Impact Evaluation Report 4

Does marginal cost pricing of electricity affect groundwater pumping behaviour of farmers?

Evidence from India

JV Meenakshi, Abhijit Banerji, Aditi Mukherji and Anubhab Gupta

October 2013

International Initiative for Impact Evaluation

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Executive summary

The purpose of this 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 a 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. Program theory suggested that we should see a decline in pumping use overall, but the impact on water use on farms 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 that included changes in cropping patterns and crop output.

The quantification of impact was made feasible through surveys conducted in 2004 and 2007 as part of other studies (Mukherji 2007b; Mukherji *et al*. 2009) which served as a baseline; the policy of metering tube wells 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 tube wells, and thus these served as controls. 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.[1] There is also some evidence that this decrease was not confined to own-farm irrigation, but that water sales and purchases were also adversely affected as a consequence. Yet, metering did not influence either cropping patterns or the output of *boro* paddy. The latter could well be explained by the overuse 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*[2] and *rabi*[3] seasons. The evidence of decreased sales and purchases may have 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 metering. The fact that many of the signs have the expected negative sign, but are insignificant, may mean that our sample was underpowered to detect impact. Drawing policy implications from these impact results requires further analysis. We are currently modelling 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] The Bengali term *boro* originates from the Sanskrit word *Boro*, which refers to a cultivation from November–May under irrigated conditions.
[2] *Kharif* refers to crops sown in the rainy (monsoon) season in the Asian subcontinent.
[3] *Rabi* refers to agricultural crops sown in winter and harvested in the spring.

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1. Intervention, evaluation questions and policy relevance

1.1 The intervention: Metering of electric tube wells

The intervention for which we conducted this impact evaluation is metering agricultural tube wells in the Indian state of West Bengal. According to the fourth and latest minor irrigation census (Government of India 2011), the state has 519,000 groundwater-extracting mechanisms. These include dug wells, shallow tube wells and deep tube wells. Of these mechanisms, approximately 109,000 run on electricity (electric pumps, also called electric tube wells or bore wells) and the rest run on diesel, kerosene or a mix of both.

The West Bengal State Electricity Distribution Company initiated the process of metering electric tube wells in 2007. Until 2009–2010, it had completed metering of around 70 per cent of electric tube wells in the state. Of interest to us in this evaluation is the pumping behaviour of electric pump owners in the aftermath of metering electric tube wells. Why is the pumping behaviour of pump owners likely to change because of metering? Prior to metering tube wells, all electric tube well owners in the state were subject to a flat electricity tariff ranging from 8,800–10,800 Indian rupees (INR)[4] per year for a standard five horsepower 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 quantity of pumping was reflected in their electricity bills. Farmers whose tube wells have been metered are now subject to a time of the day tariff, while those whose tube wells have not yet been metered still continue to pay a flat tariff. Table 1 shows time of the day rates and flat tariff rates.

Table 1 Time of the day tariffs and flat tariffs in West Bengal, 2008–2011

	Metered time of the day tariff			**Unmetered (flat) tariff for a standard five horsepower pump**	
Year	**Normal hours: 6 a.m. – 5 p.m. (paisa per unit)**	**Peak hours: 5 p.m. – 11 p.m. (paisa per unit)**	**Off-peak hours: 11 p.m. – 6 a.m. (paisa per unit)**	**Electrical centrifugal pumps (EC) (INR per year)**	**Electrical submer-sible pumps (ES) (INR per year)**
2008–2009	130	490	74	8,800	10,800
2009–2010	140	510	79	8,800	10,800
2010–2011	218	588	152	10,736	13,176

Source: West Bengal State Electricity Board Company Limited

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 tube wells will have decreased. However, whether this is reflected in reduced water sales as well as reduced use on farms depends on a number of variables that are set out in the propositions developed in Section 3. 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 significant economic consequences: of the 6.1

[4] The average exchange rate for the period January 2004 to December 2007 was INR 43.92 per USD. The study uses baseline data from two rounds of survey in 2004 and 2007.

million farming households in West Bengal, only 1.1 million report owning wells and tube wells, while 4.6 million farming households report using irrigation (National Sample Survey Organisation 1999). Of these, 3.1 million households (or 50.4 per cent 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 agricultural tube wells in West Bengal on groundwater users (pump owners and water buyers) and informal groundwater markets. Our evaluation questions are:

How has the shift in policy from a flat-rate tariff to a metered tariff influenced the number of hours pumped and its breakdown between water used for irrigating the pump owner's farm versus sales? Are there seasonal patterns to this impact?

What have been the effects of this policy change on water buyers? In particular, how have volumes sold and bought changed as a consequence?

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 agricultural tube wells was implemented to achieve better energy audits, reduce transmission and distribution losses and improve collection rates. The primary beneficiaries are the West Bengal State Electricity Distribution Company and agricultural electricity consumers who have supposedly obtained better services since the reform. While the total cost of the reform is not available, the company has invested at least INR 1.1 billion in remotely readable electronic meters.[5]

West Bengal has about 100,000 electric pumps (NSSO 1999), and our survey suggests that each pump owner sells water to more than 10 on average (aggregated across seasons). Hence, more than one million farmers could have been 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 the cropping decisions of electric pump owners and their water buyers.

