Private investment in groundwater irrigation: Do the public institutions matter?[$*]

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ABSTRACT

The paper aims at explaining the factors that determine private investment in groundwater irrigation in West Bengal. It also addresses the issues pertaining to institutional arrangements, particularly provision of facilities by the government. The study is based on data collected from surveys conducted in the major agro-climatic zones in West Bengal. It relates the variations in the spread of HYV paddy cultivation in the monsoon season and the spread of summer paddy cultivation across West Bengal in terms of variations in irrigation facilities. In the process the role of public institutions are explained. It has been shown that emergence of private investment in groundwater irrigations is largely governed by geo-physical conditions, such as the presence of hard rock close to the surface and other factors such as the presence or absence of reliable public provision for irrigation. It is also shown that mere providing public infrastructure, such as electrification of agricultural fields, does not ensure the emergence of private investment in groundwater. It fosters private investment in groundwater irrigation *provided* that other conditions are satisfied.

Over the last thirty odd years the agricultural sector of West Bengal, a state located in the eastern part of India, has witnessed remarkable changes. West Bengal is primarily a paddy producing state, though traditionally other crops like jute, potato, oilseeds and pulses are also grown. What was essentially a mono-cropped, rain-fed, traditional seed variety paddy based production system has been transformed into a production system using High Yielding Variety (HYV) paddy seeds and complementary inputs, and paddy cultivation now occurs both during the rainy (monsoon) season as well as in the summer (*boro*) paddy. Time series data published by the Government of West Bengal reveals that in terms of area under cultivation, the acreage under boro paddy is second only to the area under monsoon paddy in the state. In many areas of the state, boro paddy cultivation has replaced the cultivation of oilseeds and pulses, two major post-monsoon crops in yesteryears. However, this transformation has not been uniform and regional disparities across agro-climatic zones have emerged or widened in the wake of the green revolution in the state.

The most widely publicized explanation of growth had been the land reforms in the form of limited land redistribution and the establishment and enforcement of tenancy rights that took place over the same period. However, this may have had little direct impact on growth, largely because the quantum of land involved is a small fraction of the total agricultural area of the state[1]. An alternative, though largely underemphasized, and sometimes disparagingly rejected, explanation is the positive role of the state machinery, both government line departments and decentralized local self government agencies (*Panchayats*), in providing irrigation, electricity and agricultural extension services to foster the adoption of the new agricultural (HYV) technology and the spread of cultivation both in the *Rabi* season as well as in the spread of

[1] See Banerjee, Gertler and Ghatak (2002) for a very compelling incentive based argument that the establishment of tenancy rights may have had a significant impact on agricultural growth in West Bengal; and Bardhan and Mukherjee (2004) for estimates of the area covered by the land reforms programmes.

summer paddy cultivation. While the quality of service provided by the state owned facilities have been erratic and often unreliable in places, their large direct role, at least in the early years of the transformation, is perhaps undeniable. However, from the early 1980s, real public investment in agricultural infrastructure has followed a declining trend across India[2] and, except perhaps for brief periods, the pattern is similar in West Bengal.

Paddy is a very water intensive crop and while the traditional varieties are as a general rule relatively resilient to fluctuations in water availability, HYV paddy requires adequate and controlled irrigation. Thus, the spread of adoption of new HYV technology was constrained by the availability of adequate and controlled irrigation facilities. In the first phase of the spread of the HYV technology, this was provided by state owned canal systems, river lift irrigation systems, deep tube wells, and by privately owned shallow tube wells usually purchased at subsidized prices. From the early 1980s, real public investment in irrigation facilities began to decline. This triggered off the phase of rapid expansion of private investment in groundwater irrigation and a concomitant emergence and spread of markets for privately supplied groundwater irrigation. This paper aims at an identification and analysis of the factors that determine the emergence and extent of private investment in groundwater extraction mechanism that has driven the process of adoption of new agricultural technology in the state.

Some work has been done on the role of private investment in groundwater extraction mechanism. For example, Shah (1991), (1994), Shah and Raju (1988) addressed the role of groundwater irrigation in agricultural development in India. Dubash (1998), Webster (1999) highlight the role of institutions, both public and private. Wood (1999) shows how neglect of public provisioning in groundwater irrigation technology has led to private provisioning in North

[2] Report of the Committee on Capital Formation in Agriculture, Ministry of Agriculture, Government of India (2003).

Bihar, another state of India. Fujita and Hossain (1995) discusses the role of private investment in groundwater irrigation and the associated market for Bangladesh which is situated in the similar agro-climatic zone as West Bengal to a large extent. Menizen-Dick (1996) has addressed similar issues for Pakistan. Deb Roy and Shah (2002), Janakrajan (1994), Mohanty and Gupta (2002) are some other important studies in this area. But focus of most of these studies is confined to some particular area or zone and, hence, arriving at general conclusions on the basis of these studies is difficult. Deb Roy and Shah (2002) suffers from a different type of problem. While the geographical spread of their study is immense, the sample is too thin and inferences are also further tarnished by the absence of careful econometric scrutiny. Our study is aimed at filling the lacunae in this respect. It is our view that this ubiquitous phenomenon has been almost completely neglected both at the official and at the academic levels in the state [3].

The present study, largely empirical in nature, is based on a large scale survey in close to one thousand *moujas*[4] spread across different agro-climatic zones in the state. We consider how cropping patterns and irrigation facilities emerged at the ground level in different agro-climatic zones under different patterns of public investment in irrigation. We also consider the role of rural electrification for the emergence of private investment in groundwater extraction mechanism. An important result of our study impinges on the fact that private groundwater extracting devices coexist with government irrigation facilities in many *moujas*.

The rest of the paper is organized as follows. In Section 2 we present a more detailed background of the study. It begins with a descriptive account of the changes in the agricultural

[3] The Bureau of Applied Economics and Statistics, Government of West Bengal, Statistical Abstract 2001-2002 asserts that in "West Bengal irrigation is done mainly through Government Canals". Mukherjee (2004) is a good survey of the literature on the subject. A striking feature of the survey is that it reveals how little careful work has been done in this area in West Bengal.

[4] A *mouja* is a land revenue unit used by the Census of India. In rural areas, a *mouja* may contain one or more villages. However, some large villages lie in more than one *mouja*. While residents of a *mouja* may own land outside the *mouja*, and non-residents may own land within it, it is reasonable to assume that for the most part residents of the *mouja* have most of their land within their home *mouja*.

scenario in West Bengal over the last thirty years. We then present the research question and discuss the econometric methodology. Section 3 contains the empirical results and Section 4 is devoted to conclusions.

2. Agrarian Change, Research Question and Methodology

The first part of this section describes the evolution of the agricultural production in West Bengal over the last thirty years. This helps us to tentatively identify the causal connections between the pattern of spread of private groundwater investment, and public investment in irrigation and agro-climatic conditions. Finally, it discusses the survey and econometric methodology.

An analysis of the area of cultivation for some major crops in West Bengal[5] from 1970-71 to 2000-01 reveals a clear pattern. During this period the area under *khariff aman* paddy far exceeded the cultivation under any other crop. The area under *aus*[6] paddy increased up to the late 1970s, fluctuated in the next decade and then fell sharply in the nineteen nineties. The area under wheat and *boro* (summer) paddy expanded in the 1960s but the rate of growth was much larger in the former than in the latter. These trends appear to have continued throughout the next decade. In the next two decades, the area under *boro* cultivation increased sharply while that under wheat fell and then remained more or less stationary at a low level. The area under *boro* paddy rose from 3.91% of the total area under *aus* and *aman* paddy in 1970-71 to 35% in 2000-01 in spite of a crop loss due to a major flood in October in 2000. It is interesting to note that in 2000-01 the area under wheat was around 10.56 percent of the area under monsoon paddy and the area under jute, which had the third largest coverage after monsoon paddy and *boro* paddy,

