39): A104–A116. https://www.jstor.org/stable/4364959

Chattopadhyay, M.; Sengupta, A. 1999. Farm size and productivity. *Economic & Political Weekly*, *33*, 1147–1148. Vol. 32, No. 52 (Dec. 27, 1997 - Jan. 2, 1998), pp. A172-A175 https://www.jstor.org/stable/4406232

Gazdar, H.; Sengupta, S. 1999. Agricultural growth and recent trends in well-being in rural West Bengal. In: Rogaly, B.; Harriss-White, B.; Bose, S. (eds.) *Sonar Bangla? Agricultural growth and agrarian change in West Bengal and Bangladesh*. New Delhi, India: Sage Publishers. pp. 60–91.

GoWB (Government of West Bengal). 1996. *Economic reform, 1995-96*. Kolkata, West Bengal: Government of West Bengal.

GoWB. 2004. *West Bengal human development report*. West Bengal, India: Development and Planning Department, Government of West Bengal.

Harriss, J. 1992. Does the ‘depressor’ still work? Agrarian structure and development in India: A review of evidence and argument. *The Journal of Peasant Studies* 19(2): 189–227. https://doi.org/10.1080/03066159208438478

Harriss, J. 1993. What is happening in rural West Bengal: Agrarian reforms, growth and distribution. *Economic and Political Weekly* 28(24): 1237–1247.

Imai, K.; In Song Kim. 2019a. On the use of two-way fixed effects regression models for causal inference with panel data. Cambridge. http://web.mit.edu/insong/www/pdf/FEmatch-twoway.pdf

Imai, K.; In Song Kim. 2019b. When should we use unit fixed effects regression models for causal inference with longitudinal data?' *American Journal of Political Science* 63(2): 467–490. https://doi.org/https://doi.org/10.1111/ajps.12417.

Lieten, G.K. 1996. Land reforms at centre stage: The evidence on West Bengal. *Development and Change* 27(1): 111–130. https://doi.org/10.1111/j.1467-7660.1996.tb00580.x

Majumdar, K.; Basu, P. 2005. Growth decomposition of foodgrains output in West Bengal: A district level study. *Indian Journal of Agricultural Economics* 60(2): 220–234. https://doi.org/10.22004/ag.econ.204397

Meenakshi, J.V.; Banerji, A.; Mukherji, A.; Gupta, A. 2013. *Does marginal cost pricing of electricity affect groundwater pumping behaviour of farmers? Evidence from India*. 3ie Impact Evaluation Report 4. New Delhi, India: International Initiative for Impact Evaluation (3ie). Available at https://www.3ieimpact.org/evidence-hub/publications/impact-evaluations/does-marginal-cost-pricing-electricity-affect (accessed on June 17, 2020).

Mukherji, A. 2007a. 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. https://doi.org/10.1016/j.enpol.2007.08.019

Mukherji, A. 2007b. Implications of alternative institutional arrangements in groundwater sharing: Evidence from West Bengal. *Economic and Political Weekly* 42(6): 2543–2551.

Mukherji, A.; Das, B.; Majumdar, N.; Nayak, N.C.; Sethi, R.R.; Sharma, B.R. 2009. Metering of agricultural power supply in West Bengal, India: Who gains and who loses? *Energy Policy* 37(12): 5530–5539. https://doi.org/10.1016/j.enpol.2009.08.051

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

Mukherji, A.; Das, A. 2014. The political economy of metering agricultural tube wells in West Bengal, India. *Water International* 39(5): 671–685. https://doi.org/10.1080/02508060.2014.955408

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. https://www.jstor.org/stable/4398942

Palmer-Jones, R.W. 1999. Slowdown in agricultural growth in Bangladesh: Neither a good description nor a good to give. In: Rogaly, B.; Harriss-White, B.; Bose, S. (eds.) *Sonar Bangla? Agricultural growth and agrarian change in West Bengal and Bangladesh*. New Delhi, India: Sage Publishers. pp.92–136.