What is the relevance of the West Bengal metering intervention? Section 2 provides a brief review of the history of the energy–irrigation nexus in India's agricultural sector and its impact of groundwater markets. It also explains why metering tube wells is an important 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.

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[5] Sharma, A., 6 April 2006, Genus to sell meters for Bengal farms. *Business Standard*, [online] Available at: www.business-standard.com/india/news/genus-to-sell-meters-for-bengal-farms/241998/

2. Literature review

2.1 Why is the energy–irrigation nexus in India's agricultural sector of policy interest?

Indian policy discourse on the most suitable mode of agricultural electricity tariff has come full circle. Until the early 1970s, all state electricity boards charged their tube well owners based on metered consumption. However, as the number of tube wells increased manifold during the 1970s and 1980s, state electricity boards found the transaction costs of metering to be prohibitively high compared with 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 flat tariffs remained perpetually low (Dubash and Rajan 2001). This resulted in losses to state electricity boards estimated at around INR 270 billion per year in 2001 (World Bank 2002) and INR 320 billion in 2008 – part of which was expected to be paid from a subsidy of INR 190 billion for supply to agriculture. Unmetered electricity supply also became a convenient garb for state electricity boards to hide their inefficiencies in terms of transmission and distribution losses (Sant and Dixit 1996). Over time, state electricity boards came to treat their agricultural consumers as a liability. As a result, the quality of power in rural areas deteriorated and states such as Bihar, Orissa and West Bengal saw 'de-electrification' (Mukherjee 2008) and stagnation in agricultural electricity consumption. In other states, where electricity consumption in agriculture grew over time (such as Gujarat, Andhra Pradesh, Punjab, Haryana and 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 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 an 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, a 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). By contrast, in areas of abundant rainfall and rich alluvial aquifers with adequate recharge during the monsoon season, such as West Bengal, Bihar, eastern Uttar Pradesh and Assam (Mukherji 2007a, 2007b), the flat tariff system has not yet resulted in declining groundwater tables (Mukherji *et al*. 2012); however, there is clearly no cost to overusing water irrigation either.

A low flat tariff and the resulting electricity subsidy have also been criticised 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 fitted with electric pumps (Howes and Murgai 2003; World Bank 2002). However, under a scenario of active groundwater markets, it is not the landholding size of pump owners that matters; what matters more is the total command area of the tube wells, including the area of 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 hectares of land may be irrigated through these markets (Mukherji 2008). In most cases, these markets also have 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 estimates of the total electricity consumed by the agricultural sector, with the result that these estimates vary widely from 30 per cent to 50 per cent. This creates uncertainty in subsidy calculations, which are often provided to electricity utilities by the state government for providing electricity to farmers either free of cost (as in Punjab, Haryana and Karnataka) or at highly subsidised rates as in most other states, although not in West Bengal. The problems facing the electricity sector due to unmetered supply to agriculture and the 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 the top of the policy agenda (Planning Commission, 12th Plan Strategy Challenges).[6]

2.2 Metering in West Bengal against the backdrop of the Electricity Act 2003

In view of the criticism of a flat tariff and unmetered supply to agriculture, there was, and still is, growing pressure from the government of India and international donor agencies such as the World Bank and Asian Development Bank to revert to metering agricultural electricity supply. This is also articulated in the Electricity Act of 2003 (Article 55:1), which states that the following: '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.'

While donor agencies and the government of India 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 national government and the government of West Bengal in 2000, the state government has agreed to the universal metering of consumers. In view of this, metering agricultural consumers started in 2007 and by March 2011, over 90 per cent of the state's 110,000 electric tube wells had been metered.[7] The purpose of this paper is thus 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 several papers (Singh and Singh 2004; Jacoby *et al.* 2004; Kajisa and Sakurai 2005; Banerji *et al*. 2011) have examined various aspects of the functioning of groundwater markets in India, including its spread, extent, functioning and efficiency and equity impacts, relatively few papers have assessed 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 a high and rational flat tariff encourages proactive water selling by pump owners and leads to the creation of fairly competitive and equitable markets. In particular, he showed that after the change in tariff from a metered to a flat rate in 1987 in Gujarat, water markets expanded rapidly and small and marginal farmers benefitted. However, it also led to groundwater overexploitation in places such as North Gujarat. In view of the rapid pace of groundwater overexploitation, Shah *et al*. (2007) proposed the 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 eight hours of high quality electricity to agriculture and 24 hours of electricity to the rural domestic sector. Shah and Verma (2008) carried out a qualitative impact assessment of the program and found

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[6] http://12thplan.gov.in/forum_description.php?f=14

[7] Chairman and Managing Director of the West Bengal State Electricity Distribution Company, 2011. Discussion on metering agricultural consumers (personal communication, March 2011).

that while pump owners had benefitted due to a better and reliable electricity supply, water buyers and sharecroppers did not fare as well and had to exit these markets. Mukherji (2007a) looked at the functioning of groundwater markets in West Bengal and explained how the motive power of pumps (diesel vs. electricity) affects outcomes in the state's water markets. A high flat tariff and compulsion on the 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 tube wells in 2007. Immediately afterwards, Mukherji *et al*. (2009) undertook exploratory fieldwork 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 per cent and pump owners were less likely to sell water than before. However, none of the studies mentioned above involved a rigorous evaluation of the 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-differences estimates to measure the impact of metering on a number of outcome variables of interest.