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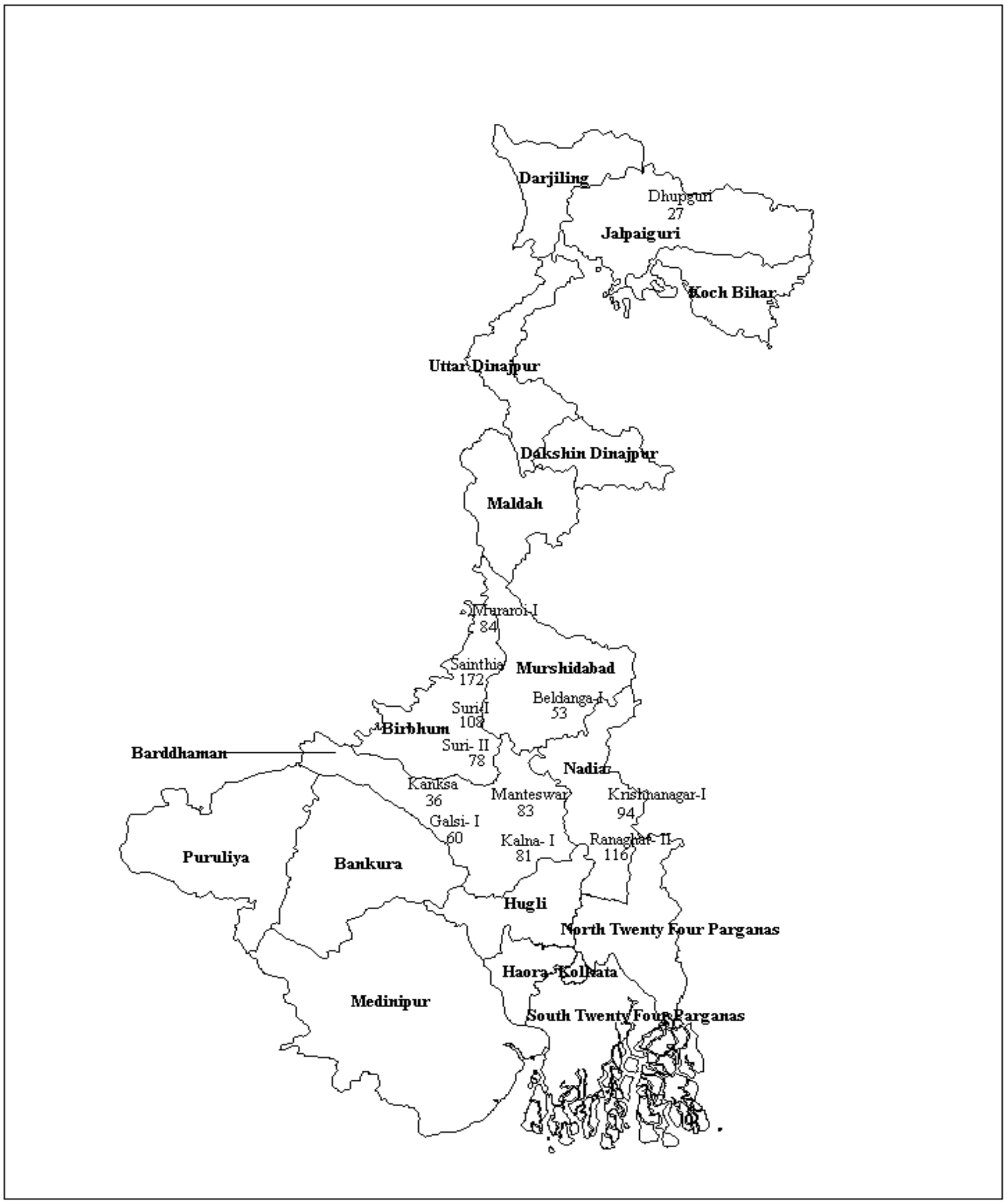
[5] These findings are based on data published by Statistical Abstract, Bureau of Applied Economics and Statistics, Government of West Bengal for various years. The details can also be found in Moitra and Das (2004).

[6] For official purposes Aus paddy is defined as monsoon paddy that is harvested on or before 31 October.

was 15.2 percent of the area under monsoon paddy. Another significant development is that over this period there has been an almost complete shift from traditional seed varieties to HYV seeds.

It is worth noting that the pattern discussed above is not uniform throughout the state, there are wide variations in the growth patterns across agro-climatic zones. Unfortunately, disaggregated official data provided by the state government is available for administrative districts and not for agro-climatic zones and so one has to superimpose an agro-climatic map of the state on the district level maps. This yields a rather vexing problem as a particular administrative district may contain several broad agro-climatic zones.

Goswami (1995) groups the entire area of the state into five broad physiographic zones. The North Bengal Hill Zone consisting of some parts of Darjeeling District. The North Bengal Alluvial Plain and Fan Zone consisting of the Districts of Jalpaiguri, Cooch Behar, North Dinajpur, South Dinajpur, Malda and parts of Darjeeling District. This zone begins at the base of the Himalayan range where the soil is rocky and porous and the annual rainfall, concentrated over five months is among the highest in the state. The soil conditions improve as one moves southwards into the South Bengal Alluvial Plain. The eastern parts of Birbhum, Bankura, Midnapore, Burdwan districts and the districts of Howrah, Hugli, Nadia nad Murshidabad lie in this zone. Except for their coastal regions, the Districts of South and North 24 Parganas are also within this zone. The Coastal Plain, contains the coastal areas of Midnapore, South 24 Parganas and North 24 Parganas Districts. In this zone the soil is relatively poor and often has serious salinity problems. Finally, The Western Bengal Undulating Upland. This zone contains the western parts of Birbhum, Bankura, Midnapore Districts and all of Purulia District. The top soil in this zone is poor, rocky and laeteritic. There is hard rock close to the surface and soil erosion is a major problem. The western part of Burdwan has similar soil characteristics.



Map showing Block-wise distribution of sample *moujas* across the State of West Bengal

Expansion of cropping in the post monsoon season has been fairly rapid is many districts and practically stationary in others. Further, the timing of the "take-off" varies across districts. Cropping intensities have risen in all the districts other than Purulia. Till the late nineteen sixties, the cropping intensities in Nadia and Murshidabad districts were significantly higher than in other districts and the cropping intensities in Burdwan, Birbhum, Bankura, and Midnapore districts were similar to that in Purulia. While the terrain in the western parts of Burdwan, Birbhum, Bankura and Midnapore is similar to that in Purulia, the eastern parts of these districts lie in the South Bengal Alluvial Plain. In the 1960s these areas were largely monocropped. Cropping intensities started rising in the 1970s in these districts but the sharp jump occurred in some districts in the early 1980s and in most districts in the late 1980s and early 1990s.

Starting from a very low coverage prior to 1970-71, net cultivated area under summer paddy started rising thereafter but area expansion was confined largely to a few districts – Burdwan, Midnapore[7], Hooghly and to a somewhat lesser extent in Howrah, Nadia and Malda – in the decade of the eighties. This general pattern changed somewhat in the next decade as cultivation expanded rapidly in Howrah, Nadia and North 24 Parganas (from 13.55%, 1.38% and 3.27% in 1970-71 to 55.6%, 49.5% and 41.98% in 2000-01 respectively), and especially so after the middle of the decade. In the decade of the 1990s, large scale *boro* cultivation was taking place in Burdwan, Midnapore, Hooghly, Howrah, 24 Parganas (North), Nadia and Uttar Dinajpur. The point is that except for Purulia, Jalpaiguri and the plains areas of Darjeeling districts *boro* cultivation became a major feature of agricultural activity in the 1980s and particularly so in the decade thereafter.

Overall, it appears from the state level as well as district level data that at least from the mid nineteen eighties, cultivation of *boro* paddy has emerged as the most important agricultural activity after cultivation of rain-fed paddy in most districts. Clearly, this change has been driven

[7] In Burdwan and Midnapore districts, the spread of summer paddy cultivation occurs mainly in the eastern parts of the districts. Depending on local micro level agro-climatic conditions, some localized cultivation of summer paddy does occur in the other parts of the districts as well. Recently, Midnapore district has been split into two administrative districts, East Midnapore and West Midnapore, virtually along agro-climatic boundaries.

by the relatively higher profitability from cultivation of summer paddy. But there is wide variation across districts. The question then is: what explains the differences in percentage of net cultivated area under *boro* paddy across districts?

The previous discussion reveals that the increase in the agricultural growth rate in West Bengal has occurred because of the spread of HYV paddy cultivation[8] during the monsoon season and the expansion of *boro* cultivation. These in turn hinge on the adequate and controlled availability of water at the appropriate time as HYV paddy is extremely moisture sensitive as well as water intensive.[9] Thus the success of increased agricultural activities has to be traced back to the availability of irrigation facility in the state.