Rogaly, B.; Harriss-White, B.; Bose, S. 1999. Introduction: Agricultural growth and agrarian change in West Bengal and Bangladesh. In: Rogaly, B.; Harriss-White, B.; Bose, S. (eds.) *Sonar Bangla? Agricultural growth and agrarian change in West Bengal and Bangladesh*. New Delhi, India: Sage Publishers. pp.1–18.

Rudra, A. 1968. More on returns to scale in Indian agriculture. *Economic and Political Weekly* 3(43): A33–

A38. https://www.jstor.org/stable/4359235

Saha, A.; Swaminathan, M. 1994. Agricultiral growth in West Bengal in the 1980s: A disaggregation by districts and crops. *Economic and Political Weekly* 29(13): A2–A11. https://www.jstor.org/stable/4400994

Sarkar, A. 2006. Political economy of West Bengal: A puzzle and a hypothesis. *Economic and Political Weekly* 41(4): 341–348. https://www.jstor.org/stable/4417736

Sen, A. 1962. An aspect of Indian agriculture. *The Economic Weekly* 14(4–6): 243–246.

Shah, T.; Ul Hassan, M.; Khattak, M.Z.; Banerjee, P.S.; Singh, O.P.; Rehman, S.U. 2009. Is irrigation water free? A reality check in the Indo-Gangetic Basin. *World Development* 37(2): 422–434. https://doi.org/10.1016/j.worlddev.2008.05.008

Shah, T.; Giordano, M.; Mukherji, A. 2012. Political economy of the energy-groundwater nexus in India: Exploring issues and assessing policy options. *Hydrogeology Journal* 20(5): 995–1006. https://doi.org/10.1007/s10040-011-0816-0

Shah, M.; Daschowdhury, S.; Shah, T. 2019. *Pro-poor agricultural power policy for West Bengal*. In: Paper presented at the 3rd World Irrigation Forum (WIF3), September 1–7, 2019, Bali, Indonesia.

Sidhu, B.S.; Kandlikar, M.; Ramankutty, N. 2020. Power tariffs for groundwater irrigation in India: A comparative analysis of the environmental, equity, and economic tradeoffs. *World Development* 128: 104836. https://doi.org/10.1016/j.worlddev.2019.104836

Thorner, D. 1956. *The agrarian prospect in India*. New Delhi, India: Allied Publishers.

11. ANNEXURES

Table A1. List of administrative blocks which were combined to match with WESEDCL's Customer Care Centers (CCCs)

District	Blocks to be merged	CCC
Burdwan (335)	Ausgram-II (02276) and Ausgram-I (02277)	GUSKARA CCC
Burdwan (335)	Ketugram-II (02280) and Ketugram-I (02279)	KETUGRAM CCC
Murshidabad (333)	Bhagawangola-II (02232) and Bhagawangola-I (02231)	BHAGABANGOLA CCC
Murshidabad (333)	Suti-I (02225) and Suti-II (02226)	AHIRAN CCC, AURANGABAD CCC
Murshidabad (333)	Raninagar-I (02236) & Raninagar-II (02233)	CHAKISLAMPUR CCC, RANINAGAR CCC
North 24 Parganas (337)	Sandeshkhali-II (02335) and Sandeshkhali-I (02334)	SANDESHKHALI CCC, SARBERIA CCC
Paschim Medinipur (344)	Garhbeta-III (02445) and Garhbeta-II (02443)	CHANDRAKONA ROAD CCC
Paschim Medinipur (344)	Gopiballavpur-II (02456) with Gopiballavpur-I (02457)	Gopiballavpur CCC
Purba Medinipur (345)	Kerjuri-I (02486) and Khejuri-II (02487) blocks	KHEJURI CCC
Purba Medinipur (345)	Nandigram-II (02485) and Nandigram-I (02484)	NANDIGRAM CCC
Purba Medinipur (345)	Patashpur-II (02478) and Patashpur-I (02477)	PATASHPUR CCC, AMARSHI CCC
South 24 Parganas (343)	Bhangore-I (02418) and Bhangore-II (02419)	KOLKATA LEATHER COMPLEX CCC, BHANGAR CCC
South 24 Parganas (343)	Bishnupur-I (02415) and Bishnupur-II (02416)	BISHNUPUR CCC, RADHANAGAR CCC, AMTALA CCC
South 24 Parganas (343)	Budge-Budge-II (02414) and Budge-Budge-I (02413)	BUDGE BUDGE CCC
South 24 Parganas (343)	Joynagar-II (02432) and Joynagar-I (02431)	JOYNAGAR CCC, DAKSHIN BARASAT CCC
South 24 Parganas (343)	Mathurapur-II (02436) and Mathurapur-I (02430)	MATHURAPUR CCC

