The purpose of the evaluation was to quantify the impact of the recent policy change in West Bengal relating to the pricing of electricity from a flat rate tariff to metered tariff. The study attempted to assess its impact on the total number of hours pumped, especially in the summer season, and its distribution across use on the pump owner's own farm and sales to other farmers.

DOES MARGINAL COST PRICING OF ELECTRICITY AFFECT GROUNDWATER PUMPING BEHAVIOR OF FARMERS?

Evidence from West Bengal, India

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EXECUTIVE SUMMARY

The purpose of the evaluation was to quantify the impact of the recent policy change in West Bengal relating to the pricing of electricity from a flat rate tariff to metered tariff. The study attempted to assess its impact on the total number of hours pumped, especially in the summer season, and its distribution across use on the pump owner's own farm and sales to other farmers. The program theory suggested that we should see a decline in pumping use overall, but the impact on water use on farm, and on sales could be mitigated through various factors. We also examined the impact of this policy change on a set of secondary impact variables which included changes in cropping pattern and crop output.

Quantification of impact was made feasible through surveys conducted in 2004 and 2007 as part of other studies (Mukherji, 2007; Mukherji et al. 2009), which served as a baseline; the policy of metering of tubewells had not yet been initiated then. A 3ie-funded follow-up survey was conducted in 2010 revisiting the same villages and households, to create a panel data set for analysis. Since in 2010, metering had not been implemented in full, some of the baseline villages and households did not have metered tubewells, serving as a control. We also augmented the baseline sample by adding additional villages and households within a village, for a total sample size of over 850 households.

Our major result is that the expected impact on reducing pumping hours was felt only in the boro season. There is also some evidence that this decrease was not confined to irrigation on own-farm, but that water sales and purchases were also adversely affected as a consequence. Yet the metering did not influence either cropping patterns, or the output of boro paddy. The latter could well be explained by over use of water among those who irrigate their own farms, so that reductions in water use do not translate into decreased output. The impact was insignificant for all indicators in the *kharif* and *rabi* seasons. Evidence of decreased sales and purchases potentially has implications for equity, especially if small farmers are being driven out of the market completely. Yet their decreased access to water does not seem to have altered cropping patterns.

These impacts have to be seen against the backdrop of an overall decline in pumping hours that was seen in both control and treatment groups, which may have served to swamp the impact of the metering. The fact that many of the signs have the expected negative sign, but are insignificant, may mean that our sample was under-powered to detect impact. Drawing policy implications from these impact results requires further analysis. We are currently modelling the production technology and the economics of water use to assess whether alternative options, such as a two-part tariff may be an optimal policy to pursue.

1.0 INTERVENTION, EVALUATION QUESTIONS AND POLICY RELEVANCE

1.1 THE INTERVENTION: METERING OF ELECTRIC TUBEWELLS

The intervention for which we conducted this impact evaluation is metering of agricultural tubewells in the Indian state of West Bengal. According to the 4th and latest round of Minor Irrigation Census (GOI, 2011), the state has a total of 5.19 lakhs groundwater extracting mechanisms (GWEMs). These include dugwells, shallow tubewells and deep tubewells. Of these 5.19 GWEMs, approximately 1.09 lakh run on electricity (electric pumps, also called electric tubewells or borewells) and the rest run on either diesel or on kerosene or a mix of both.

The West Bengal State Electricity Distribution Company Limited (WBSEDCL) initiated the process of metering of electric tubewells in 2007. Till 2009-10, it had completed metering of around 70% of electric tubewells in the state. Of interest to us in this evaluation is the pumping behaviour of electric pump owners in the aftermath of metering of electric tubewells. Why is the pumping behaviour of pump owners likely to be changed by metering? Prior to metering of tubewells, all electric tubewell owners in the state were subjected to a flat electricity tariff ranging from Rs. 8800/year to Rs. 10800/year for a standard 5horse power (HP) pump. This meant that there was no marginal cost of pumping and farmers were likely to keep pumping for as many hours as electricity was available. Charging pump owners on a metered rate meant that farmers now incurred a marginal cost of pumping and their total quantum of pumping got reflected in electricity bills. Farmers whose tubewells have been metered are now subjected to a time of the day tariff, while those whose tubewells have not yet been metered still continue to pay flat tariff. Table 1 shows TOD timings, rates and flat tariff rates.

Standard economic theory can be invoked to predict the outcome of this change: it is expected that the total number of hours pumped by owners of tubewells will have decreased. However whether this is reflected in reduced water sales as well as reduced use on farm depends on a number of variables that are set out in propositions developed later in the section on the theory of change. We therefore canvassed information on water selling and buying behaviour, to assess whether the net impact was a contraction in water sales and purchases. Such a contraction would have significance economic consequences: of the 6.1 million farming households in West Bengal, only 1.1 million report owning wells and tubewells, while 4.6 million farming households report using irrigation (NSSO, 1999). Of these, 3.1 million households (or 50.4% of all farming households) report hiring irrigation services from other farmers.

1.2 EVALUATION QUESTIONS

Our primary goal is to understand the impact of metering of agricultural tubewells in West Bengal on groundwater users (pump owners and water buyers) and informal groundwater markets. Our evaluation questions are:

1. How has the shift in policy from flat rate tariff to metered tariff influenced the number of hours pumped, and its breakup between water used for irrigating the pump owner's farm versus sales? Are there seasonal patterns to this impact?
2. What have been the effects of this policy change on water buyers? In particular how have volumes sold and bought changed as a consequence?
3. What are the secondary impacts of the policy change, in terms of its impact on cropping patterns, and output?

1.3 POLICY RELEVANCE OF THE INTERVENTION

Metering of agricultural tubewells was implemented to achieve better energy audits, reduce transmission and distribution losses, and improve collection rates. The primary beneficiaries are the WBSEDCL and agricultural electricity consumers who have supposedly obtained better service after the reform. While the total cost of the reform is not available, the WBSEDCL has invested at least USD 24.5 million in remotely readable electronic meters (http://www.business-standard.com/india/news/genus-to-sell-meters-for-bengal-farms/241998/).

West Bengal has about 100,000 electric pumps (NSSO, 1999) and on an average, our survey suggests that each pump owner sells water to more than 10 (aggregated across seasons). Hence, more than 1.0 million farmers could potentially have been directly affected by this intervention both directly through its impact on pumping behaviour, and indirectly, through its effects on groundwater markets. Many more may be affected indirectly through changes in cropping decisions of electric pump owners and their water buyers.

What is the relevance of the West Bengal metering intervention? The next section provides a brief review of the history of the energy-irrigation nexus in India's agriculture and its impact of groundwater markets. It also explains why metering of tubewells is an important intervention – an intervention that is likely to be replicated by other Indian states in years to come given that the Electricity Act of 2003 has made metering mandatory for all categories of electricity consumers.

2.0 LITERATURE REVIEW

2.1 WHY IS ENERGY-IRRIGATION NEXUS IN INDIA'S AGRICULTURE OF POLICY INTEREST?

The Indian policy discourse on the most suitable mode of agricultural electricity tariff has come full circle. Until the early 1970s, all state electricity boards (SEBs) charged their tubewell owners based on metered consumption. However, as the number of tubewells increased manifold during the 1970s and the 1980s, the SEBs found the transaction costs of metering to be prohibitively high as compared to the total revenue generated from the agricultural sector. In response, during the 1970s and 1980s most states introduced flat tariffs for agricultural electricity supply (Shah et al. 2007).

While this solution lowered the transaction costs of bill collection, it resulted in a set of still graver problems affecting both the electricity and the groundwater sectors. For one, many state governments soon started using the electricity tariff as an electoral tool of appeasement and hence the flat tariffs remained perpetually low (Dubash & Rajan 2001). This resulted in losses to the SEBs estimated at around Rs. 270 billion per year in 2001(World Bank, 2002) and is estimated to have risen Rs. 320 billion in 2008 – part of which was expected to be paid from a subsidy of Rs.190 billion for supply to agriculture. Unmetered electricity supply also became a convenient garb for the SEBs to hide their inefficiencies in terms of transmission and distribution losses (Sant & Dixit, 1996). Over time, the SEBs came to treat their agricultural consumers as a liability. As a result, quality of power in rural areas deteriorated and some states like Bihar, Orissa and West Bengal saw 'de-electrification' (Mukherjee, 2008) and stagnation in agricultural electricity consumption[i] In other states, where electricity consumption in agriculture grew over time (Gujarat, Andhra Pradesh, Punjab, Haryana, Tamil Nadu), the number of hours of electricity supply came down from 18-20 hours in the 1980s to as low as 6-10 hours in the 2000s. Rationing, that too of low quality electricity, soon became the norm.