In the early part of the transition to *boro* cultivation, state owned canals; deep tube-wells, river lift irrigation schemes etc. were the main sources of irrigation for cultivation of *boro* paddy. Canals are the main source of public irrigation in the state. Data published by the state government[10] indicates that the size of the area that receives canal irrigation increased marginally in the 1980s and has remained virtually stationary thereafter. It is unclear whether these figures are for supplementary irrigation during the monsoon or for irrigation during the *boro* paddy cultivation season when irrigation water requirements are far greater. No area data is provided for the command areas of the public sector minor irrigation schemes, but the number of deep tube wells, river-lift irrigation schemes, etc. has remained virtually unchanged over twenty years. The irrigation capacity of a large proportion of these machines have deteriorated over the years primarily because of poor maintenance and it is not unusual to see privately owned shallow tube-wells operating in within the official command areas of these machines. Over time, as HYV

[8] In much of the virtually mono-cropped western part of the Western Bengal Undulating Upland, cultivation of rainfed local paddy varieties was the norm even in the late nineteen-nineties.
[9] Cultivation of *boro* requires four times water than for wheat.
[10] Statistical Abstracts (2001-02).

paddy cultivation during the monsoon expanded and particularly so because of the rising interest in *boro* paddy cultivation, farmers installed shallow tube wells (STWs) and later on submersible pump tube wells (SMTWs) to draw groundwater. This investment took place mainly in areas where irrigation from government sources was either unavailable or erratic. In many areas, including those near the tail ends of canals where irrigation water is completely unavailable in the summer, private groundwater extraction is the sole dependable means of irrigation for *boro* paddy. A similar problem exists in many areas for river lift irrigation systems or deep tube-wells.

An explanation for the inter-regional variation in the extent of *boro* cultivation emerges from this. Given paddy prices, *boro* cultivation is most profitable in areas where water is cheap. Thus, in the command areas of reliable government funded irrigation schemes like canals, deep tube-wells etc., where the price that people pay for water is low, *boro* cultivation is widespread. Outside such areas, the cost of water is typically significantly higher and varies with the nature of the soil, the state of the aquifer, the gradient of the land, energy prices (both diesel and electricity) and the availability of electricity for running the pump sets. Thus, the link between agro-climatic conditions and expansion of both HYV paddy cultivation and summer paddy cultivation based on irrigation by privately owned groundwater extraction devices become apparent.

The degree of porosity of the soil determines the number of times water has to be supplied to a plot over the cropping season. In areas where the soil has high clay content, the total amount of water required is lower than in areas where the soil is lighter. In areas where the water table is low, or falls sharply over the summer months, the cost of boring and pipes can be quite high. In areas where one has to bore through hard rock to reach the water table, the cost of boring is prohibitive given current technology.[11]

In the first phase of expansion of private groundwater extraction, machines were typically run using diesel as fuel. With the electrification of agricultural fields owners of groundwater extraction devices switched to electricity operated machines as the cost of electricity operated equipment was significantly lower than the cost of diesel operated machines and also because operating costs were much lower. In West Bengal, the fixed fee charges for electricity for irrigation have been low for a long time. Over the last few years, these have been raised but default is still quite widespread.[12]

With this in mind, one can provide tentative explanations for the variation in the extent of *boro* cultivation across districts. To address our research question the first step is to identify the areas where private investment in groundwater extraction mechanism has taken place to a significant extent.

We have chosen our sample *moujas* in such a way that all there agro-climatic zones are included in our sample. However, even within a broad group there are variations and different broad groups co-exist within a particular district. For example, some of the blocks in Kalna Sub-Division of Burdwan district which belong to Gangetic alluvial zone have sandy loam land while in some other blocks the land has high clay content. These two types of land have different water retention capacity. On the other hand Western part of Burdwan, Bankura and Birbhum exhibit the geo-physical characteristics of Purulia.

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[11] This problem exists in Purulia district and in the western parts of Bankura, Birbhum, Burdwan and Midnapore districts as well.

[12] Electricity operated pump sets are cheaper than the diesel run sets. However, recently, connection charges have risen sharply as farmers have to pay for the cost of the additional electrical poles and wires required to connect their machines to closest point from which electricity supply is available. This acts as a deterrent to switchovers in many cases.

We talked to officers of Agriculture Department at various levels to understand the characteristic of the different regions of a district. Based on the information that we gathered we chose our sample *moujas*. In the process we had to depend more on judgement than strict statistical method.[13] However, we were careful that different agro-climatic regions are represented with adequate weightage. We also got the services of the *Krishi Prajukti Sahayak* (Agricultural Field Staff), who have the best micro level knowledge about the type of soil and its composition, cropping pattern, availability of different sources of irrigation and other factors that we use as our explanatory variables for a *mouja*. *Krishi Prajukti Sahayaks* are employed by the Agriculture Department of the Government of West Bengal and act as the primary link between the farmer and the Agriculture Department. They are the collectors of agricultural information that is compiled at a later stage by the government. However, to monitor the quality of data we employed trained research assistants who worked as Field Supervisors and assisted us in our field level interviews[14].

We estimated the econometric model both by *logit* and OLS regression with *mouja* level survey data conducted in 2003-04. The objective of the econometric exercise centres around one primary theme: Why does private investment in groundwater extraction mechanisms occur in some regions and not in others? The most appropriate dependent variable for our purpose is the existence[15] or non-existence of private investment in groundwater extraction at the *mouja* level. Thus the dependent variable is best captured as a qualitative variable. Thus probit or *logit* regressions are the most appropriate method for our case. As the cumulative normal distribution

[13] The ideal method would have been a two stage stratified random sampling where in the first stage each strata is defined by geo-physical characteristics. But this is voluminous work and time consuming. So we adopted a short cut for this.

[14] It may, however be mentioned that approximately one third of the posts of *Krishi Prajukti Sahayak* are lying vacant, thanks to fund crunch of the state government. So in some cases we had to abandon the survey in some *moujas* that we selected.

[15] By existence or non-existence we mean significant existence or non-existence where the cut-off value for significant existence is decided to be more than 10% of cultivable land irrigated by private STW and SMTW.

and the logistic distribution[16] are very close to each other except at the tails, we are not likely to get very different results with either of them[17]. Throughout this study we have used *logit* regressions. In addition we also estimated some of the econometric models by OLS methods with an appropriate dependent variable.

3. Empirical results

We conducted survey in 992 *moujas* in five districts of West Bengal spread across three agro-climatic zones. The names of the blocks and the number of *moujas* surveyed are given in Table 1. It clearly shows that we chose most of our blocks in the belt running from Birbhum in the west to Murshidabad and Nadia in the east[18]. This belt contains all the agro-climatic zones in the state except for the hilly areas on the north where groundwater extraction is not possible, the immediate sub-Himalayan plains (represented by Dhupguri block in our sample of blocks) and the narrow coastal plains zone. Table 1 reveals that *Khariff* paddy cultivation is done on virtually all the land available for cultivation in all the *moujas* and *boro* cultivation is very high in majority of the *moujas,* except in two blocks of Birbhum, and Dhupguri block in Jalpaiguri District. Table 2 gives the distribution of private sources of groundwater irrigation (STW and SMTW). It shows that there are large differences in this respect across blocks both for *khariff* and *boro*. Table 3 reveals that the area irrigated by private sources of irrigation in the *boro* cultivating blocks is much larger than the area served by public sources of irrigation. It also shows that wherever there is low public irrigation, private irrigation is higher. Public sources of irrigation being cheaper, it prompts one to conclude that it is the non-availability of public source

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[16] For probit model the disturbance term is assumed to be normal while it is assumed to be logistic for the *logit* model.

[17] But the estimates of regression coefficients β_j s from the two methods are not directly comparable, because the logistic distribution has a variation $\pi^2/3$. Hence the estimates of β_j s obtained from the *logit* model have to be multiplied by $3^{1/2}/\pi$ to be comparable to the estimates obtained from the *probit* model. Amemiya (1981) suggested logit estimates be multiplied by 0.625 instead of $3^{1/2}/\pi$ as this transformation gives a better approximation. However, in the case of conditional probability the model estimates vary.