Table A2. Coefficient estimates of interrupted time series analysis at the state level including 2017

	Pre-monsoon groundwater level		Post-monsoon groundwater level	
Pre-intervention trend	-0.0604**	-0.0670**	-0.0392***	-0.0492**
	(0.024)	(0.027)	(0.013)	(0.019)
Level change after 2011	-0.957**	-1.068**	-0.737**	-0.799**
	(0.413)	(0.489)	(0.338)	(0.327)
Trend change after 2011	0.320*	0.347*	0.246*	0.276*
	(0.171)	(0.186)	(0.134)	(0.139)
Rainfall		-0.0004		-0.0004
		(0. 0005)		(0.0005)
Constant	-5.892***	-5.131***	-4.747***	-3.926***
	(0.165)	(0.989)	(0.115)	(1.007)
N	21	21	21	21
Adjusted R^2	0.719	0.717	0.411	0.383

Notes: Robust standard errors in parentheses. *** significant at the 1% level, ** significant at the 5% level, * significant at the 10% level.

Table A3. Regression discontinuity (RD) estimates, area, production and yield of major crops.

	(1) Area *boro*	(2) Area *Aman*	(3) Area pulses	(4) Area oilseeds
RD estimate	6,059**	2,314	1,035	-50.04
	(2,454)	(5,888)	(927.7)	(2,153)
	Production *boro*	Production *aman*	Production pulses	Production oilseeds
RD estimate	22.28***	-2.863	0.796	27.63
	(8.615)	(21.45)	(0.729)	(31.71)
	Yield *boro*	Yield *aman*	Yield pulses	Yield oilseeds
RD estimate	364.5*	-880.5**	1,845	32,306
	(217.9)	(434.4)	(2,420)	(33,525)
Effective observations	430	430	430	430
Observations	2,370	2,370	2,370	2,370

Notes: The assignment variable is the decline in groundwater level in the post-monsoon period, and the sharp cut-off is fixed at 20 cm. The bandwidth selection procedure is based on minimal mean squared errors and two different bandwidth selectors below and above the cut-off. Clustering at block level and year dummy variables are included as covariates. Robust standard errors in parentheses. *** significant at the 1% level, ** significant at the 5% level, * significant at the 10% level.

Table A4. Regression discontinuity estimates of groundwater depth.

	(1) Groundwater depth Pre-monsoon	(2) Groundwater depth Post-monsoon
Treated	3.382	1.077
	(4.114)	(2.871)
Effective observations	640	640

Notes: The assignment variable is the decline in groundwater level in the post-monsoon period, and the sharp cut-off is fixed at 20 cm. The bandwidth selection procedure is based on minimal mean squared errors and two different bandwidth selectors below and above the cut-off. Clustering at block level and year dummy variables are included as covariates. Robust standard errors in parentheses. *** significant at the 1% level, ** significant at the 5% level, * significant at the 10% level.

Table A5. Two-way fixed effects of average treatment effect (ATE) on area, production and yields of major crops.

Variables	(1) Area *boro*	(2) Area *boro*	(3) Area *aman*	(4) Area *aman*	(5) Area pulses	(6) Area pulses	(7) Area oilseeds	(8) Area oilseeds
Number of permanent electric pumps added	1.288*	-2.717	0.223	2.749	-0.0329	-0.144	0.417	0.105
	(0.689)	(5.097)	(1.188)	(3.840)	(0.113)	(0.253)	(0.661)	(1.002)
Observations	1,956	839	1,956	839	1,956	839	1,956	839
Number of blocks	326	288	326	288	326	288	326	288
Years	2011-2018	2011-2018	2011-2018	2011-2018	2011-2018	2011-2018	2011-2018	2011-2018
Covariates	No	Yes	No	Yes	No	Yes	No	Yes
R-squared	0.011	0.043	0.023	0.169	0.185	0.053	0.071	0.046