There were equally serious implications for the groundwater sector. Since the marginal cost of extracting groundwater was close to zero, it provided incentive for over-pumping. In many areas this spawned active groundwater markets. These markets emerged in response to unmet demand for irrigation and the flat tariff system. However, in arid and semi-arid regions with hard rock aquifers, flat tariff was directly responsible for over-pumping and, given the low recharge potential of these aquifers, water tables declined sharply. This in turn put in jeopardy the livelihoods of millions of poor farmers dependent on groundwater irrigation (Moench, 2007). In contrast, in areas of abundant rainfall and rich alluvial aquifers with adequate recharge during the monsoon season, such as in West Bengal, Bihar, eastern Uttar Pradesh and Assam (Mukherji 2007a and 2007b); the flat tariff system has not yet resulted in declining groundwater tables (author's analysis based on SWID data) but there is clearly no cost to overusing water irrigation either.

Low flat tariff and the resulting electricity subsidy have also been criticized from an equity perspective because much of the agricultural electricity subsidy goes to the rural rich who own a major proportion of the water extraction mechanisms (WEMs) fitted with electric pumps (Howes & Murgai, 2003; World Bank, 2002).

However, under a scenario of active groundwater markets, it is not the landholding size of the pump owners that matters, what matters more is the total command area of the tubewell including the area of the water buyers. Recent work has shown that informal groundwater markets are indeed an all-encompassing feature in Indian agriculture and as much as 20 million ha land may be irrigated through these markets (Mukherji, 2008a). In most cases these markets also had beneficial impacts on water buyers (Shah 1993, Palmer-Jones 2001).

However, the main drawback of the flat tariff system has been the total lack of energy accounting, with the result that there is hardly any accurate estimate of the total electricity consumed by the agricultural sector, with the result that these estimates vary widely from 30 to 50%. This creates uncertainty in subsidy calculations – subsidy that is often provided to electricity utilities by the state government for providing electricity to farmers either free of cost (as in Punjab, Haryana, Karnataka) or at highly subsidized rates as in most other states, though not in West Bengal. The problems facing the electricity sector due to unmetered supply to agriculture and consequent lack of incentives among farmers to make efficient use of electricity and among the utilities to do robust energy accounting is now widely acknowledged and is at top of the policy agenda (Planning Commission, 12th Plan Strategy Challenges http://12thplan.gov.in/forum_description.php?f=14).

2.2 METERING IN WEST BENGAL AGAINST THE BACKDROP OF THE ELECTRICITY ACT OF 2003

In view of several criticisms of flat tariff and unmetered supply to agriculture, there was and still is growing pressure from the government of India and the international donor agencies such as the World Bank and the Asian Development Bank (ADB) to revert to metering of agricultural electricity supply. This is also articulated in the Electricity Act of 2003 which states that: “No licensee shall supply electricity, after the expiry of two years from the appointed date, except through installation of a correct meter in accordance with the regulations to be made in this behalf by the Authority” (Electricity Act 2003, Article 55 (1)).

While the donor agencies and the Government of India (GOI) are pushing hard for metering, there are very few takers for universal metering. The state of West Bengal is an exception in this regard. As per a memorandum of understanding signed between the GOI and Government of West Bengal (GoWB) in 2000, the state government has agreed to universal metering of consumers (http://powermin.nic.in). In view of this, metering of agricultural consumers started in 2007 and by March 2011, over 90% of the state’s 1.1 lakh electric tubewells had been metered (personal communication with Chairman and Managing Director of West Bengal State Electricity Distribution Company Ltd. WBSEDCL in March 2011).

The purpose of this paper is to understand the impact of metering on pump owners and water buyers and on the overall operation of the groundwater economy in the state.

2.3 HOW ELECTRICITY TARIFF POLICY INFLUENCES INFORMAL WATER MARKETS

While there are several other papers (Singh and Singh 2004; Jacoby et al 2004, Kajisa and Sakurai 2005; Banerji et al. 2011 to name but a few) that examine various aspects of functioning of groundwater markets in India, including its spread, extent, functioning and efficiency and equity impacts, there are relatively few papers that look at the impact of electricity tariff policy on the functioning of these markets. Shah’s (1993) work on groundwater markets in India was the first to point out that high and rational flat tariff encourages pro-active water selling by pump owners and leads to a creation of fairly competitive and equitable markets. In particular, he showed that after change in tariff from metered to flat rate in 1987 in Gujarat, water markets expanded rapidly and small and marginal farmers benefitted. However, it also led to groundwater over-exploitation in places like North Gujarat. In view of rapid pace of groundwater over-exploitation, Shah et al. (2007) proposed intelligent rationing of electricity supply to meet peak crop demand. This recommendation was later adopted by the government of Gujarat which undertook feeder segregation and started supplying 8 hours of high quality electricity to agriculture and 24 hours of electricity to rural domestic sector. Shah and Verma (200*) did a qualitative impact assessment of the program and found that while pump owners had benefitted due to better and reliable electricity supply, water buyers and sharecroppers did not fare as well and had to exit these markets. Mukherji (2007) looked at functioning of groundwater markets in West Bengal and explained how the motive power of pumps (diesel vs. electricity) affects outcomes in state's water markets. High flat tariff and the compulsion on part of the electric pump owner to recover the electricity bill through water selling led to the emergence of highly competitive markets with positive equity impacts. As mentioned earlier, West Bengal started the process of metering of tubewells in 2007. Immediately afterwards, in 2008, Mukherji et al. (2009) undertook an exploratory fieldwork and tried to assess the likely impact of metering on pump owners, water buyers and groundwater markets. In this ex-ante assessment based on survey data and qualitative fieldwork, they found that in the immediate aftermath of metering, water prices had gone up by 30-50% and pump owners were less likely to sell water than before. However, none of the studies mentioned above involved a rigorous evaluation of impact of metering on groundwater use. To the best of our knowledge, this is the first study of its kind that uses panel data and difference in difference estimates to measure the impact of metering on a number of outcome variables of interest.

2.4 ROLE OF GROUNDWATER IN AGRARIAN GROWTH STORY OF WEST BENGAL

Why is groundwater irrigation of concern in West Bengal and why should we be studying the impact of metering of tubewells? This is because of two reasons. First, as already mentioned in the previous section, majority of farming households in West Bengal get access to irrigation through informal groundwater markets where they purchase water from their neighbours. Functioning of water markets is profoundly influenced by electricity tariffs and diesel prices (Mukherji, 2007). Second, groundwater played an important role in agrarian transition in Bengal.

Agrarian growth in Bengal and its slowdown is well documented. Briefly, the story of this growth may be captured in three distinct phases – the first from 1900 to 1980 tells a sad tale of "hunger in a fertile land" (Boyce 1987:1), the second (1981 - early 1990s) a triumphant account of a rate of foodgrain production that was "highest among 17 major states of the Indian union" (Saha & Swaminathan 1994:A2) and the third of agricultural growth that "significantly slowed down in the 1990s" (Sarkar 2006:342).

Boyce in his seminal work captured the dynamics of the first phase when the proverbial '*Sonar Bangla*'[1] that once abounded "with every necessary (*sic*) of life" (Bernier 1914 quoted in Boyce 1987:4) became the abode of some of the poorest people in the world. This paradox of hunger amidst plenty was explained by him and other scholars in terms regressive agrarian structure and high rural inequality that prevented unleashing of technological improvements in the production frontier. In particular he recognised water control as the key input that could propel the agricultural economy of the region on an upward spiral and noted that development of private groundwater irrigation was hampered due to small and fragmented land holdings and sharp rural inequalities.

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[1] *Sonar Bangla* translates into 'golden Bengal'. It refers to the once famed prosperity of Bengal in general and fields overflowing with golden ripe paddy in particular.