[18] See the map.

that has led to the investment in private irrigation. This is confirmed later by our econometric results. Table 4 provides information about the degree of importance of private sources of irrigation in moujas where private STWs and SMTWs are in use. What the table does is that it provides a more nuanced understanding of the information presented in Tables 1- 3. In Manteswar BlockBoro paddy is cultivated in all 80 moujas (Table 1). In 90.36 percent of these moujas STWs and SMTWs are used for irrigation of the boro paddy crop (Table 3). In 98.66 percent of these moujas SMTWs, which draw water from much deeper levels than STWs (Table 2), are used indicating that the water table in most parts of the block is relatively low at least during the summer[19]. What Table 4 says is that in 88 percent of the moujas in this block where private sources of irrigation are in use (perhaps together with public sources of irrigation), more than 70 percent of the acreage under boro paddy is irrigated by privately owned STWs and SMTWs.

Table 1: Block-wise distribution of *moujas* by type of crop cultivation (*khariff* paddy, *boro* and wheat)

Block & District	No. of *moujas*	% of *moujas* that cultivate		
		***Khariff* Paddy**	***Boro***	**Wheat**
Kalna-I, Burdwan	81	98.77	98.77	60.49
Kanksa, Burdwan	36	100	83.33	91.67
Galsi-I, Burdwan	60	100	98.33	88.33
Manteswar, Burdwan	83	100	100	75.90
Beldanga-I, Murshidabad	53	100	90.57	100
Ranaghat-II, Nadia	116	100	100	94.83
Krishnanagar-I, Nadia	94	100	100	98.94
Suri-I, Birbhum	108	99.07	59.26	93.52
Suri-II, Birbhum	78	100	97.44	100
Sainthia, Birbhum	172	100	86.63	95.93
Muraroi-I, Birbhum	84	100	64.29	98.81
Dhupguri, Jalpaiguri	27	100	96.30	100
Total	992	99.90	88.61	91.53

Source: Survey data.

[19] Compare this with the relevant figures for say Krishnanagar I block, where groundwater recharge is much better.

Table 2: Percentage distribution of *moujas* in Block by type of private source of groundwater irrigation for *khariff* and *boro* paddy cultivation

Block	Only private STWs used		Only private SMTWs used		Both STW, SMTW used	
	Khariff	*Boro*	*Khariff*	*Boro*	*Khariff*	*Boro*
Kalna-I	13.85	18.75	63.08	65.63	23.08	15.63
Kanksa	100.00	95.00	0.00	0.00	0.00	5.00
Galsi-I	93.33	89.66	0.00	0.00	6.67	10.34
Manteswar	3.57	1.33	58.93	57.33	37.50	41.33
Beldanga-I	84.00	80.43	2.00	6.52	14.00	13.04
Ranaghat-II	97.32	96.49	0.89	0.88	1.79	2.63
Krishnanagar-I	97.85	98.92	1.08	0.00	1.08	1.08
Suri-I	73.33	70.83	26.67	20.83	0.00	8.33
Suri-II	66.67	68.75	0.00	6.25	33.33	25.00
Sainthia	18.33	17.65	23.33	44.54	58.33	37.82
Muraroi-I	0.00	17.02	0.00	61.70	0.00	21.28
Dhupguri	100.00	100.00	0.00	0.00	0.00	0.00

Source: Survey data.

Table 3: Percentage distribution of *moujas* by source of irrigation for boro paddy cultivation.

Block	% of *moujas* that cultivate *boro*	% of *moujas* using private irrigation	% of *moujas* using only public irrigation
Kalna-I	98.77	80.00	17.50
Kanksa	83.33	66.67	33.33
Galsi-I	98.33	49.15	50.85
Manteswar	100	90.36	9.64
Beldanga-I	90.57	95.83	4.17
Ranaghat-II	100	98.28	1.72
Krishnanagar-I	100	98.94	1.06
Suri-I	59.26	37.50	51.56
Suri-II	97.44	42.11	57.89
Sainthia	86.63	79.87	17.45
Muraroi-I	64.29	87.04	3.70
Dhupguri	96.30	65.38	34.62

Source: Survey data.

Note: Column 3 and 4 represents the percentages for *moujas* where boro paddy cultivation occurs.

Table 4: Distribution of moujas (% of moujas that use private irrigation for Boro paddy cultivation) by %-age of area under *boro* paddy irrigated from private sources.

Block	Percent of total boro paddy acreage irrigated by privately owned sources of water		
	up to 30 %	**31% to 70%**	Above 70%
Kalna-I	46.88	21.88	31.25
Kanksa	25.00	20.00	55.00
Galsi-I	51.72	31.03	17.24
Manteswar	1.33	10.67	88.00
Beldanga-I	2.17	19.57	78.26
Ranaghat-II	5.26	39.47	55.26
Krishnanagar-I	2.15	22.58	75.27
Suri-I	29.17	33.33	37.50
Suri-II	65.63	15.63	18.75
Sainthia	5.88	12.61	81.51
Muraroi-I	0.00	4.26	95.74
Dhupguri	35.29	47.06	17.65

Source: Survey data.

In our econometric model we considered the variables that measure the role of government institutions, such as public irrigation facilities, availability of electricity[20] as well as geo-physical characteristics. We conducted our survey in 992 *moujas* of which we could use 886 observation units because the data for the remaining 106 units was either incomplete or inconsistent. We tried alternative econometric models both for the *logit* regression and for the OLS regression. For our logit regression the dependent variable is presence of private STW and SMTW while the dependent variable for OLS regression is land irrigated by private STW and / or SMTW as a proportion of total acreage under *boro* paddy[21].

Our own field experience informed our analysis of the descriptive statistics presented above. This helped us to build up a tentative explanation for the variations in the extent of use of

[20] Electricity for agricultural use is provided exclusively by the state owned State Electricity Board.
[21] There is expected to be endogenity between the proportion of land irrigated by private STW and/ or SMTW in total land cultivated in *boro* and proportion of land under *boro* cultivation or other regressors such as electricity in field, low water level, length from ground that water is available during mid February to mid March. This could have been avoided if we could use an appropriate instrument for our dependent variable. But we could not find some suitable instrument so that we were forced to use it.

the private groundwater extraction mechanism and led to the choice of the following regressors for the mouja level analysis:

BCULT = proportion of land for *boro* (summer paddy) cultivation out of total cultivable land in the *mouja*,

BGSTW = proportion of land irrigated for *boro* by govt. STW out of total land used for *boro* cultivation in the *mouja*,

BGSUB = proportion of land irrigated from govt. SMTW out of total land used for *boro* cultivation in the *mouja*,

BCAN = proportion of land irrigated by canal out of total land used for *boro* cultivation in the *mouja*,

BRLI = proportion of land irrigated by RLI out of total land used for *boro* cultivation in the *mouja*,

BDTW = proportion of land irrigated for *boro* by DTW out of total land used for *boro* cultivation in the *mouja*,

CAND3 = an exogenous dummy and takes a value one if canal irrigation exists and is regular and zero otherwise,

RLID3 = an exogenous dummy and takes a value one if RLI exists and is regular and zero otherwise,

CANAGE = age of the canal in the *mouja* (difference of 2004 and the date of completion of the canal),

RLIAGE = age of the RLI in the *mouja* (difference of 2004 and the date of installation of the RLI)[22],

DTWAGE = age of the DTW in the *mouja* (difference of 2004 and the date of installation of the DTW),

LOAM = proportion of loam land in total cultivable land of the *mouja*,

CLOCLA = proportion of clay and clay loam land in total cultivable land of the *mouja*,

SANDCLA = proportion of sandy clay land in total cultivable land of the *mouja*,

SANDLO = proportion of sandy loam in total cultivable land of the *mouja*,

[22] If there exists more than one RLI then we take the date of first installation for calculating RLIAGE. Similarly for DTW. For canals this problem does not arise for a *mouja* as there is not more than one canal in an individual *mouja*.

HROCK = an exogenous dummy with a value of one if there exists hard rock in the *mouja* and zero otherwise,

LWL = an exogenous dummy with a value of one if low water level is stated to be a constraining factor for installing STW or SMTW in the *mouja* and zero otherwise,

CLLAY = an exogenous dummy with a value of one if clay layer is stated to be a constraining factor for installing STW or SMTW in the *mouja* and zero otherwise,

PORSOIL = proportion of porous soil in total cultivable land in the *mouja*,

ELECFLD = an exogenous dummy with a value one if there is complete or incomplete electrification in the agricultural field in the *mouja* and zero otherwise,

WLF03 = length in feet from ground that water is available in the *mouja* during mid February to mid March in 2003.