2.4 Role of groundwater in the agrarian growth story of West Bengal

Groundwater irrigation is of concern in West Bengal and we are studying the impact of metering tube wells for two reasons. First, as already mentioned, the majority of farming households in West Bengal access irrigation through informal groundwater markets where they purchase water from their neighbours. The functioning of water markets is profoundly influenced by electricity tariffs and diesel prices (Mukherji 2007a). Second, groundwater plays an important role in agrarian transition in Bengal.

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

Boyce in his seminal work captured the dynamics of the first phase when the proverbial *Sonar Bangla*[8] that once abounded 'with every necessary [sic] of life' (Bernier 1914, quoted in Boyce 1987, p.4) became the abode of some of the poorest people in the world. This paradox of hunger amid plenty was explained by him and other scholars in terms of a regressive agrarian structure and high rural inequality that prevented the 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 the development of private groundwater irrigation was hampered due to small and fragmented landholdings and sharp rural inequalities.

Just as Boyce's book was published in 1987, there were telltale signs of a quiet green revolution going on in rural Bengal. Unprecedented growth in the agricultural sector at a rate of 6.5 per cent per annum[9] was recorded during the period 1981 to 1991 (Saha and Swaminathan 1994).

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[8] *Sonar Bangla* translates as 'golden Bengal'. It refers to the once-famed prosperity of Bengal in general, and fields overflowing with golden ripe paddy in particular.
[9] 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).

The enhanced agricultural growth and productivity in West Bengal in the 1980s could be explained by two opposing arguments:

- *agrarian structure,* as seen in Lieten (1988, 1990, 1992); Dasgupta (1995); Sen and Sengupta (1995); Ghatak (1995); Banerjee *et al*. (2002); Saha and Swaminathan (1994); Mishra and Rawal (2002); and Government of West Bengal 1996, 2004); and
- *market and technology*, as seen in Harriss (1993) and Palmer-Jones (1995, 1999).

Harriss (1993) found that in his study villages in Bankura and Bardhhaman, there was evidence of unprecedented growth that could be better explained in terms of the development of groundwater irrigation rather than agrarian reforms. Expansion in the area under *boro* cultivation, which is an entirely irrigated crop, and increases in the yields of all paddy crops (*aman*, *aus* and *boro*[10]) due to assured groundwater irrigation from tube wells resulted in high growth rates. This finding that groundwater irrigation unleashed the productive forces also partly confirms Boyce's thesis that water control was the 'leading input'. However, contrary to Boyce's claim that only public intervention or cooperative action could bring about groundwater development,[11] 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 land seasonally from their neighbours (changing agrarian relations). Palmer-Jones (1995) also 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 tube wells and the development of water markets) than with policies specifically designed and implemented to deal with the obstacles posed by the agrarian structure.

Whatever 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 the 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 the area under *boro* paddy cultivation in the 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 the *kharif* season (*aman* and *aus* paddy) and it is not prone to weather shocks and floods that often damage *kharif* crops. Given its high yields, *boro* paddy is thus the crop of choice of farmers in Bengal (both West Bengal and Bangladesh).

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[10] The *boro* season spans from November to May when rice is mainly grown under irrigated conditions. This is followed by the shorter *aus* season from April to August, mainly under rain-fed conditions. The *aman* rice crop follows the monsoon rains, is mainly rain-fed and runs from July to December.

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

3. Theory of change

Before delineating the pathways impacted, it is useful to reiterate some stylised 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 can also buy water from other pump owners given that land is highly fragmented. Farmers who buy water typically tend to have smaller landholdings and are often unable to install tube wells and pump sets (Banerji *et al.* 2011; Mukherji 2007b), although the 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-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, that not owning a pump did not preclude farmers from growing the crops of their choice because of the availability of groundwater to purchase. To the extent that a contraction in the number of hours pumped is seen disproportionately on water sales, this can thus have adverse implications for equity in access to groundwater resources. In addition, as noted above, the increase in the importance of summer cultivation was enabled almost entirely through the use of groundwater; these months receive virtually no rainfall and the surface water irrigation infrastructure in the state is relatively underdeveloped. It is possible, therefore, that the impact of a change in pricing regime is felt disproportionately in the summer season.

3.1 Primary variables of interest

This implies that the primary 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 later in this section.