Variables	(1) Production *boro*	(2) Production *boro*	(3) Production *aman*	(4) Production *aman*	(5) Production pulses	(6) Production pulses	(7) Production oilseeds	(8) Production oilseeds
Number of permanent electric pumps added	0.00434*	-0.0186	0.00428	0.00575	2.18e-05	-0.000263	0.000746	0.00188
	(0.00259)	(0.0205)	(0.00342)	(0.0128)	(8.33e-05)	(0.000347)	(0.000682)	(0.00160)
Observations	1,956	839	1,956	839	1,956	839	1,956	839
Number of blocks	326	288	326	288	326	288	326	288
Years	2011-2018	2011-2018	2011-2018	2011-2018	2011-2018	2011-2018	2011-2018	2011-2018
Covariates	No	Yes	No	Yes	No	Yes	No	Yes
R-squared	0.019	0.062	0.031	0.163	0.169	0.079	0.084	0.089

Variables	(1) Yield *boro*	(2) Yield *boro*	(3) Yield *aman*	(4) Yield *aman*	(7) Yield pulses	(8) Yield pulses	(9) Yield oilseeds	(10) Yield oilseeds
Number of permanent electric pumps added	-0.0529	-0.424	0.110	-0.195	0.0608*	-0.442	0.103*	0.463
	(0.0723)	(0.684)	(0.0785)	(0.374)	(0.0357)	(0.507)	(0.0616)	(0.342)
Observations	1,721	748	1,937	833	1,524	535	1,761	733
Number of blocks	324	276	325	287	325	217	322	267
Years	2011-2018	2011-2018	2011-2018	2011-2018	2011-2018	2011-2018	2011-2018	2011-2018
Covariates	No	Yes	No	Yes	No	Yes	No	Yes
R-squared	0.097	0.045	0.113	0.064	0.167	0.202	0.161	0.074

Notes: Robust standard errors in parentheses. *** significant at the 1% level, ** significant at the 5% level, * significant at the 10% level.

Table A6. Two-way fixed effects of average treatment effect (ATE) for area and groundwater depth.

Variables	(1) Groundwater depth Pre-monsoon	(2) Groundwater depth Pre-monsoon	(3) Groundwater depth Post-monsoon	(4) Groundwater depth Post-monsoon
Number of permanent electric pumps added	0.000203	0.00598**	-5.01e-05	0.000862
	(0.000291)	(0.00245)	(0.000200)	(0.00192)
Observations	2,546	837	2,547	845
Number of blocks	309	287	308	287
Years	2011-2018	2011-2018	2011-2018	2011-2018
Covariates	No	Yes	No	Yes
R-squared	0.043	0.121	0.123	0.232

Notes: Robust standard errors in parentheses. *** significant at the 1% level, ** significant at the 5% level, * significant at the 10% level.

Table A7. Cost of cultivation of winter rice (per hectare) in West Bengal (2019).

	Nature of cost	Unit requirement/ha	Price/value	Total cost (INR)
1	Fixed and variable cost			
2	Seed	60 kg/ha	INR 30/kg	1,800.00
3	Deed treatment/labor/land preparation/seed bed preparation			2,250.00
4	Rotary planter	7 hours	INR 800/hour	5,600.00
5	Total labor requirement (transplanting to harvesting)	225 hours	INR 200/person	45,000.00
6	Fertilizer - farmyard manure, and nitrogen (N), phosphorous (P) and potassium (K)		INR 2,000/***bigha***	15,000.00
7	Chemicals (herbicides, insecticides, pesticides)		INR 1,660/***bigha***	14,450.00
8	Water for irrigation		INR 2,000/***bigha***	15,000.00
9	Total production costs	Rs/ha		99,100.00
10	Production	6.30 t/ha	Sale price @INR 17,000/t	107,100.00

This is the current cost of cultivation for farmers who own land.
Source: Personal communication with a professor at *Bidhan Chandra Krishi Viswavidyalaya* (BCKV).

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