We have reported the estimated value of the coefficient for each regressor in the Tables 5 through 8 along with the corresponding t-value within parentheses. In the lower part of the tables we have reported the relevant statistics for the regression diagnostics. For *logit* regressions, we report the value of the log likelihood function, LNL(UR), McFadden's pseudo R^2, [23] Chi-squared statistic for testing H_0:$\beta = 0$ (not including the constant),[24]. We also report the ratio of predicted '$y_i = 0$' to actual '$y_i = 0$', 0-PR/AC, the ratio of predicted '$y_i = 1$' to actual '$y_i = 1$', 1-PR/AC and the proportion of actual to predicted y_i, AC/PR. For the OLS regressions we report R^2, adjusted R^2, Akaike information criteria,[25] and F value for the joint significance of the regressors, F-VALUE.

[23] pse-$R^2 = (1 - \ln L / \ln L_0)$ where ln L is LNL(UR) and $\ln L_0$ is value of the log likelihood function with β=0)

[24] $\chi^2(df) = 2(\ln L - \ln L_0)$ and df is the degrees of freedom

[25] AIC = -2(logL - K)/N.

For the OLS regressions our dependent variable is the proportion of land irrigated by private STW and / or SMTW in total land cultivated in *boro*[26]. As some of the regressors are found to be (pair wise) highly correlated, to avoid the problem of multicollinearity we first looked at the correlation matrix of the regressors. The regressors for which the co-efficient of correlation has a high absolute value (0.4 and above)[27] were not used simultaneously. Regressors that are moderately correlated (absolute value of 0.2 or above) were used but we also reported the results of the regression analysis with the regression equation containing one of these variables only.

Table 5 presents the regression results for the dependent variable y_i with $y_i = 1$ if there exists STW or SMTW in the *mouja* and $y_i = 0$, otherwise. To investigate the role of government source of irrigation we used three sets of regressors. The first set of regressions in Table 5 uses the proportion of area irrigated by government sources in total *boro* cultivation (BGSTW, BGSUB, BRLI, BDTW and BACN). In the second set these regressors were replaced by exogenous dummies for the existence of different government sources of irrigation (CAND3, RLID3 and DTWD3). The third set is in terms of the ages of the different government sources of irrigation. We did not use the three sets of the regressors in a single equation for obvious reasons.

The results reported in Table 5 do not seem to be robust. Though in many cases we find expected signs of the regressors as well as the right t-statistic for the significance level, many coefficient values often change sign or a significant t-value becomes non-significant and vice-versa as we change the combination of regressors. This prompted us test for outlier values using

[26] There is expected to be endogenity between the proportion of land irrigated by private STW and/ or SMTW in total land cultivated in *boro* and BCULT or other regressors such as ELECFLD, LWL, WLF03 or soil type. This could have been avoided if we could use an appropriate instrument for our dependent variable. But we could not find some suitable instrument so that we were forced to use it.
[27] The correlation co-efficient between acreage under *boro* cultivation and the acreage under wheat was 0.67. Hence we used the acreage under *boro* only.

the *hat matrix a la* Belsley, Welsh and Kuh (1980). A total of 251 observations were found to be outliers. After dropping them we repeated the regression exercises. The results are reported in Table 6. The corresponding OLS regressions are reported in Tables 7 and 8 where the latter reports the results without outliers. In both the cases we checked for heteroscedasticity using Breusch and Pagan test. The null of heteroscedasticity is rejected. Further we repeated the regression exercises dropping several observations from the beginning, from the end and from the middle. This is done to avoid any possible undetected multi-collinearity resulting in parameter instability. These exercises did not yield instability of parameter values. Hence we can conclude safely that the regression results so reported are robust.

The results of the econometric analysis shows that proportion of land for *boro* (summer paddy) cultivation out of total cultivable land in the *mouja* and proportion of land irrigated for *boro* by state owned STWs out of total land used for *boro* cultivation in the *mouja* do not affect private investment in STWs or SMTWs. The existence of large coverage of major government irrigation, such as canal, RLI or even government submersible, negatively affects private investment in irrigation. This is true for OLS regressions also. But DTW is non-significant in any form in logit regressions. However, it is significant in the OLS regressions. Thus the major irrigation like canal is always robust.

Regarding types of soil[28] the regression results are nor very clear, either in terms of expected sign or in terms of level of significance or both. The proportion of loam land in total cultivable land of the *mouja* is only marginally negative significant. Though proportion of porous soil in total cultivable land in the *mouja* is negative significant in some of the regression equations, it becomes altogether non-significant in others. Only proportion of sandy clay land in total

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[28] Proportion of sandy loam in and proportion of clay and clay loam land in total cultivable land of the *mouja* are highly negatively correlated with a correlation co-efficient of –0.74, hence we used only the latter.

cultivable land of the *mouja* is found to be with an expected positive sign, but becomes non-significant in other equations. The pattern is similar in OLS regressions also.

The fact that types of soil have no role in private investment in STW or SMTW can be explained in the following terms. We are observing the spread of private investment in STW or SMTW at some advanced stage of its evolutionary path. Possibly in the initial years soil types were important determinants. For example, higher water retention capacity of clay or clay loam positively affected the investment pattern in the respective areas. On the other hand, porosity of soil with lower water retention capacity is non-conducive to private investment in ground water extraction. As *boro* prices rose, lands that were previously not considered suitable for paddy cultivation began to be used. It is possible that the regression is not picking up the effect of differences in soil characteristics because we are looking at cross section data in a much later phase of transition.

Among other geo-physical characteristics, presence of hard rock in the *moujas* negatively affects private investment in groundwater irrigation. The result also holds in the OLS regressions. It is also very robust whether we exclude outliers or not, even co-efficient estimates remain almost the same. But the co-efficient estimate of low water level as a constraining factor, though sometimes appear with an expected negative sign (and significant) is not robust. This is possibly because of the fact that it may be a constraining factor for STWs, but if the water table is low then, *ceteris paribus* private investment in groundwater extraction takes place through SMTWs. The co-efficient estimate of length in feet from ground to the level where water is available in the *mouja* during mid February to mid March in 2003 also shows similar pattern[29].

[29] We have data for depths of water table for the years 1993, 1998 and 2003. Since these are pair wise correlated with a high degree of correlation, we used the data for 2003.

Contrary to common sense the presence of clay layer does not affect emergence of STW or SMTWs.

Electrification of the agricultural fields is negative and significant in both the *logit* as well as OLS regressions. This result is robust, independent of whether we exclude outlier observations or not. This result appears to fly in the face of an existing consensus of opinion that introduction of electricity leads to an increase in private investment on groundwater extraction devices and so has to be interpreted very carefully. For the OLS regressions our dependent variable is the proportion of land irrigated by private STW and / or SMTW in total land cultivated in *boro*. What the corresponding econometric result says is that the availability of electricity in the agricultural fields is a significant explanatory variable but the association between the proportion of area under *boro* paddy that is irrigated by private irrigation sources and the presence of electricity in the *mouja* is negative. To see why this result makes sense, we consider first the *moujas* where the proportion is low. In these *moujas*, the primary sources of irrigation are government canals and to other state owned devices like DTWs, RLIs, cluster STWs etc.

The availability of electricity may have little or no encouraging effect on private investment in groundwater extraction devices either because available state owned sources provide sufficient water for the irrigation of *boro* paddy in much of the agricultural area as in Galsi I block in Burdwan district which is agriculturally intensive, or as geophysical conditions are such that investment in groundwater extraction devices is unprofitable as in Suri I block in Birbhum. In the areas where the proportion of total area under *boro* paddy that is irrigated by privately owned groundwater extraction devices is high, soil and other geophysical conditions are such that