Just as Boyce's book was published in 1987, there were telltale signs of a quiet Green Revolution going on in rural Bengal. An unprecedented growth in the agricultural sector at the rate of 6.5 percent per annum[2] was recorded during the period 1981 to 1991 (Saha and Swaminathan 1994). Enhanced agricultural growth and productivity in West Bengal in 1980s was sought to be explained in terms of two very opposing arguments – that of "agrarian structure" (Lieten 1988, 1990 & 1992, Dasgupta 1995, Sen and Sengupta 1995, Ghatak 1995, Banerjee et al. 2002, Saha and Swaminathan 1994, Mishra & Rawal 2002, GoWB 1995-96 & 2004) and "market and technology" (Harriss 1993, Palmer-Jones 1995, 1999).

Harriss (1993) found that in his study villages in Bankura and Bardhaman, there was evidence of unprecedented growth that could be better explained in terms of development of groundwater irrigation rather than agrarian reforms. Expansion in area under *boro* cultivation, which is entirely an irrigated crop and increase in yield of all paddy crops (*aman, aus* and *boro*) due to assured groundwater irrigation from tubewells, 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'. But quite contrary to Boyce's claim that only public intervention or cooperative action could bring about groundwater development[3], Harriss found that groundwater irrigation expansion was taking place through private investment. He also found that farmers were able to overcome the scale problems arising from small and fragmented holdings by selling water to neighbouring farmers (water markets) and by leasing in land seasonally from their neighbours (changing agrarian relations). Palmer-Jones (1995) too noted that in the context of Bangladesh and 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 tubewells and the development of water markets) than with policies specifically designed and implemented to deal with the obstacles posed by the agrarian structure". Whatever be the exact pathway of this transformation, the fact remains that groundwater irrigation played a central role in agrarian change in West Bengal. Any policy that affects groundwater pumping behaviour of farmers in the state is therefore likely to be of key concern.

West Bengal's agrarian growth story is synonymous with rapid expansion in area under boro paddy cultivation in late 1980s and early 1990s. Boro paddy is an entirely irrigated crop and is largely irrigated using the state's ample groundwater resources. Boro paddy also has higher yields than more traditional varieties of paddy grown in kharif season (aman and aus paddy) and not prone to weather shocks and floods that often damage kharif crops. Given high yields, boro paddy is the crop of choice of farmers in Bengal (both West Bengal and Bangladesh).

3.0 THEORY OF CHANGE

Before delineating pathways to impact, it is useful to reiterate some stylized facts about the groundwater economy of West Bengal. First, water sales and purchases are common: thus farmers who pump groundwater, not only use it to irrigate their own fields, but also sell water to other farmers. Conversely, pump owners may also buy water from other pump owners given that land is highly fragmented. Farmers who buy water typically tend to have smaller land holdings and are often unable to install tubewells and pump sets [Banerji et. al., 2011; Mukherji, 2007], although fragmentation of land can also explain water transactions. In the pre-metering scenario, water buyers grew exactly the same crops as pump owners and this included water

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

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

intensive crops such as summer boro paddy, even if the magnitude of crop shares varied across pump owners and buyers. This meant, in the pre-metering scenario, not owning a pump did not preclude farmers from growing crops of their choice because of the availability of groundwater to purchase. Thus to the extent that a contraction in the number of hours pumped is seen disproportionately on water sales, this can have adverse implications for equity in access to groundwater resources. Also, as noted above, the increase in the importance of summer cultivation was enabled almost entirely through the use of groundwater; these are months which receive virtually no rainfall and surface water irrigation infrastructure in the state is relatively under-developed. It is possible therefore, that the impact of a change in pricing regime is felt disproportionately in the summer season.

3.1 PRIMARY IMPACT VARIABLES OF INTEREST

This implies that the primary impact variables of interest are:

- Total number of hours of groundwater pumped, by season. The hypothesis is that this would decrease, *particularly* in the summer season, where there are no alternatives to groundwater. In all our study villages, groundwater is the main and in most cases, the only source of irrigation. With inelastic demand, however, it could remain the same.
- Number of hours of groundwater used for irrigating one's own farm, by season. As argued below, this can either stay the same or decrease
- Number of hours of groundwater sold, by season. The expectation is that this would either decrease, or remain unchanged, depending on various factors as delineated in section 3.2.1 and 3.2.2.

We discuss a set of secondary impact variables subsequently but note here that the propositions developed below assume no change in extent of leasing-in or leasing-out of land.

As detailed later in Section 4, quantification of impact is made feasible through surveys conducted in 2004 and 2007 as part of other studies (Mukherji, 2007), which serve as a baseline, since the policy of metering of tubewells had not yet been initiated. A follow-up survey was conducted in 2010 revisiting the same villages and households, to create a panel data set for analysis. Since in 2010, metering had not been implemented in full, some of the baseline villages and households did not have metered tubewells, serving as a control.

This report thus computes difference-in-difference (DID) in key outcome variables using the panel generated by the repeat survey (2010) of the baseline villages and households (2004, 2007). Our primary finding, as set out below, is that the primary impact of metering (in the sense of being statistically significant) is seen in the boro season, in the form of reduced water use over all, as well as that sold and bought; any reduction in water use by other categories of farmers and in other seasons is insignificant. Since pump owners did not pay any per unit electricity price for pumping (the entire payment being a fixed annual charge) in the previous, pre-metering regime, whereas post-metering they pay a price per unit of electricity used (and no fixed charge), it is possible to explain reduced water sales by water buyers through simple models.

Before putting down two such models, it is useful to set out the other factors/variables that a switch to metering can affect in the boro season, even though the impact variable we focus on is water use and water purchased. These include the price at which water is sold, exclusion of some water buyers from the water market, post metering, changes in cropping pattern to less water intensive crops post metering, as well as the distribution of water sales at different times-of-day (and so at different electricity rates, as post metering, the unit rate of electricity is priced at differential peak and off peak rates). The last of these impacts can only be picked up in a first difference estimation, as there was no unit pricing of power pre-metering; so the models address these variables as well.

One potentially important consideration in putting down a model of water transactions is that for boro paddy, the water price is a per acre price for the entire season; it is not a price per unit volume or per unit time of pumping. The reason often given for this kind of price, pre-metering, was that paddy was too irrigation intensive for hours of pumping by a water buyer to be tracked; it was less costly to simply charge a price for the season, especially because absent a unit price of electricity, the marginal cost of selling water was close to zero. But, pricing water in this way, using a price for use over the entire season, has not changed post metering. Our qualitative survey of key informants in each village revealed that post metering, apart from an increase in price, sellers now demanded payment at the beginning of the season, rather than after the harvest under the old regime, but there was otherwise no change in the terms of the contract per se.

It is possible that this price per season is simply a reflection of an implicit per unit (volume or hours of pumping) price, multiplied by an implicitly agreed volume/hours of water purchased. This will be one of our benchmarks. But it is also possible that a price per season per acre is used as an instrument for the water seller to directly share the surplus generated by the water buyer's cultivation. This is our second benchmark.

In this report, the water-price determination models we describe are cast in the simplest setting of a single pump owner who cultivates as well as sells water, and a single water buying farmer; (the existence of multiple buyers for this single seller is not too different). It is either not profitable for the water buyer to invest in a tubewell and pump of his own (due to small landholding, say), or low wealth and a borrowing constraint prevents him from doing so. We also abstract away from the possibility that one of these farmers can lease or buy the other farmer's land. In the first model below, we assume that the water price is de facto a per unit volume price, (and it is customary to aggregate this up to a price for water use over the entire season).

3.2.1 BENCHMARK 1: WATER PRICE PER UNIT VOLUME

Pre Metering: We abstract away from productive inputs other than water. The value of output from a volume w of water equals bf(w) for the water buying farmer, where f is twice continuously differentiable, with f' > 0, f'' < 0, $f'(x) \to \infty \; as \; x \to 0$. Also assume that $f'(x)$ becomes equal to zero at some x. We interpret b as the price of output multiplied by a parameter capturing productivity or land size. Assume that the water selling farmer (Farmer S) has some monopoly power, and offers a water price p to the water buyer (Farmer B). Then Farmer B chooses w to maximize profit bf(w) – pw. Let *D(p)* be the interior optimum water demand that solves this problem. So, $D(p) = f'^{-1}(p/b)$.