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

As detailed in Section 4, the quantification of impact is made feasible through surveys conducted in 2004 and 2007 as part of other studies (Mukherji 2007b), which serve as a baseline, since the policy of metering tube wells 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 tube wells, and thus these served as controls.

This report thus computes the difference-in-differences 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 overall, 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 or 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, the exclusion of some water buyers from the water market post-metering, changes in cropping patterns to less water-intensive crops post-metering and the distribution of water sales at different times of day (and thus 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; thus, 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 without a unit price of electricity, the marginal cost of selling water was close to zero. However, pricing water in this way, namely 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. However, 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 or hours of water purchased. This will be one of our benchmarks. However, 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). Either it is not profitable for the water buyer to invest in a tube well and pump his own (due to small landholding, say) or low wealth and borrowing constraints prevent 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).

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:

$$f' > 0,\ f'' < 0,\ f'(x) \to \infty \text{ as } x \to 0.$$

- We 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 maximise profit *bf(w)* – *pw*.
- Let *D(p)* be the interior optimum water demand that solves this problem.
- Thus: $D(p) = f'^{-1}(p/b)$.
- 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 maximise $sf(w_s) + pD(p) - F$ 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 was zero (as the unit price of electricity was zero).
- Thus, w_s is chosen to set the marginal product of water to zero.
- Let this amount equal w_s^0.
- Separately, *p* is chosen to maximise *pD(p)*.
- We assume that water demand is not too convex, so the solution to the first-order condition $pD'(p) + D(p) = 0$ characterises the monopoly price.
- Let this price equal p_0.
- Clearly, this monopoly price is strictly positive. Therefore, 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 or hours of pumping becomes important. Thus, the following seems 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:

$$Max_{w_S,p} \; sf(w_S) - cw_S + (p-c)D(p) - m$$

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 $(p_1 - c)D(p_1) < m$ (1)

then Farmer S would 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*, high enough *c* and elasticity of demand for water (corresponding to a low mark-up $p_1 - c$) 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 mark-up 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 be excluded from the water market post-metering if the water market is less monopolistic;
(iv) The electricity rate post-metering varies throughout 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; and
(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 mark-up on the unit cost c of water extraction; thus, the water price post-metering is higher and water usage is lower (both for the water buyer as well as for the water seller's own land). We collect these conclusions as an informal proposition.

Proposition 1. Under 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 mark-up is too low; or (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 the 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) Despite the possibility of the 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 per cent of pumping takes place during off-peak hours when the unit price of electricity is low. Since *boro* paddy can be irrigated off peak, that is, during the night, and is the mainstay of the summer season, the impact of metering is mitigated.[12]

(ii) It is possible for pump owners' own-farm irrigation hours to decline more than sold hours. This depends on changes in the curvature of crop output response to water; pre-metering, the unit cost of irrigation was near to 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 lead to large amounts of own-farm irrigation by pump owners. Post-metering, there could be significant contraction in this component of irrigation owing to the positive marginal cost of irrigation.

(iii) Contraction in water use may be insufficient to affect output significantly; this can happen if pre-metering, there was an overuse of water relative to the agronomic requirement for *boro* paddy. This dovetails with point (ii).

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

(vi) Water use may decline across the board, in control as well as in 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 parameters b and s for the water buyer and water seller.

Benchmark 2: Water price for the 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 to extract the entire surplus from the 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 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 and Farmer B's lands are efficient, as they solve:

$$Max_{w_s,w_b}\ sf(w_s)+P-F \text{ subject to } bf(w_b)-P\geq\bar{\pi}$$

- 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 the 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*, we assume that in the absence of a negotiated water agreement, the water buyer's land will fetch zero output and profit.
- Further, 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:

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

- Thus, 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.

- We call these water volumes w_{sN}^1, w_{bN}^1. They solve the following problem:
  $Max_{w_s,w_b}\ \ sf(w_s)-cw_s+P-cw_b-m$ subject to $bf(w_b)-P\geq\bar{\pi}$, 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 water seller, respectively. Thus, for the setting to be non-vacuous, we need m to be small enough to satisfy the inequality below:

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

Thus, as in Benchmark Model 1, if the cost of monitoring *m* is large enough to violate equation (2), the water buyer is excluded from purchasing water. In addition, 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 two 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 $P_1 = (bf(w_{bN}^1) + cw_{bN}^1 + m)/2$.
- In other words, the agreed price results in the sharing of the water buyer's revenue and the water seller's cost of water extraction for the buyer as well as 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 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; or (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 the 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 are other ways in which farmers adapt to a change in pricing regime. First, cropping patterns may shift, which can happen across all seasons; in other words, there is a decline in the share of the area cultivated in the summer season with a corresponding increase in the share of the 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, difference-in-differences 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. Evaluation design

The evaluation design takes advantage of the surveys conducted prior to the introduction of the power pricing reforms, when flat-rate electricity pricing prevailed (see Mukherji 2007b). 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 five districts and interviewed 155 respondents. Since the roll-out of the metering was staggered, and only 70 per cent had been completed by 2010, this provided a unique natural experimental setting to examine the impact of 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, it was in principle possible to use a difference-in-differences framework to analyse impact.