Table 5: Results from *logit* regression

SL NO. -->		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
REGRESSORS	**CONSTANT**	3.9 (7.2)	3.08 (7.3)	3.10 (7.4)	2.8 (7.7)	1.53 (8.3)	4.95(9.5)	4.491 (10.5)	4.42 (8.4)	4.63 (10.7)	2.4 (8.1)	2.31 (14.4)	4.71 (8.9)	4.86 (11.1)	2.75 (8.6)	2.81 (15.4)
	BCULT	0.014 (2.42)	0.013 (2.7)	0.013 (2.74)	0.0125 (2.27)	0.035 (6.7)	-0.002 (-0.7)		0.0013 (0.3)		0.0003 (0.1)		0.002 (0.5)		0.001 (0.23)	
	BGSTW	0.049 (1.5)			0.0436 (1.4)		0.019 (1.3)		0.036 (5.6)	0.038 (6.1)	0.026 (4.04)	0.027 (4.7)	0.04 (6.1)	0.041 (6.5)	0.03 (4.98)	0.03 (5.3)
	BGSUB	-0.039 (-5.9)	0.023 (2.9)	0.028 (9.7)	-0.033 (-5.3)	-0.02 (-3.4)	-0.037 (-5.9)	-0.035 (-5.9)	-0.0341 (-5.6)	-0.036 (-5.8)	-0.024 (-4.1)	-0.025 (-4.3)	-0.038 (-5.8)	-0.0389 (-6.2)	-0.028 (-4.6)	-0.0281 (-4.9)
	BCAN	-0.034 (-10.1)	-0.026 (-9.1)	-0.026 (-9.2)	-0.037 (-11.1)	-0.032 (-10.4)										
	BRLI	-0.023 (-4.4)	0.49 (0.68)		-0.022 (-4.3)	-0.009 (-1.9)	-0.013 (-2.7)	-0.011 (-2.33)								
	BDTW	0.049 (1.6)			0.051 (1.6)		0.033 (2.3)	0.048 (6.3)								
	CAND3								-0.68 (-2.8)	-0.74 (-3.3)	-0.75 (-3.3)	-0.82 (-3.8)				
	RLID3								0.52 (1.3)		0.699 (0.09)					
	DTWD3								0.44 (1.1)		0.84 (2.32)	0.82 (2.3)				
	CANAGE												-0.002 (-4.7)	-0.022 (-5.1)	-0.002 (-5.1)	-0.024 (-5.9)
	RLIAGE												-0.04 (-0.31)		0.013 (0.10)	
	DTWAGE												0.0001 (0.9)		0.0002 (0.12)	
	LOAM	-0.001 (-0.6)					-0.001 (-0.6)		-0.001 (0.5)				-0.007 (-0.5)			
	CLOCLA	0.002 (0.55)			0.004 (1.1)		-0.003 (-0.9)		-0.028 (-0.8)		-0.17 (-0.5)		-0.0002 (-0.5)		-0.64 (-0.19)	
	SANDCLA	-0.001 (-0.4)					-0.0001 (-0.01)		-0.0004 (-0.35)				-0.24 (-0.16)			
	HROCK	-1.14 (-4.2)	-1.09 (4.7)	-1.08 (-4.6)	-1.23 (-4.5)	-1.3 (-6.1)	-1.48 (-6.2)	-0.33 (-6.1)	-1.41 (-5.7)	-1.41 (-6.4)	-0.002 (-6.8)	-1.57 (-7.4)	-1.34 (-5.04)	-1.4 (-6.3)	-1.51 (-6.3)	-1.6 (-7.5)
	LWL	-0.086 (0.32)			-0.095 (-0.35)		-0.007 (-0.03)		0.056 (0.24)		0.11 (0.5)		0.15 (0.6)		0.18 (0.8)	
	CLLAY	0.004 (0.01)			-0.12 (-0.23)		-0.42 (-0.9)		-0.39 (-0.9)		-0.66 (-1.6)		-0.4 (-0.91)		-0.69 (-1.6)	
	PORSOIL	-0.71 (-1.34)			-0.73 (-1.4)		-0.79 (-1.69)		-0.95 (-2.03)	-0.88 (-1.9)	-1.10 (-2.4)	-1.16 (-2.67)	-0.98 (-2.1)	-0.992 (-2.23)	-1.09 (-2.42)	-1.24 (-2.9)
	ELECFLD	-0.51 (-2.84)	-0.38 (-2.33)	-0.38 (-2.34)			-1.04 (-6.1)	-1.036 (-6.3)	-0.89 (-5.1)	-0.98 (-5.7)			-0.88 (-5.1)	-0.93 (-5.6)		
	WLF03	0.0026 (0.54)			0.001 (0.28)		-0.002 (-0.5)		-0.036 (-0.08)		-0.003 (-0.65)		-0.002 (-0.4)		-0.004 (-0.9)	
	LNL(UR)	-257.82	-303.41	-303.67	-262.49	-325.3	-323.16	-327.48	-323.01	-325.75	-338.74	-341.94	-314.92	-316.68	-330.19	-334.51
STATISTICS	**pse-R^2**	0.435	0.336	0.335	0.425	0.288	.0.292	0.283	0.293	0.287	0.258	0.251	0.310	0.360	0.277	0.266
	χ^2(df)	397.57 (15)	306.39 (6)	305.89 (5)	388.23 (12)	262.61 (5)	266.89 (14)	258.26 (5)	267.19 (15)	261.71 (6)	235.74 (12)	229.33 (6)	283.38 (15)	279.86 (6)	252.83 (12)	244.20 (5)
	0-PR/AC	175/187	155/187	154/187	191/187	98/187	119/187	100/187	128/187	126/187	136/187	148/187	145/187	141/187	130/187	138/187
	1-PR/AC	711/699	731/699	732/699	695/699	788/699	767/699	786/699	758/699	760/699	750/699	738/699	741/699	745/699	756/699	748/699
	AC/PR	782/886	770/886	769/886	770/886	719/886	750/886	741/886	747/886	751/886	737/886	739/886	750/886	752/886	729/886	727/8886

Table 6: Results from ***logit*** **regression – without out**lier

SL NO. -->		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
REGRESSORS	**CONSTANT**	4.89 (7.2)	5.23 (8.5)	5.01 (10.3)	4.89 (8.7)	5.57 (8.9)	5.27 (10.2)	6.3 (7.77)	6.3 (8.7)	5.47 (7.5)	5.62 (8.8)	5.62 (7.6)	5.97 (8.8)	7.5 (8.6)	6.8 (9.6)	6.98 (8.5)	7.2 (8.6)
	BCULT	0.79 (1.1)															
	BGSUB	-0.10 (-2.65)	-0.098 (-2.6)	-0.12 (-2.86)	-0.09 (-2.5)	-0.09 (-2.5)	-0.10 (-2.7)	-0.05 (-1.3)		-0.046 (-1.23)		0.05 (-1.29)		-0.09 (-2.3)	-0.095 (-2.49)	-0.094 (2.29)	-0.096 (-2.3)
	BCAN	-0.05 (-9.1)	-0.05 (-9.3)	-0.052 (-9.6)	-0.051 (-9.4)	-0.05 (-9.4)	-0.052 (-9.8)										
	BRLI	-0.004 (-4.6)	-0.041 (-4.6)	-0.038 (-4.5)	-0.41 (-4.7)	-0.043 (-4.9)	-0.039 (-4.9)										
	BDTW																
	CAND3							-0.9 (-3.1)	-1.1 (-3.5)	-1.07 (-3.6)	-1.23 (-4.3)	-1.08 (-3.6)	-1.1 (-3.8)				
	RLID3							0.26 (0.4)		0.19 (0.34)		0.29 (0.5)					
	DTWD3							0.89 (1.4)		0.89 (1.41)		0.82 (1.28)					
	CANAGE													-0.05 (-5.7)	-0.53 (-6.5)	-0.051 (-5.9)	-0.051 (-5.9)
	RLIAGE													-0.02 (-1.2)		-0.022 (-1.2)	-0.193 (-1.1)
	DTWAGE													0.26 (0.1)		0.0045 (0.19)	0.002 (0.1)
	LOAM					-0.014 (-1.9)						0.001 (0.1)					0.0003 (0.05)
	CLOCLA	-0.002 (-0.51)	-0.29 (-0.5)					-0.010 (-2.1)	-0.12 (-2.4)					-0.007 (-1.4)			
	SANDCLA	0.54 (0.3)	0.0052 (0.3)		0.45 (0.3)	0.002 (0.09)		0.04 (2.5)	0.039 (2.2)	0.05 (2.9)	0.05 (2.86)	0.05 (3.0)	0.05 (3.1)	0.034 (2.003)	0.038 (2.35)	0.038 (2.29)	0.0398 (2.32)
	SANDLO				0.01 (1.7)					0.008 (1.63)						0.005 (1.1)	
	HROCK	-1.46 (-3.4)	-1.61 (-3.9)	-1.18 (-3.3)	-1.72 (-4.0)	-1.55 (-3.8)	-1.39 (-3.6)	-1.6 (-4.5)	-1.4 (-4.13)	-1.54 (-4.4)	-1.08 (-3.5)	-1.4 (-4.2)	-1.4 (-4.3)	-1.3 (-3.4)	-0.93 (-2.98)	-1.24 (-3.3)	-1.16 (-3.18)
	LWL	-0.66 (-1.5)	-0.78 (-1.9)		-0.71 (-1.7)	-0.90 (-2.2)	-0.67 (-1.7)	-0.63 (-1.9)		-0.64 (-1.9)		-0.74 (-2.2)	-0.7 (-2.4)	-0.33 (-0.8)		-0.3 (-0.8)	-0.37 (-1.03)
	CLLAY	-0.60 (-0.9)	-0.62 (-0.9)			-0.67 (-1.0)				-0.99 (-1.9)		-1.06 (-1.99)	-1.1 (-2.1)	-0.79 (-1.4)		-0.81 (-1.43)	-0.85 (-1.5)
	PORSOIL																
	ELECFLD							-1.3 (-5.1)	-1.4 (-5.6)	-1.28 (-4.9)	-1.35 (-5.6)	-1.3 (-5.1)	-1.3 (-5.4)	-1.25 (-4.9)	-1.26 (-5.3)	-1.24 (-4.9)	-1.24 (-5.0)
	WLF03	0.008 (0.96)	0.0071 (0.8)			0.008 (0.98)		0.001 (0.1)		0.001 (0.1)		0.002 (0.3)		-0.003 (-0.4)		-0.003 (-0.4)	-0.002 (-0.29)
STATISTICS	**LNL(UR)**	-114.32	-114.97	-117.84	-113.67	-113.41	-116.36	-173.33	-178.64	-174.16	-181.71	-175.53	-177.22	-154.18	-157.28	-154.63	-155.21
	pse-R^2	0.521	0.518	0.506	0.523	0.525	0.512	0.273	0.251	0.270	0.238	0.264	0.257	0.354	0.341	0.352	0.349
	χ^2(df)	248.39 (10)	247.09 (9)	241.36 (4)	249.70 (9)	250.22 (9)	244.31 (5)	130.38 (11)	119.76 (5)	128.13 (11)	113-62 (4)	125.98 (11)	122.60 (6)	168.67 (11)	162.47 (5)	167.81 (11)	166.62 (11)
	0-PR/AC	83/79	84/79	93/79	86/79	84/79	71/79	34/79	37/79	38/79	29/79	38/79	37/79	54/79	41/79	48/79	51/79
	1-PR/AC	552/556	551/556	442/556	549/556	551/556	564/556	601/556	598/556	597/556	606/556	597/556	598/556	581/556	594/556	587/556	584/556
	AC/PR	589/635	588/635	589/635	590/635	584/635	581/635	572/635	579/635	569/635	565/635	567/635	565/635	568/635	563/635	570/635	567/635