Farmer S, who has some monopoly power, chooses the water price p and the volume of water w_s to administer to his own land, to maximize $sf(w_s) + pD(p) - F$, where F is the fixed payment for electricity use that Farmer S pays. This expression for profit assumes for simplicity that pre-metering, the marginal cost of water extraction is zero (as the unit price of electricity is zero). So, w_s is chosen to set the marginal product of water (MPW) to zero; let this amount equal w_s^0. Separately, p is chosen to maximize pD(p). We assume that water demand is not too convex, so the solution to the first order condition $pD'(p) + D(p) = 0$ characterizes the monopoly price; let this price equal p_0. Clearly, this monopoly price is strictly positive. So, the water buyer gets less water relative to the water seller's own land (per unit of land or land productivity), but the volume of water bought can be large, since the marginal cost of providing it is zero.

Post Metering: The unit price of electricity translates into a unit cost c of water extraction. There is no fixed cost for electricity use that Farmer S has to pay. The positive unit cost of water extraction incurred by the water seller, Farmer S, also implies that monitoring the volume of sale/hours of pumping becomes important. Thus the following appears to be a reasonable assumption.

Monitoring Assumption: Selling water to a water buyer involves a monitoring cost m for the water seller. The magnitude of m may depend on the unit price of electricity, and the crop cultivated by the water buyer. In a setting with multiple buyers, the monitoring cost would increase with the number of buyers. A simple way of incorporating this case is to simply interpret m as the monitoring cost *per* buyer.

The water buyer's water demand function is still D(p); however, the water seller's problem post metering changes to:

$$Max_{w_s,p} \quad sf(w_s) - cw_s + (p-c)D(p) - m \, .$$

Here, for simplicity, we assume that the cost of monitoring, m, does not depend on c. Let the optimal choices be w_s^1, p_1. Note first that if

$$(p_1 - c)D(p_1) < m \tag{1}$$

then Farmer S will in fact not sell any water to Farmer B. This has the following implications. (i) Using an Envelope Theorem, it is easy to see that a low enough b, and high enough c and elasticity of demand for water (corresponding to a low markup $p_1 - c$), can result in Farmer B being excluded from the water market post metering. (ii) A low b corresponds to small landholding: thus smallholders are more likely to be excluded from the water market. (iii) A low monopoly markup can correspond to a higher level of competition in the water market; thus it is possible to get the somewhat counterintuitive result that small farmers that were water buyers pre-metering are more likely to get excluded from the water market post metering if the water market is *less* monopolistic. (iv) The electricity rate post metering varies across the day, with high rates at 'peak' times and low off-peak rates. From (i), it follows that smallholder water buyers are more likely to get water at off-peak times, when the electricity rate, and the corresponding unit cost of water extraction, is low. (v) If the cost of monitoring is less for less water intensive crops, we may also see a switch in cropping patterns for water buyers.

If it is optimal for the water seller to sell water, we get the standard result that the water price is a markup on the unit cost c of water extraction; so the water price post-metering is higher, and water usage is lower (both for water buyer as well as for the water seller's own land). We collect these conclusions as an informal Proposition.

Proposition 1. Under the Benchmark Model 1, post metering:

(a) The water seller may exclude the water buyer from purchasing water under any of the following conditions: (i) the buyer's landholding is too small; (ii) the time of day electricity rate is too high; (iii) the monopoly markup is too low; (iv) the water buyer's crop is too water intensive, making the cost of monitoring water use too high.

(b) The water seller's own water use contracts; if the water buyer does get water, the water price is higher post metering and water sales are lower. Profits are lower for the water buyer; for the water seller, the direction of change of profit is ambiguous, since post metering there is no fixed payment for electricity use.

Four implications of the Proposition that bear upon the results discussed in Section 7 are worth isolating here. (i) First, despite the possibility of exclusion of water buyers post metering, the Proposition also implies that if the unit price of electricity is low (off peak), and landholding is sufficient, exclusion will not happen. The data show that in fact 80% of pumping takes place in the off peak hours, when the unit price of electricity is low. Since Boro paddy can be irrigated in the off peak, night hours, and is the mainstay of the summer season, the impact of metering is mitigated[4]. (ii) Second, it is possible for pump owners own-farm irrigation hours to decline more than sold hours. This depends on changes in curvature of crop output response to water; pre-metering, the unit cost of irrigation was near zero for pump owners (but not so for buyers if the water market is monopolistic); if the marginal product of water declines only very gradually to zero, this would have led to large amounts of own-farm irrigation by pump owners. Post metering, there could be significant contraction in this component of irrigation, owing to positive marginal cost of irrigation. (iii) Third, contraction in water use may also not be so much as to affect output significantly: this can happen if pre metering, there was overuse of water relative to the agronomic requirement for boro paddy. This dovetails with point (ii) above. (iv). Finally, water use may decline across the board, in control as well as treatment areas, if some relevant parameter such as the relative price of Boro paddy changes. This is captured in the above model by changes in the parameters *b* and *s* for water buyer and water seller.

3.2.2 BENCHMARK 2: WATER PRICE FOR ENTIRE SEASON

In the second benchmark model, we assume that Farmer S charges a water price P for water use for the entire season. If this is a take-it-or-leave-it offer, then he can choose it to extract the entire surplus from cultivation obtained by Farmer B. Since this is unrealistic, we assume that the level of P is instead arrived at as a surplus-sharing arrangement. To keep things at the simplest, we assume that it is part of a symmetric Nash Bargaining solution.

Pre Metering: The Nash Bargaining solution quantities of water use on Farmer S's and Farmer B's lands are efficient, as they solve

$$Max_{w_s, w_b}\ sf(w_s) + P - F$$

subject to $bf(w_b) - P \geq \overline{\pi}$.

Efficiency can be seen from the fact that the constraint will bind; using this to substitute for P in the objective, we see that w_s, w_b are chosen to equate marginal value products of water on the farms to the zero unit cost of water extraction. Let these efficient water volumes be called w_{sN}^0, w_{bN}^0, (the N in the subscript being 'Nash Bargaining'; and the superscript referring to pre-metering). For the determination of *P*, assume that in the absence of a negotiated water agreement, the water buyer's land will fetch zero output and profit; and the water seller will not get any income from water sales, and will be restricted to the maximum profit from cultivating his own land, minus the fixed electricity cost F that he must pay regardless of whether he sells water or not. Using these as threat points, the Nash Bargaining solution P solves

$$Max_P (P - F - (-F))(bf(w_{bN}^0) - P) .$$

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[4] Other crops, such as potato, are much less tolerant to irrigation in the night.

So, we get $P_0 = bf(w_{bN}^0)/2$. The agreed price shares the water buyer's revenue equally with the water seller.

Post Metering: The Nash Bargaining water volumes on the farmers' lands are again efficient, equating marginal value products to the positive unit cost c of water extraction. Call these water volumes w_{sN}^1, w_{bN}^1. They solve the following problem:

$$Max_{w_s, w_b} \quad sf(w_s) - cw_s + P - cw_b - m$$

subject to $bf(w_b) - P \geq \overline{\pi}$, where m is the cost of monitoring water use, when metering is introduced. For determining the water price that is part of the Nash Bargaining solution, note that the price *P* must satisfy $bf(w_{bN}^1) \geq P \geq cw_{bN}^1 + m$. These inequalities make the transaction profitable for the water buyer and the water seller respectively. So, for the setting to be non vacuous, we need that m be small enough to satisfy the inequality below:

$$bf(w_{bN}^1) - cw_{bN}^1 \geq m \tag{2}$$

So, as in Benchmark Model 1, if the cost of monitoring m is large enough to violate equation (2), the water buyer gets excluded from purchasing water. Also, exclusion can happen if the unit price of electricity, as reflected in the unit cost of water extraction c, is too large, or if the landholding, as reflected in b, is too small. A comparison of equation (2) with equation (1) shows, however, that since water use by the buyer under Nash Bargaining is at its efficient level, the possibility of exclusion is less stringent under Nash Bargaining. (Specifically, in comparing the 2 equations, note that $bf(w_{bN}^1) > bf(w_b^1) > p_1 w_b^1$).

Suppose equation (2) holds, so the water buyer is not excluded from the water market. Then the water price P_1 that is part of the Nash Bargaining solution is a solution to

$Max \quad (P - cw_{bN}^1 - m)(bf(w_{bN}^1) - P)$, over the feasible set

$$\{P \mid P \in [cw_{bN}^1 + m, bf(w_{bN}^1)]\}.$$

Thus if the solution is in the interior, then $P_1 = (bf(w_{bN}^1) + cw_{bN}^1 + m)/2$. That is, the agreed price results in sharing of the water buyer's revenue and the water seller's cost of water extraction for the buyer, and the cost of monitoring. Alternatively, P_1 could be on the boundary of the feasible set. Comparing the expressions for the interior P_1 and the pre-metering water price P_0, we see that even though the water buyer's revenue is lower post metering, the water price is likely to be larger, since the buyer must share the seller's costs of the transaction.