4.1 The metering roll-out

Our identification strategy would clearly fail if there were systematic patterns to the metering roll-out. As described below, the way in which the metering was in fact accomplished provided us with at least two ways to identify impact: the identification strategy exploits both geographic and farmer-specific variations in the roll-out. In particular, the staggered and largely (but not entirely) unsystematic 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 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 agricultural tube wells started in 2007. Two private firms, whom we term M/s T and M/s H, were given the contract of metering nearly 100,000 electric tube wells in the state and each received a contract for metering roughly 50,000 tube wells each. These two firms were assigned electricity supply offices – the lowest supply unit of the West Bengal State Electricity Distribution Company – where they were required to install meters on agricultural tube wells and carry out meter readings. While this was not randomised *per se*, M/s H and M/s T were assigned electricity supply offices in a district that had similar hydrogeological and cropping pattern conditions.

The metering roll-out happened unevenly. M/s T went about completing its task faster and by 2009, it had installed meters in over 45,000 tube wells (or roughly 90 per cent). These meters were also of good quality and were functional during our study. By contrast, M/s H faced several quality-related issues in its implementation and this slowed its overall progress in installing meters. Until 2009, it had installed only 60 per cent of its targeted meters. In addition, over 20 per cent of M/s H meters malfunctioned and the West Bengal State Electricity Distribution Company had to revert to a flat tariff (personal communication with the Chairman and Managing Director of the electricity company). Thus, although two companies were entrusted with the task of installing meters, one of them was slower in its implementation process and installed a high rate of defective meters.

At the time of the survey, nearly all districts in the baseline survey contained both metered and unmetered villages. Table 2 provides a distribution of the sample across the various districts.

Table 2 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
	Bardhhaman	6	2
	Hugli	7	5
	Murshidabad – Rarh	3	2
	Total	36	18

One significant exception was the near-complete metering in the North 24 Parganas and Nadia districts, implying that most sample villages in these two districts would fall into the treatment group. In addition, metering coverage was relatively low in Murshidabad and Birbhum; thus, a high proportion of our control villages were expected to be drawn from the districts of Murshidabad and Birbhum. As indicated in Table 3, the number of control and treatment villages per stratum was unbalanced in the electric tube well but reasonably balanced in the second stratum, the old alluvium zone.

Table 3 Number of villages in treatment and control groups

Zone	Village classification	Number of villages with metres in 2009 (treatment)	Number of villages with no metres 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

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

Even within treated villages, some installed meters were faulty; as noted earlier, this was a particular problem with M/s H. Consequently, these farmers continued to pay for electricity on a flat-rate basis. The number of surveyed farmers that did and did not have functioning meters thus became yet another way to distinguish between control and treatment groups. Crucial to this allocation was the fact that the distribution of faulty meters, although a function of the metering company, was not related to the 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–

2010 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 the treatment group and 57 for the control group, as presented in Table 4, with once again a greater degree of balance between control and treatment groups seen between the two strata.

Table 4 Number of baseline farmers who did or did not receive metered bills

	2008–2009		**2009–2010**	
	Received metered bills (treatment)	**Did not receive metered bills (control)**	**Received metered bills (treatment)**	**Did not receive metered bills (control)**
New alluvium zone	61	19	65	15
Old alluvium zone	52	51	61	42
Total	113	70	126	57

Second, given the substantial increase in metering coverage between the crop years 2008–2009 and 2009–2010, 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 baseline villages. Although there is likely to be recall bias in using 2008–2009 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 (2008–2009) 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 and a greater number of control farmers.

Thus, three treatment definitions were used: at the village level, at the farmer level in 2009–2010 and at the farmer level in 2008–2009. 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 treatments are presented in Table A1 in Appendix A.

5. Sampling design and power calculations

5.1 Sampling design in baseline and endline surveys

In the baseline survey, the main objective was to characterise the nature and functioning of groundwater markets in West Bengal. It is widely recognised that geo-hydrological factors (such as types of aquifers and depth of the 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 on 764 observation wells regularly monitored by the Central Groundwater Board in West Bengal. These 764 villages from which the Central Groundwater Board 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 the higher the utilisation 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 net cropped area. To select the villages a number was assigned to each village in a district and then through random number generation, the requisite number of villages in each district was chosen.