Table7: Results from OLS regression

	SL NO. -->	1	2	3	4	5	6	7	8
REGRESSORS	CONSTANT	96.21 (61.3)	94.9 (68.8)	94.84 (68.7)	119.74 (23.5)	113.18 (23.12)	113.26 (23.12)	122.72 (24.5)	117.40 (24.4)
	BCULT								
	BGSTW	-1.2 (-12.7)	-1.11 (-12.6)	-1.11 (-12.6)	-0.61 (-3.3)	-0.57 (-3.1)	-0.57 (-3.03)	-0.83 (-4.5)	-0.81 (-4.4)
	BGSUB	0.91 (-12.8)	-0.94 (-13.2)	-0.94 (-13.2)	0.80 (-5.3)	-0.88 (-5.8)	-0.88 (-5.8)	-0.89 (-6.0)	-0.97 (-6.6)
	BCAN	-0.92 (-52.3)	-0.93 (-52.9)	-0.93 (-53.1)					
	BRLI	-0.94 (-29.7)	-0.94 (-29.8)	-0.94 (-29.7)					
	BDTW	-0.61 (-13.8)	-0.62 (-13.9)	-0.62 (-13.9)					
	CAND3				-25.04 (-7.8)	-26.7 (-8.31)	-26.8 (-8.3)		
	RLID3				-33.4 (-8.19)	-33.45 (-8.1)	-33.38 (-8.09)		
	DTWD3				-13.26 (-4.1)	-14.8 (-4.5)	-14.93 (-4.5)		
	CANAGE							-0.56 (-10.0)	-0.59 (-10.7)
	RLIAGE							-1.26 (-9.2)	-1.27 (-9.2)
	DTWAGE							-0.46 (-4.4)	-0.51 (-5.0)
	LOAM			0.31 (0.51)			0.321 (0.25)		0.44 (0.35)
	CLOCLA	-0.04 (-1.8)			-0.17 (-3.9)			-0.15 (-3.4)	
	SANDCLA	-0.42 (-0.8)	-0.57 (-0.8)	-0.639 (-1.02)	-0.79 (0.07)	0.143 (0.1)	-0.47 (-0.35)	0.001 (0.17)	-0.002 (-0.17)
	SANDLO		0.13 (0.23)			-0.56 (-0.47)			
	HROCK	-6.1 (-3.4)	-5.76 (-3.2)	-5.76 (-3.24)	-21.66 (-5.8)	-20.25 (-5.4)	-20.38 (-5.3)	-20.03 (-5.4)	-18.8 (-5.1)
	LWL	-2.35 (-1.8)	-2.68 (-2.04)	-2.681 (-2.052)	0.51 (0.02)	-1.52 (-0.54)	-1.14 (-0.5)	2.03 (0.74)	0.93 (0.34)
	CLLAY	-4.45 (-1.6)	-5.76 (-2.04)	-5.3 (-1.9)	-14.65 (-2.52)	-18.21 (-3.13)	-18.54 (-3.19)	-19.19 (-3.39)	-22.7 (-4.02)
	PORSOIL	-10.8 (-3.3)	-10.19 (-1.91)	-10.11 (-3.12)	-20.35 (-2.98)	-18.3 (-2.65)	-18.06 (-2.6)	-22.43 (-3.37)	-20.48 (-3.1)
	ELECFLD				-13.74 (-7.4)	-13.58 (-7.5)	-13.62 (-7.29)	-12.57 (-6.96)	-12.38 (-6.8)
	WLF03	-0.10 (-0.33)	-0.10 (0.32)	-0.103 (-0.32)	-0.38 (-0.56)	-0.33 (-0.47)	-0.36 (-0.5)	-0.59 (-0.89)	-0.06 (-0.9)
STATISTIC	LnL(UR)	2958.34	-2959.93	-2959.83	-3487.5	-3495.26	-3495.34	-3469.57	-3475.39
	R^2	0.85	0.85	0.85	0.337	0.322	0.322	0.3694	0.359
	Adj R^2	0.85	0.85	0.85	0.324	0.309	0.309	0.358	0.347
	AIC	8.37	8.4	8.37	9.86	9.89	9.89	9.81	9.83
	F- VALUE	330.71	328.97	329.09	27.18	25.44	25.42	31.63	29.98