We therefore have the following informal proposition.

Proposition 2: Under the Benchmark Model 2, post metering:

(a) The water seller may exclude the water buyer from purchasing water under any of the following conditions: (i) the buyer's landholding is too small; (ii) the time of day electricity rate is too high; (iii) the water buyer's crop is too water intensive, making the cost of monitoring water use too high.

(b) The water seller's own water use contracts; if the water buyer does get water, the water price is likely to be higher post metering and water sales are lower. Profits are lower for the water buyer; for the water seller, the direction of change of profit is ambiguous.

Note that in Model 2, the irrigation volumes for both water buyers and pump owner sellers who cultivate, are efficient. In this case, one would expect a more symmetric contraction in water use by buyers and sellers alike (if monitoring costs are insignificant), post metering, than in the monopoly Model 1, where the marginal cost of irrigation can be much more asymmetric especially pre-metering (see point (ii) in the remarks on implications, following Proposition 1).

There can be other ways in which farmers adapt to a change in the pricing regime. First, it is possible, cropping patterns may shift: this can happen across seasons; that is, there is a decline in the share of area cultivated in the summer season with a corresponding increase in the share of area cultivated in the rabi season. Cropping patterns may also shift within a season, away from more water intensive crops (in the case of West Bengal agriculture, paddy). Thus DID estimates were computed for these secondary impact variables:

- Share of total operational holding (aggregated across three seasons) accounted for by the summer season
- Share of total and summer area accounted for by paddy
- Paddy output, particularly in the boro season.

4.0 EVALUATION DESIGN

The evaluation design takes advantage of surveys conducted prior to the introduction of the power pricing reforms, when flat-rate electricity pricing prevailed (see Mukherji, 2007). These surveys were conducted in 2004 and 2007. The 2004 survey covered 40 villages in 14 districts and interviewed 580 respondents including pump owners and water buyers. The 2007 survey covered 15 villages in 5 districts and interviewed 155 respondents. Since the roll out of the metering was staggered, and only 70% completed by 2010, this provided a unique natural experiment setting to examine the impact of the metering on the set of impact variables described above. Through the resurvey in 2010 (funded by 3ie) which involved revisiting the same households and villages in 2010, it was in principle possible to use a difference-in-differences framework to analyze impact.

4.1 THE ROLL OUT OF METERING

Our identification strategy can clearly fail if there were systematic patterns to roll out of the metering. As described below the way in which the metering was in fact accomplished provided us at least two ways to identify impact: the identification strategy exploits both geographic and farmer-specific variations in the rollout. In particular, the staggered and largely (but not entirely) non-systematic patterns of geographic coverage enabled us to define whether or not a village was metered; thus one of our treatment variables is defined at the village level. (In two villages, some farmers had meters while others did not; we allocated these villages to the treatment group). Furthermore, because one of the firms entrusted with providing meters often installed defective or non-operational meters, this provided yet another path to identification: it was possible for us to allocate *farmers* as belonging to either treatment or control groups depending on whether or not meters were installed *and* they received a bill based on unit pricing.

As noted earlier, metering of agricultural tubewells started in 2007. Two private firms, whom we shall call M/s T and M/s H were given the contract of metering nearly one hundred thousand electric tubewells in the state and each roughly got a contract of metering 50,000 tubewells each. These two firms were assigned Electricity Supply (ES)offices—the lowest supply unit of WBSEDCL where they were required to install meters on agricultural tubewells and then also carry out meter readings on behalf of WBSEDCL. While this was not randomized per se, M/s H and M/s T got ES assigned from within the same district with similar hydrogeological and cropping pattern conditions. The rollout of metering happened unevenly, one company M/s T went about completing its task faster and by 2009, they had installed meters in over 45,000 tubewells (or roughly 90%) in their assigned Electricity Supply offices. These meters were also of good quality and were functional during our study. The other company M/s H faced several quality related issues in their implementation and this slowed down their overall progress in installing meters. Till 2009, they were able to install only 60% of the meters that they were assigned to do. In addition, over 20% of the M/s H meters malfunctioned and here WBSEDCL had to revert to flat tariff (personal communication with CMD, WBSEDCL). Thus although two companies were entrusted with the task of installing meters by WBSEDCL, one of them was slower in its implementation process and also had a high rate of defective meters installed.

By the time of the survey, nearly all districts of the baseline survey contained both metered and unmetered villages. One significant exception was that were there was near-complete metering in North 24 Parganas and Nadia districts, implying that there would be a high probability that most of our sample villages in these two districts would fall under the treament group. Also, coverage of metering was relatively low in Murshidabad and Birbhum so that it was likely that a high proportion of our control villages could be drawn from the districts of Murshidabad and Birbhum. As indicated in table 2, The number of control and treatment village per stratum was unbalanced in the electric tubewell (10 treatment and 4 control villages) but reasonably balanced in the second stratum (12 treatment and 10 control villages in the old alluvium zone).

Even within treated villages, some meters that had been installed did not function as they were faulty; as noted earlier, this was a particular problem with M/s H. As a consequence these farmers continue to pay for electricity on a flat rate basis. The number of farmers, then, from among those surveyed in the baseline, who did and did not have functioning meters thus became yet another way to distinguish control and treatment groups. Key to this allocation is the fact that the distribution of faulty meters, though a function of the metering company, was not related to impact variables of interest. Thus, we defined two further ways of allocating the baseline sample to treatment and control groups: first, farmers who received a metered bill in 2009/10 were assigned to the treatment group, while those who did not (either because their meters were faulty, or had not yet been installed) were assigned to the control group.   This translates into sample sizes of 126 for treatment and 57 for control, as presented in Table 3, with once again a greater degree of balance between control and treatment groups seen between the two strata.

Second, given substantial increase in coverage of metering between the crop year 2008/9 and 2009/10, the survey instrument canvassed information for both crop years in order to enhance our chances of finding equal numbers of control and treatment groups from among the baseline villages. Although there is likely to be recall bias in using 2008/9 as the basis for comparing outcomes, given that these are unlikely to be systematically different across treatment and control villages, these biases should be washed out in the double difference. Thus farmers who reported receiving a metered bill in the previous year (2008/9) were allocated to the treatment group, while those who did not, were allocated to the control group. As expected, this resulted in fewer treatment farmers (117) and greater control farmers (70) (Table 4).

Thus three different treatment definitions were used: at the village level, at the farmer level in 2009/10 and at the farmer level in 2008/9. In the rest of this report, we present estimates based on the village-level treatment as this is based on the largest sample size, corresponding estimates based on the farmer-level treatment are presented in Appendix Table A.

5.0 SAMPLING DESIGN AND POWER CALCULATIONS

5.1 SAMPLING DESIGN IN BASELINE AND ENDLINE SURVEYS

In the baseline survey, the main objective was to characterize the nature and functioning of groundwater markets in West Bengal. It is widely recognized that geo-hydrological factors (such as type of aquifers, depth of water table below ground level) affect the functioning of water markets. Therefore, the first step of the sampling strategy was to collect location and hydrogeological data of 764 observation wells that is regularly monitored by the Central Groundwater Board (CGWB) in West Bengal. These 764 villages from which CGWB collected groundwater data became the universe from which our sample villages were chosen. The number of sample villages was chosen in proportion to the net withdrawal of groundwater resources per unit of net cultivated area. This meant higher the utilization of groundwater per unit area of cultivable land in a district, the more the number of sample villages from it. As a rule of thumb, one village to a district was assigned for every 500 m^3 of water extraction per hectare of NCA.   For selecting the villages, a number was assigned to each village in a district and then through random number generation, requisite number of villages in each district was chosen.

In each village, two distinct sets of farmers were surveyed: those who owned a tubewell and pumped water (whether or not they sold it); and those who only bought water. It was unfortunately not possible to map all the buyers per seller, so a complete matching exercise between sellers and buyers could not be undertaken. Therefore estimates of the number of hours sold by water sellers need not be (and are not) identical to estimates of the numbers of hours of irrigation water purchased by buyers.