In each village, two distinct sets of farmers were surveyed: those who owned a tube well 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, the estimates of the number of hours sold by water sellers need not be (and are not) identical to the 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 was unbalanced, the sample size numbers for 2008–2009 would be adequately powered to detect an effect size of a hypothesised 20 per cent decrease in irrigation pumping hours and sales. As it transpired, there was a material decline in hours of groundwater pumping and sales between the baseline and follow-up, swamping a treatment effect that 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 the first-difference estimates of impact (using matching techniques) could be computed. In selecting these augmented villages, we purposely oversampled from control villages in the new alluvium zone in order to ensure a better balance in the distribution of villages between the control and treatment groups. Thus, 18 new villages were surveyed, meaning that 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, as nearly six years had elapsed since the first baseline and there were concerns about 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, 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 follow-up. Of the 521 respondents interviewed in the baseline, we were able to re-interview 427 of them, while 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 not seem to be a problem for our sample. None the estimates of impact presented in this report therefore account for attrition bias.

6. Data collection

The baseline data from 2004 and 2007 were available before the start of the survey to allow lists of farmers, their father's name and their localities and addresses within villages to 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 fieldwork started on 24 July 2010, and it was completed within 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 personal digital assistants (PDAs) to capture informant information; this facilitated immediate crosschecks and call backs.

The survey instrument consisted of six modules:

- Module 1. Canvassed information on the agricultural household, including the number of earning members, details of landholding (owned, leased-in, leased-out) by season and cropping patterns.
- Module 2. Focused on crop economics in the expectation that it could inform how production technology influenced input use, particularly 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.
- Module 3. Dealt with details of wells and pump technology, with information on the costs of installation and maintenance, on the hours of operation by season and on the breakdown between self-use and sales.
- Module 4. Focused on water sellers, and the terms under which water sales took place each season
- Module 5. Obtained similar 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.
- Module 6. Attempted to deal qualitatively with issues related to service delivery – of irrigation equipment and complementary inputs. To the extent possible, we maintained the same definitions across the baseline and follow-up.

7. Results

7.1 Comparability of treatment and control groups in the baseline

Table 5 shows the differences between the treatment and control groups of the villages for several of the impact variables in the baseline. The standard errors are clustered and they take into account the two strata and the village clustering. It is clear that for nearly all the impact variables 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 per cent of all the groundwater pumped, and therefore the lack of equality of means in this variable is not economically significant. Thus, *ex post* randomisation seems to have worked, at least in the sense that most of the key variables do not differ between control and treatment groups.

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

	Baseline			Follow-up		
	Control	**Treatment**	**p-value**	**Control**	**Treatment**	**p-value**
Total hours pumped	761 (131)	833 (86)	0.65	442 (76)	596 (61)	0.14
Hours used for irrigating own farm	289 (68)	355 (37)	0.40	173 (33)	251 (27)	0.08
Hours sold	472 (106)	477 (80)	0.97	269 (53)	344 (47)	0.32
Hours pumped in *kharif* 2009	124 (36)	114 (24)	0.82	97 (20)	110 (12)	0.60
Hours pumped in *rabi* 2009	51 (12)	100 (21)	0.05	60 (16)	123 (26)	0.05
Hours pumped in summer 2010	586 (117)	619 (0.83)	0.82	284 (57)	362 (40)	0.28
Only buyers						
Total hours purchased	167 (36)	267 (50)	0.12	165 (25)	225 (36)	0.21
Hours purchased in summer 2010	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

Note: The *p*-values refer to a test of equality of means in the baseline (column 4) and follow-up (column 7).

Moreover, the availability of the baseline survey enables a difference-in-differences estimation, thereby alleviating any remaining selection bias in allocating villages or farmers to the treatment group. 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 Section 8.