Table 8: Results from OLS regression - without outliers

	SL NO. -->	1	2	3	4	5	6	7	8	9	10	11	12
REGRESSORS	**CONSTANT**	97.56 (52.9)	98.81 (60.0)	95.88 (62.4)	95.001 (55.7)	105.235 (19.2)	119.29 (21.78)	113.42 (20.8)	110.109 (19.9)	124.307 (23.2)	120.147 (22.4)	116.040 (21.4)	118.85 (22.3)
	BCULT	0.32 (1.5)											
	BGSTW	-0.98 (-8.1)	-0.98 (-8.1)	-0.97 (-8.0)	-0.98 (-8.1)	-0.534 (-1.9)	-0.67 (-2.37)	-0.64 (-2.3)	-0.673 (-2.4)	-0.875 (-3.2)	-0.86 (-3.1)	-0.888 (-3.2)	-1.107 (-3.9)
	BGSUB	-1.2 (-6.6)	-1.21 (-6.6)	-1.225 (-6.6)	-1.25 (-6.8)	-1.03 (-2.4)	-0.974 (-2.28)	-1.022 (-2.4)	-1.06 (-2.5)	-1.09 (-2.6)	-1.151 (-2.7)	-1.170 (-2.8)	-1.467 (-3.5)
	BCAN	-0.96 (-55.9)	-0.95 (-56.3)	-0.957 (-56.6)	-0.95 (-56.3)								
	BRLI	0.95 (-26.5)	-0.959 (-26.6)	0.964 (-26.6)	0.954 (-26.4)	-0.729 (-8.6)							
	BDTW	0.89 (-17.4)	-0.89 (-17.3)	-0.89 (-17.2)	-0.91 (-17.4)	-0.50 (-4.1)							
	CAND3						-27.398 (-8.0)	-28.7 (-8.6)	-27.65 (-8.2)				
	RLID3						-30.69 (-6.7)	-30.775 (-6.7)	-29.94 (-6.5)				
	DTWD3						-14.19 (-4.04)	-14.94 (-4.2)	-15.73 (-4.5)				
	CANAGE									-0.62 (-10.6)	-0.644 (-11.1)	-0.631 (10.9)	-0.548 (-9.5)
	RLIAGE									-1.12 (-7.6)	-1.11 (-7.6)	-1.108 (-7.4)	-1.063 (-7.2)
	DTWAGE									-0.052 (-4.7)	-0.55 (-4.9)	-0.559 (-5.1)	
	LOAM				0.467 (1.7)	0.23 (3.52)			0.141 (2.2)			0.131 (2.1)	
	CLOCLA	-0.06 (-2.9)	-0.06 (-2.6)				-0.13 (-2.6)			-0.111 (-2.3)			-0.136 (-2.8)
	SANDCLA	0.18 (-3.5)	-0.18 (-3.7)		-0.134 (-2.8)	0.414 (3.6)	0.27 (2.43)	0.360 (3.2)	0.41 (-3.7)	0.133 (1.2)	0.198 (1.8)	0.249 (2.3)	0.166 (0.1)
	SANDLO			0.03 (1.2)				-0.27 (0.5)			0.26 (0.05)		
	HROCK	-6.6 (-3.7)	-7.29 (-4.2)	-6.9 (-3.9)	-6.57 (-3.8)	25.31 (-6.3)	20.49 (-5.1)	-19.3 (-4.8)	-18.78 (-4.7)	-16.36 (-4.1)	-14.94 (-3.7)	-14.64 (-3.7)	-14.606 (-3.6)
	LWL	0.48 (-0.4)	-0.6 (-0.47)	-1.13 (-0.8)	-0.97 (-0.8)	-2.11 (-0.7)	0.266 (0.01)	-1.12 (-0.4)	0.41 (-0.1)	3.864 (1.3)	2.70 (0.9)	3.458 (1.2)	5.653 (1.9)
	CLLAY	-5.07 (-1.8)	-5.44(- 1.8)	-5.9 (-2.05)	-6 (-2.09)	-23.95 (-3.5)	-17.908 (-2.7)	-19.4 (-2.9)	-18.91 (-2.8)	-17.868 (-2.8)	-19.6 (-2.9)	-18.558 (-2.8)	-17.161 (-2.6)
	PORSOIL	4.56 (0.3)	4.62 (0.3)	5.33 (0.4)	4.73 (0.33)	30.92 (0.926)	25.189 (0.7)	26.02 (0.8)	25.64 (0.8)	19.46 (0.6)	19.633 (0.6)	19.748 (0.6)	23.136 (0.7)
	ELECFLD					-15.113 (-7.7)	-13.72 (-7.1)	-13.70 (-7.0)	-140.10 (-7.2)	-13.154 (-6.9)	-13.161 (-6.9)	-13.45 (-7.1)	-12.19 (-6.4)
	WLF03	0.006 (0.17)	0.004 (0.12)	0.003 (0.1)	0.009 (0.3)	-0.858 (-1.1)	-.100 (-1.3)	-0.100 (0.2)	-0.818 (-1.0)	-0.105 (-1.4)	-0.104 (-1.3)	-0.885 (-1.1)	-0.135 (0.1)
Statistic	LnL(UR)	- 2578.26	- 2579.42	- 2582.223	- 2581.57	- 3127.09	- 3114.69	- 3118.08	- 3115.79	- 3094.69	- 3097.41	- 3095.17	- 3105.84
	R^2	0.872	0.872	0.871	0.8712	0.282	0.309	0.301	0.307	0.353	0.348	0.350	0.3281
	Adj R^2	0.87	0.869	0.868	0.869	0.268	0.295	0.287	0.292	0.337	0.332	0.367	0.315
	AIC	8.16	8.165	8.174	8.172	9.89	9.854	9.865	9.858	9.791	9.8	9.793	9.82
	F- VALUE	326.78	353.11	349.55	350.37	320.32	21.38	20.64	21.13	25.87	25.24	25.76	25.31

investment in groundwater extraction devices was profitable at least during the period when paddy prices were high and diesel prices were lower. In some areas, where the proportion of agricultural area under *boro* paddy is very high, state owned sources of irrigation have little or no role. In these areas, the number of *moujas* where only diesel operated STWs and SMTWs are in operation far outnumber the number of *moujas* where operated devices exist so that the association between availability of electricity and proportion of area under *boro* paddy that is cultivated with water from privately owned sources is quite likely to be negative. Further, in these blocks, as in Manteswar block of Burdwan district, the introduction of electricity in a *mouja* had little or no impact on the area under cultivation of *boro* paddy. For the most part, existing diesel operated machines were converted to use electricity and where new machines were installed, the command areas were reallocated to accommodate the new entrants.

This has an important implication from policy perspective. It shows that electrification of agricultural fields may not go hand in hand with private investment in ground water extraction mechanism; in fact it can go in the opposite direction as our study shows. The electrification of agricultural fields should be targeted keeping other factors in mind.

4. Conclusion

The most revealing conclusion of our paper is that the extent to which the emergence of the private groundwater irrigation has been instrumental in the agricultural growth of West Bengal. This has had seldom received recognition in the official circuit and among the academia. Investment in groundwater irrigation in the private sector had come up to supplement the public source of irrigation which is often inadequate and erratic. Over time it grew in importance as HYV paddy cultivation spread to areas that had little or no access to public irrigation. It is perhaps fair to suggest that the fund constrained state and national governments would never have been able to achieve the spectacular growth that the agricultural sector has witnessed on their own had private investment in small groundwater extraction devices by private farmers driven by the lure of the profits from adoption of the new agricultural technology not been undertaken on this scale. To be fair to the government, it must be recognized that the initial impetus was provided by the state in the form of cheap irrigation, fertilizers, seeds, agricultural extension, etc. This helped to keep costs low for farmers in the first phase of adoption of the new technology and perhaps induced greater willingness to experiment with the new technology. As familiarity with the technology increased, farmers began to recognize the profit yielding potential of the new seed technology. Low input costs and rising paddy prices drove the spread of HYV paddy cultivation both during the monsoon season and in the summer. As Boyce (1987) had recognized long ago, the primary constraint to agricultural growth in West Bengal in the early years of the green revolution was the availability of controlled and adequate irrigation. The solution, as our large scale survey based study indicates, emerged endogenously. On a more sobering note, this very process of private investment also may have had the effect of widening regional disparities in the rural sector.

Our study of groundwater irrigation has covered all the major agro-climatic zones of the state except the hilly regions in the north and the agriculturally backward, narrow coastal zone in the southern part of the state. The study has isolated the conditions under which such investment takes place to a large extent. In general, wherever the hard rock lies close to the surface, investment in groundwater extraction is scarce. Further, the availability of reliable and adequate water from canals has acted as a deterrent to investment in these devices. In areas where the reliability of canal irrigation is low, or canal irrigation is unavailable, private investment in groundwater extraction is to be found.

Our study reveals that mere electrification of agricultural fields may not be sufficient to induce private investment in irrigation. Unless agro-climatic conditions are sufficiently favourable or the input and output prices are “right” it may not be worthwhile for farmers to invest in the groundwater extraction equipment. Further, electrification may not even be necessary. When diesel prices were low and paddy harvest prices were rising, even very small farmers invested in their own water extraction devices run with diesel engines. Those who did not took advantage of the rapidly emerging market for privately supplied groundwater. This helps us to draw a major policy conclusion about the electrification programme. If the policy target is to increase the area under cultivation of a particular crop that is constrained by the availability of irrigation, inducing private investment by providing electricity will work only if the areas where electricity is provided are either not already saturated with diesel operated machines or have the right geophysical conditions and low investment in groundwater extraction devices. Otherwise, existing diesel operated machines will be converted to use electricity as a source of power as in the first case, or new machines will not be installed as unfavourable geophysical conditions will make such investment unprofitable.

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