The definition of treatment and control groups at the farmer level did raise concerns about whether the sample sizes would be adequate for detecting differences in the key impact variables. Based on variances calculated using the baseline data, our initial power calculations suggested that even though the size of the control and treatment groups is unbalanced, the sample size numbers for 2008/9 would be adequately powered to detect an effect size of a hypothesized *20% decrease* in irrigation pumping hours and sales. As it transpired, there was a secular decline in hours of groundwater pumping and sales between the baseline and follow-up, swamping a treatment effect which was much smaller in comparison, the only exception being the summer season where a significant effect could be discerned.

The sample sizes in the village-level allocation were much larger, but unbalanced especially in the new alluvium zone. However, as a back-up strategy in case we were underpowered to detect impact we also augmented the baseline villages so that first-difference estimates of impact (using matching techniques) could be computed. In selecting these augmented villages, we purposively oversampled from control villages in the new alluvium zone, so as to ensure a better balance in the distribution of villages across between control and treatment groups. Thus, a total of 18 new villages were surveyed, so that a total of 54 (36 baseline plus 18 augmented) villages were surveyed in all in 2011. The distribution of the sample villages, across those surveyed in the baseline and those augmented in 2010 is presented in Table 2. In all, 857 respondents in these 54 villages were canvassed.

5.2 ATTRITION

The augmentation also served as a guard against attrition since nearly six years had elapsed since the first baseline, and there were concerns that there might by high rates of attrition. As it transpired, attrition was extremely low. Enumerators were instructed that in cases where they could not find the original respondent, that they should attempt to find another family member who was engaged in the cultivation and water use decisions for the same plot as that surveyed in the baseline. We also relied on two of the enumerators from the previous survey as scouts during the followup. Of the 521 respondents interviewed in the baseline, we were able to re-interview 427 of them, in 82 cases, we interviewed a family member who was cultivating the same plots in the baseline, and in 12 cases, we could not find the respondent at all. Thus even if one were to restrict attention to the sample of 521 respondents (out of the 857 interviewed overall), bias due to attrition would appear not to be a problem for our sample. All the estimates of impact presented in this report therefore do *not* account for attrition bias.

6.0 DATA COLLECTION

The baseline data from 2004 and 2007 were available before the start of the survey, so lists of farmers, their father's name and their localities and addresses within the villages could be prepared. A team of scouts preceded the enumerators' team to track down the original respondents and to schedule appointments for the main survey. The field work started on 24 July 2010, and was completed over a two month period. The 54 villages were located in two major hydro-ecological zones in West Bengal, namely the Old (Hugli, Bankura and Bardhhaman and one part of Murshidabad district) and the New Alluvium zones (Nadia, N. 24 Parganas and another part of Murshidabad district). A notable feature of the data collection was the use of PDAs to capture informant information; this facilitated immediate cross-checks and call backs.

The survey instrument consisted of six modules: the first canvassed information on the agricultural household, including the number of earning members, details of land-holding (owned, leased-in, leased-out) by season, and cropping patterns. The second part focused on crop economics, in the expectation that it could inform how the production technology influenced input use, and in particular any substitutions induced by the changed pricing regime. Since the pitfalls of estimating production functions using a single cross section are well known, we also canvassed information for the previous crop year, relying on recall. The third module dealt with details of wells and pump technology, with information on costs of installation and maintenance, on the hours of operation by season, and its break up by self-use versus sales. The fourth module focused on water sellers, and the terms under which water sales took place each season, and fifth module similarly obtained information from water buyers. As mentioned earlier, it was not possible to match buyers with the owners of the pumps from which they made their purchases. The sixth module attempted to deal qualitatively with issues related to service delivery—of irrigation equipment and also of complementary inputs. To the extent possible, we maintained the same definitions across the baseline and follow up.

7.0 RESULTS

7.1 COMPARABILITY OF TREATMENT AND CONTROL GROUPS IN THE BASELINE

Table 5 examines whether there are differences between the treatment and control groups of villages for several of the impact variables in the baseline. The standard errors are clustered and take into account the two strata, and the village clustering. It is clear that for nearly all the impact variables being considered, the difference between treatment and control villages in the baseline was insignificant, with the exception of the number of hours of irrigation pumped in the rabi season. However, rabi accounts for less than 10 percent of all the groundwater pumped, and therefore the lack of equality of means in this variable is not economically significant. Thus the ex-post randomization seems to have worked, at least in the sense that most of the key variables do not differ between control and treatment groups.

Moreover, the availability of the baseline survey enables difference-in-differences (DID) estimation, thereby alleviating any remaining selection bias in allocating villages/farmers to treatment. A remaining concern is that the sample sizes of control and treatment groups are unbalanced, with about two-thirds of farmers allocated to the latter; the implications of this are discussed briefly in the concluding section.

7.2 SECULAR DECLINE IN THE NUMBER OF IRRIGATION HOURS

Table 5 also highlights the substantial decreases in the total number of irrigation hours across *both* the treatment and control groups. This decrease is seen both in the number of hours used for irrigating own farms, as well as in the number of hours sold, with the decrease being slightly greater in the latter. Comparing across seasons, the summer season (which also accounts for the largest share of total irrigation hours) accounts for much of the decline. Thus the impact of metering needs to be understood in light of a *secular* decline in the number of irrigation hours pumped, used and sold, especially in the summer season. Interestingly, viewed from the buyers' perspective, the decrease in the number of hours purchased is not as large.

This appears to have been accompanied by a decrease in the area under cultivation (and under paddy in particular) between the baseline and endline surveys. To what extent is this credible? Data from the West Bengal government's Directorate of Agriculture suggests that in 2010 area under paddy declined in Bankura, North 24 Parganas, Nadia and Murshidabad districts as compared to previous years, while it remained the same in Hugli and increased in Bardhhaman. Another data source, using satellite images to estimate area, conducted by IWMI in the boro season suggests that although the overall boro area has increased, it did decrease between 2008 and 2010 in the districts of Bankura, North 24 Paraganas, Nadia and Murshidabad (Figure 1). These are, perhaps not-coincidentally, districts with a predominance of electric centrifugal (EC) and electric submersible (ES) pumps. EC pumps are mounted on the ground and can suck water from within a suction head of 30 feet while ES pumps are submerged below water and push water up through propulsion. Districts with a predominance of EC pumps are Nadia, North 24 Parganas and eastern half of Murshidabad district adjoining Nadia district. Districts with a predominance of ES pumps are western part of Murshidabad, Hugli, Bardhhaman and Bankura.

Farmers shift from EC to ES when water levels fall below 30 feet at any time of the year. Some farmers also shift to ES as a pre-emptive strategy. Given the different nature of pumping technology, our impact evaluation treats them as two independent categories. Also, as noted later, it is only for these pumping technologies that the impact of metering can be seen.

7.3. CALCULATING DOUBLE-DIFFERENCE ESTIMATES OF IMPACT

If the treatment villages saw a greater decrease in the number of hours pumped or sold, as compared to the control villages, this could be attributed to the impact of metering, independent of the secular decrease mentioned in the previous paragraph. To evaluate this, the following sets of regressions were run:

1. $\Delta Y_{ij} = \alpha + \beta V_j + \varepsilon$ where $\Delta Y_{ij} = Y_{ijf} - Y_{ijb}$ is the difference between the followup (f) and baseline (b) in the impact variable (Y) for the ith farmer in the jth village, and V is a dummy variable which takes value 1 if the jth village is a treatment village, and 0 if it is a control village. We label this the 'vtmt' treatment.