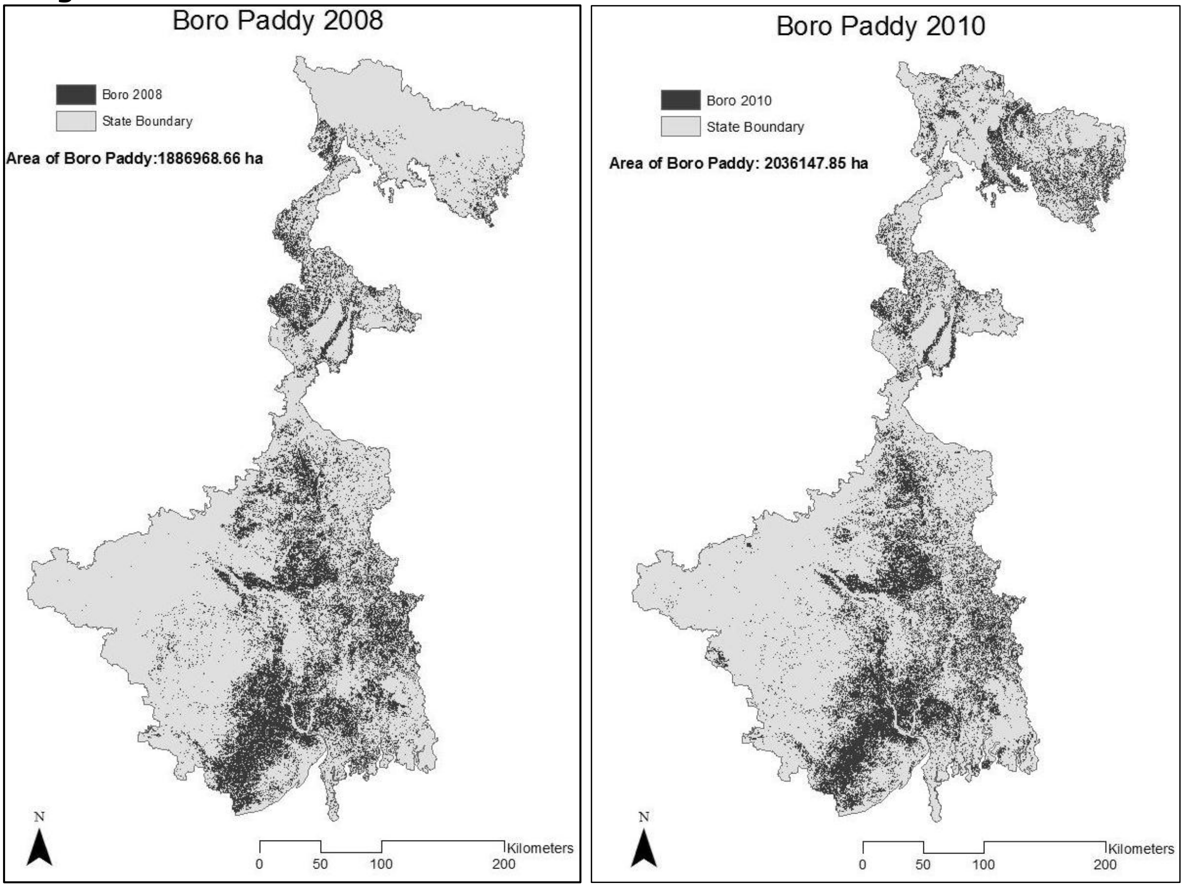
7.2 Material decline in the number of irrigation hours

Table 5 also highlights the substantial decreases in the total number of irrigation hours across both treatment and control groups. This decrease is seen both in the number of hours used for irrigating own farms and in the number of hours sold, with the decrease slightly greater in the latter. Comparing 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 material decline in the number of irrigation hours pumped, used and sold, especially in the summer season. Interestingly, viewed from buyers' perspectives, the decrease in the number of hours purchased is not as large.

This seems 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 suggest that in 2010 the area under paddy declined in Bankura, North 24 Parganas, Nadia and Murshidabad districts compared with previous years, while it remained the same in Hugli and increased in Bardhhaman.

Another data source, using satellite images to estimate area, conducted by the International Water Management Institute in the *boro* season suggests that although the overall *boro* area increased, it decreased between 2008 and 2010 in the districts of Bankura, North 24 Parganas, Nadia and Murshidabad (Figure 1).

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



These are, perhaps not coincidentally, districts with a predominance of electric centrifugal and electric submersible pumps. Electric centrifugal pumps are mounted on the ground and can suck water from within a suction head of 30 feet, whereas electric submersible pumps are submerged below water and push water up through propulsion. Districts with a predominance of electric centrifugal pumps are Nadia, North 24 Parganas and the eastern half of Murshidabad district adjoining Nadia district. Districts with a predominance of electric submersible pumps are the western part of Murshidabad, Hugli, Bardhhaman and Bankura.

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

7.3 Calculating the double-difference estimates of impact

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

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

b) $\Delta Y_{ij} = \alpha + \beta V_j E_{ij}^{S,C} + \varepsilon$ where $\Delta Y_{ij} = Y_{ijf} - Y_{ijb}$ and V are as above, and $E_{ij}^{S,C}$ is a dummy variable that takes a value of 1 if the *i*th farmer in the *j*th village had either an electric submersible or an electric centrifugal pump. We label this the '*vtmt*EC/ES*' treatment.

c) $\Delta Y_{ij} = \alpha + \beta V_j E_{ij}^{S} + \varepsilon$ where $\Delta Y_{ij} = Y_{ijf} - Y_{ijb}$ and V are as above, and E_{ij}^{S} is a dummy variable that takes a value of 1 if the *i*th farmer in the *j*th village had an electric submersible pump. We label this the '*vtmt*ES*' treatment.

d) $\Delta Y_{ij} = \alpha + \beta F_{ij9} + \varepsilon$ where $\Delta Y_{ij} = Y_{ijf} - Y_{ijb}$ is the difference between the follow-up *(f)* and baseline *(b)* in the impact variable *(Y)* for the *i*th farmer in the *j*th village, while *F* is a dummy variable that takes a value of 1 if the *i*th farmer in the *j*th village received metered bills in 2009–2010 (treatment) and 0 if he did not. We label this the '*f9tmt*' treatment.

e) $\Delta Y_{ij} = \alpha + \beta F_{ij9} E_{ij}^{S} + \varepsilon$ 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.

f) $\Delta Y_{ij} = \alpha + \beta F_{ij8} + \varepsilon$ where $\Delta Y_{ij} = Y_{ijf} - Y_{ijb}$ is the difference between the follow-up *(f)* and baseline *(b)* in the impact variable *(Y)* for the *i*th farmer in the *j*th village, while *F* is a dummy variable that takes a value of 1 if the *i*th farmer in the *j*th village received metered bills in 2008–2009 (treatment) and 0 if he did not. This is the same specification as in *(d)* above, except reference is made to the receipt of metered bills in the previous (2008–2009) crop year. We label this the '*f8tmt*' treatment.

g) $\Delta Y_{ij} = \alpha + \beta F_{ij8} E_{ij}^{S} + \varepsilon$ where all the variables are as defined above. This is the same specification is *(e)* above, except reference is made to the receipt of metered bills in the crop year 2008–2009. We label this the '*f8tmt*ES*' treatment.