2. $\Delta Y_{ij} = \alpha + \beta V_j E_{ij}^{S,C} + \varepsilon$ where $\Delta Y_{ij} = Y_{ijf} - Y_{ijb}$ and V are as above, $E_{ij}^{S,C}$ and is a dummy variable which takes value 1 if ith farmer in the jth village had either an electric submersible or an electric centrifugal pump. We label this the 'vtmt*EC/ES' treatment
3. $\Delta Y_{ij} = \alpha + \beta V_j E_{ij}^{S} + \varepsilon$ where $\Delta Y_{ij} = Y_{ijf} - Y_{ijb}$ and V are as above, E_{ij}^{S} and is a dummy variable which takes value 1 if ith farmer in the jth village had an electric submersible pump. We label this the 'vtmt*ES' treatment.
4. $\Delta Y_{ij} = \alpha + \beta F_{ij9} + \varepsilon$ where $\Delta Y_{ij} = Y_{ijf} - Y_{ijb}$ is the difference between the followup (f) and baseline (b) in the impact variable (*Y*) for the ith farmer in the jth village, and *F* is a dummy variable which takes value 1 if the ith farmer in jth village received metered bills in 2009/10 (treatment), and 0 if he did not. We label this the 'f9tmt'treatment.
5. $\Delta Y_{ij} = \alpha + \beta F_{ij9} E_{ij}^{S} + \varepsilon$ where all the variables are as defined above; this examines whether farmers with electric submersible pumps who received metered bills had a significantly greater change in the impact variable than those who did not. We label this the 'f9tmt*ES'treatment.
6. $\Delta Y_{ij} = \alpha + \beta F_{ij8} + \varepsilon$ where $\Delta Y_{ij} = Y_{ijf} - Y_{ijb}$ is the difference between the followup (f) and baseline (b) in the impact variable (*Y*) for the ith farmer in the jth village, and *F* is a dummy variable which takes value 1 if the ith farmer in jth village received metered bills in 2008/9 (treatment), and 0 if he did not. This is the same specification as in #4 above, except the reference is to the receipt of metered bills in the previous (2008/9) crop year. We label this the 'f8tmt' treatment.
7. $\Delta Y_{ij} = \alpha + \beta F_{ij8} E_{ij}^{S} + \varepsilon$ where all the variables are as defined above, this is the same specification is #5 above, except the reference to receipt of metered bill is to crop year 2008/9. We label this the 'f8tmt*ES' treatment.

In all cases, the coefficient β represents the impact estimate, while ε refers to an error term where the farmer and location subscripts have been suppressed.

7.4 DID ESTIMATES FOR PRIMARY IMPACT VARIABLES (IRRIGATION HOURS PUMPED, SOLD AND BOUGHT, BY SEASON)

In table 6, we present impact estimates (the estimated β) pertaining to specifications, 2 and 3, for a range of impact variables. We relegate the impact estimates from the remaining formulations to Appendix table A, noting only in the text when a change in the impact measure is consistent (in direction if not magnitude) across treatment definitions, and when it is not.

Consider first the variables related to total pumping hours, and the allocation of hours pumped to self-irrigation and sales. None of the double difference impact estimates is significant at conventional levels, for formulation (2); the coefficient has a p-value of 22%. Thus at least as far as these aggregate figures are concerned, the metering appeared to have no impact. Note however, that all the signs are correct; it is therefore more accurate to say that the impact of the metering was overwhelmed by the decrease in irrigation pumping hours seen across the board.

When irrigation hours are examined by season, however, a different picture emerges. In the summer season, there is a statistically significant decrease in the number of irrigation hours among owners of electric pumpsets; this is also seen among owners of electric submersibles at a p-value of 0.20. Corroboration of a significant reduction in number of irrigation hours purchased is also seen among water buyers, but it is not statistically significant.

These results are consistent with the program theory outlined above which suggests

1. Reduction in pumping, both self and sold/bought, post metering; but the magnitude could be limited if the unit cost of electricity is low. This is so in off peak, and about 80% of pumping happens then. Also, for boro paddy cultivation, if summer acreage share falls over time as has happened in a large subset of our districts, this can dilute the treatment effect. Finally, if water demand is relatively inelastic (depends on cultivation technology). This last aspect remains a question for further research as the data can be used to estimate a production function.

2. Exclusion of especially smallholders from water buying, if the cost of monitoring water trades is significant. This is mitigated if unit cost of electricity is low; if water buyers not that small; and if there is secular decline in paddy cultivation in boro anyway (since that's water intensive cost with possibly high monitoring cost of water trading). It may also happen if trust at the village level reduces monitoring costs for a significant fraction of sellers and buyers.

7.5 DID ESTIMATES FOR SECONDARY IMPACT VARIABLES (CROPPING PATTERN AND PRODUCTIVITY)

It is of course possible that the adjustment to a changed tariff regime was felt though impact on cropping patterns, either by reducing reliance on boro cultivation with a corresponding increase in rabi shares, or a switch away from rice in the boro season. But the evidence in table 6 suggests otherwise: there was no statistically significant impact either on seasonal shares or on share of boro paddy.

At the same time, the decrease in water use in the boro season, and in sales in that season, has not adversely affected paddy output; the impact coefficient although negative, is not significant. This is not entirely unexpected and may be symptomatic of the overuse of water under a flat rate regime. In that case, pre metering, with zero unit cost of extraction for self irrigation, there may have been significant water 'overuse.' However, to the extent that buyers paid a markup price, there could not have been any overuse on buyers'plots. Thus post metering, with a positive unit cost of extraction, overuse by self irrigators could have been wiped out. By overuse we mean use of water beyond crop requirements; reduction would then show up as no significant decline in crop yield.

7.6 SINGLE DIFFERENCE IMPACT ESTIMATES

A noticeable feature of Tables 5 and Appendix Table A is the large number of correct negative signs, but p values that are considerably above 0.05. This could be an indication that the sample was, expost, not powered to detect impact, although we had used baseline figures to compute variances (but had assumed a 20% effect size in pumping hours). Even there, the variances of the pumping hours were high.

Since the follow up survey augmented the sample appreciably, it is possible that a first difference formulation, relying only on the follow up data may detect statistically significant impact, even though the advantages of using a panel data set, and the ability of the double-difference to wash out noise or systematic biases, is then lost.

Unmatched comparisons of means between control and treatment groups show however that there was no significant impact. Similarly, preliminary estimates of propensity-score matched comparisons of control and treatment groups shows that there was no difference in the hours pumped by pump owners by the control and treatment groups, irrespective of how the treatment group is specified, and despite conditioning on technology.

We do not present these estimates in a table, as these are still subject to further research, but an important issue related to the use of first-differences is the *interpretation* of the first stage equation in the propensity-score matching exercise, when the allocation of respondents to control and treatment groups is near random. Although the literature suggests that these first stage estimates not be given a behavioural interpretation, and merely to use them to match respondents from control and treatment groups, the meaning attached to the probability of adoption of metering, when the metering itself was randomly rolled out required further elaboration. This is currently still being investigated

8.0 CONCLUSIONS AND POLICY IMPLICATIONS

As far as the impact of the metering of tubewells is concerned, our major conclusion is that the expected impact was felt only in the boro season, which saw a greater reduction in pumping hours in the treatment groups as compared to the control groups. There is also some evidence that this decreased was not confined to irrigation on own-farm, but that water sales and purchases were also adversely affected as a consequence. Yet the metering did not influence either cropping patterns, or the output of boro paddy. The latter could well be explained by over use of water among those who irrigate their own farms, so that reductions in water use do not translate into decreased output. The impact was insignificant for all indicators in the kharif and rabi seasons. This result is not surprising given the overwhelming reliance of boro paddy on irrigation water. Evidence of decreased sales and purchases potentially has implications for equity, especially if small farmers are being driven out of the market completely. Yet their decreased access to water does not seem to have altered cropping patterns.

These impacts have to be seen against the backdrop of an overall decline in pumping hours that was seen in both control and treatment groups, which may have served to swamp the impact of the metering. The fact that many of the signs have the expected negative sign, but are insignificant, may mean that our sample was under-powered to detect impact (our power calculations did not account for these secular changes)[5]. It is useful to note also that the unbalanced sample sizes, with about two-thirds of farmers allocated to treatment, inflates the standard errors by about 12% to 15%. A balanced sample could lend significance at conventional levels to estimates that at present have P-values up to possibly 0.2. This interpretation reinforces the impression (see Table 6 and Appendix A) that metering caused a significant decline in hours pumped in the economically crucial summer season, but that there is less of a decline in hours sold and purchased; the insignificance of the decline in boro paddy output (conditional on metering) would remain, in all likelihood, even on this liberal interpretation.

Before drawing policy conclusions from these results, further analysis is necessary. Credible estimates of the elasticity of water demand (derived, say from a production function estimation facilitated by the availability of our panel dataset) may help validate or negate conclusions about water overuse on own farms by pump owners, prior to the intervention. It may also help in evaluating alternative policies on tariff levels and tariff structures, or policies that make it easier for those who are currently water buyers to invest in pumps, especially in areas that are ‘white’. We are also continuing to work on whether a different set of conditioning variables may help detect statistically significant impact in the larger set of impact variables. We expect to have defensible policy implications once these additional analyses are completed.

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[5] However, a simple comparison of (first-difference) means in the treatment and control groups using an augmented sample also does not reveal any statistically significant impact of metering either.

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TABLES AND FIGURES

Table 1: Time of the Day tariffs and flat tariffs in West Bengal, 2008-2011

	Metered Time of the Day (TOD) tariff			Unmetered (flat) tariff for a standard 5 HP pump	
Year	Normal Hours (06.00 a.m to 5.00 p.m) (In Paisa/unit)	Peak Hours(5.00 p.m to 11 p.m) (In Paisa/unit)	Off-peak Hours (11p.m to6 p.m) In Paisa/unit)	EC (in Rs/year)	ES in Rs/year)
2008-09	130	490	74	8800	10800
2009-10	140	510	79	8800	10800
2010-11	218	588	152	10736	13176

Source: West Bengal State Electricity Board State Electricity Company Limited

Table 2: Number of villages in treatment and control groups

Zone	**Village classification**	**Number of villages with meters in 2009 (Treatment)**	**Number of villages with no meters in 2009 (Control)**	**Both***	**Total**
New Alluvium Zone	Baseline	9	4	1	14
	Augmented	2	2	0	4
Old Alluvium Zone	Baseline	11	10	1	22
	Augmented	3	11	0	14

*These are villages with some households reporting meters, and others with none or non-functional meters. In the analysis these were categorized as metered (treatment) villages.

Table 3. Number of baseline farmers who did or did not receive metered bills

	2008/9		2009/10	
	Received	Did not receive	Received	Did not receive

	metered bills (Treatment)	metered bills (Control)	metered bills (Treatment)	metered bills (Control)
New Alluvium Zone	61	19	65	15
Old Alluvium Zone	52	51	61	42
Total	**113**	**70**	**126**	**57**

Table 4. Number of baseline and augmented villages surveyed in 2010

Hydrological Zone	District	Resurveyed from baseline	Augmented in 2010
New Alluvium Zone	North 24 Parganas	7	3
	Nadia	6	2
	Murshidabad—Bagri	3	2
Old Alluvium Zone	Bankura	4	2
	Bardhaman	6	2
	Hugli	7	5
	Murshidabad—Rarh	3	2
	Total	**36**	**18**

Table 5. Summary statistics, using village-level definitions treatment and control groups

	Baseline			*Followup*		
	Control	Treatment	p-value	Control	Treatment	p-value
Total hours pumped (hours)	761 (131)	833 (86)	0.65	442 (76)	596 (61)	0.14
Hours used for irrigating own	289 (68)	355 (37)	0.40	173 (33)	251 (27)	0.08

farm (hours)						
Hours sold (hours)	472 (106)	477 (80)	0.97	269 (53)	344 (47)	0.32
Hours pumped in Kharif 2009 (hours)	124 (36)	114 (24)	0.82	97 (20)	110 (12)	0.60
Hours pumped in Rabi 2009 (hours)	51 (12)	100 (21)	0.05	60 (16)	123 (26)	0.05
Hours pumped in Summer 2010 (hours)	586 (117)	619 (0.83)	0.82	284 (57)	362 (40)	0.28
Only buyers						
Total hours purchased (hours)	167 (36)	267 (50)	0.12	165 (25)	225 (36)	0.21
Hours purchased in summer 2010 (hours)	119 (30)	179 (32)	0.18	84 (17)	122 (15)	0.12
Secondary Impact Indicators						
Rabi share in overall cropping pattern	0.17	0.21	0.16	0.16	0.23	0.04
Summer share in overall cropping pattern	0.37	0.35	0.70	0.32	0.32	0.90
Boro paddy share in summer cultivated area	0.73	0.76	0.23	0.67	0.74	0.35

The p-values refer to a test of equality of means in the baseline (column 4) and followup (column 7).

Table 6. Difference-in-difference estimates of Impact, using village-level treatment

	Vtmt*Electric pumpset (a)	Vtmt*Electric submersible pumpset (b)
Impact on Pump Owners		
Total hours pumped	-232 (186) [0.22]	-51 (309) [0.87]
Hours used for irrigating own farm	-103 (71)	-101 (85)

	[0.16]	[0.25]
Hours sold	-128 (157) [0.42]	-152 (261) [0.56]
Hours pumped in Summer 2010	-309 (145) [0.04]	-316 (241) [0.20]
Hours used for irrigating own farm in Summer 2010	-118 (59) [0.06]	-18 (75) [0.82]
Hours sold in Summer 2010	-191 (131) [0.15]	-298 (217) [0.18]
Impact on Water Buyers		
Total hours purchased in 2009/10	-42 (51) [0.42]	-87 (65) [0.18]
Total hours purchased in summer 2010	-28 (40) [0.50]	- 63 (50) [0.22]
Secondary Impact Indicators		
Rabi share in overall cropping pattern	-0.01 (0.02) [0.53]	-0.004 (0.02) [0.82]
Summer share in overall cropping pattern	0.01 (0.02) [0.45]	0.01 (0.03) [0.80]
Boro paddy share in summer cultivated area	-0.04 (0.09) [0.66]	0.09 (0.09) [0.34]
Boro paddy output	-368 (621) [0.56]	-537 (918) [0.56]

Notes: Coefficients of regression of difference in impact variable between followup and baseline on

(a) Village-level treatment dummy interacted with ownership of either electric submersible or electric centrifugal pumpset (specification 2)
(b) Village-level treatment dummy interacted with ownership of electric submersible pumpset only (specification 3)

Figures in round brackets are standard errors, those in square brackets are p-values associated with its significance.

Appendix A. Difference-in-difference estimates of Impact (coefficient on impact/interaction variable), using alternative definitions of treatment

	Village was metered (Vtmt)	Farmer received metered bill in 2009/10 (F9tmt)	Farmer received metered bill in 2008/9 (F8tmt)	F9tmt*Electric submersible pumpset (F9tmt*ES)	F8tmt*Electric submersible pumpset (F8tmt*ES)
Impact on Pump Owners					
Total hours pumped	82 (122) [0.50]	188 (220) [0.40]	36 (239) [0.88]	140 (227) [0.54]	5 (291) [0.98]
Hours used for irrigating own farm	12 (61) [0.84]	-12 (101) [0.91]	-105 (100) [0.30]	158 (103) [0.14]	53 (135) [0.70]
Hours sold	70 (105) [0.51]	200 (185) [0.29]	141 (213) [0.51]	-18 (213) [0.94]	-48 (282) [0.17]
Hours pumped in Summer 2010	44 (99) [0.66]	86 (161) [0.60]	-55 (151) [0.72]	-145 (191) [0.45]	-277 (207) [0.19]
Hours used for	23 (63)	-14 (95)	-93 (73)	16 (87)	-71 (116)

irrigating own farm in Summer 2010	[0.72]	[0.88]	[0.22]	[0.86]	[0.54]
Hours sold in Summer 2010	21 (82) [0.80]	100 (118) [0.40]	38 (138) [0.78]	-161 (180) [0.38]	-206(218) [0.35]
Impact on Water Buyers					
Total hours purchased in 2009/10	-41 (51) [0.43]				
Total hours purchased in summer 2010	-22 (38) [0.57]				
Secondary Impact Indicators					
Rabi share in overall cropping pattern	0.02 (0.02) [0.40]	0.02 (0.02) [0.28]	0.03 (0.02) [0.19]	0.02 (0.02) [0.31]	0.03 (0.02) [0.22]
Summer share in overall cropping pattern	0.01 (0.03) [0.70]	0.004 (0.03) [0.88]	-0.02 (0.03) [0.53]	-0.01 (0.03) [0.69]	-0.03 (0.03) [0.38]
Boro paddy share in summer cultivated area	0.04 (0.07) [0.61]	-0.14 (0.13) [0.30]	-0.06 (0.13) [0.67]	0.02 (0.12) [0.88]	0.09 (0.11) [0.41]
Boro paddy output	-876 (649) [0.18]	-713 (794) [0.38]	-592 (1060) [0.58]	291 (955) [0.76]	-95 (1218) [0.94]

Coefficients of regression of difference in impact variable between followup and baseline on

(c) Village-level treatment dummy (column 2)
(d) Village-level treatment dummy interacted with ownership of either electric submersible or electric centrifugal pumpset
(e) Village-level treatment dummy interacted with ownership of either electric submersible pumpset only

Figures in round brackets are standard errors, those in square brackets are p-values associated with its significance.

Figure 1. Area under boro paddy in 2008 and 2010 using remotely sensed images