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

7.4 Difference-in-differences estimates for the primary impact variables (irrigation hours pumped, sold and bought, by season)

In Table 6, we present the impact estimates (the estimated β) pertaining to specifications *(b)* and *(c)* for a range of impact variables. We relegate the impact estimates from the remaining formulations to Table A1 in Appendix 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.

Table 6 Difference-in-differences estimates of impact, using village-level treatment

	Vtmt*Electric pump set (a)	Vtmt*Electric submersible pump set (b)
Impact on pump owners		
Total hours pumped	−232 (186) [0.22]	−51 (309) [0.87]
Hours used for irrigating own farm	−103 (71) [0.16]	−101 (85) [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 2009–2010	−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]

Note: Co-efficients of regression of the difference in the impact variable between follow-up and baseline on:

a) Village-level treatment dummy interacted with the ownership of either electric submersible or electric centrifugal pump set (specification (b))
b) Village-level treatment dummy interacted with ownership of electric submersible pump set only (specification (c))

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

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 specification *(b)*; the co-efficient has a *p*-value of 0.22. Thus, at least as far as these aggregate figures are concerned, the metering seemed to have no impact. Note, however, that all the signs are correct; it is therefore more accurate to say that the impact of 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 pump sets; this is also seen among owners of electric submersibles at a p-value of 0.20. The corroboration of a significant reduction in the 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) A reduction in pumping, both self and sold or bought, post-metering; but the magnitude could be limited if the unit cost of electricity is low. This is the case in off-peak times, when about 80 per cent of pumping happens. In addition, 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), the same occurs. 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 trade is significant. This is mitigated if the unit cost of electricity is low, if water buyers are not that small and if there is a material decline in paddy cultivation in *boro* anyway (since that represents a water-intensive cost with a high monitoring cost of water trading). This may also happen if trust at the village level reduces monitoring costs for a significant proportion of sellers and buyers.

7.5 Difference-in-differences estimates for the secondary impact variables (cropping pattern and productivity)

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

At the same time, the decrease in water use in the *boro* season and in sales in that season did not adversely affect paddy output; the impact co-efficient, 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 the case of pre-metering with a zero unit cost of extraction for self-irrigation, there may have been significant water 'overuse'. However, to the extent that buyers paid a mark-up price, there could not have been any overuse on buyers' plots. Thus, in the case of post-metering with a positive unit cost of extraction, overuse by self-irrigators could have been eliminated. By overuse, we mean the use of water beyond crop requirements; reduction would then show up as no significant decline in crop yields.

7.6 Single-difference impact estimates

A noticeable feature of Table 5 and Table A1 in Appendix A is the large number of correct negative signs, but *p*-values that are considerably higher than 0.05. This could be an indication that the sample was, *ex post*, not powered to detect impact, although we did use baseline figures to compute the variances (but assumed a 20 per cent effect size in pumping hours). Even then, the variances in pumping hours were high.

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

Unmatched comparisons of means between control and treatment groups show however that there was no significant impact. Similarly, the preliminary estimates of the propensity score-matched comparisons of control and treatment groups show that there was no difference in the hours pumped by pump owners in the control and treatment groups, irrespective of how the treatment group was 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 should not be given behavioural interpretation, and merely used to match respondents from control and treatment groups, the meaning attached to the probability of metering adoption when metering itself was randomly rolled out requires further elaboration. This is currently being investigated.

8. Conclusions and policy implications

As far as the impact of metering tube wells 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 treatment groups compared with control groups. There is also some evidence that this decrease was not confined to own-farm irrigation, but that water sales and purchases were also adversely affected as a consequence. Yet, metering did not influence either cropping patterns or the output of *boro* paddy. The latter could well be explained by the overuse 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. The evidence of decreased sales and purchases may have 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 in both control and treatment groups, which may have served to swamp the impact of metering. The fact that many of the signs have the expected negative sign, but are insignificant, may mean that our sample was underpowered to detect impact (our power calculations did not account for these material changes).[13]

It is also useful to note that the unbalanced sample sizes, with about two-thirds of farmers allocated to the treatment group, inflate the standard errors by about 12–15 per cent. A balanced sample could lend significance at conventional levels to estimates that at present have p-values up to 0.20. This interpretation reinforces the impression (see Table 6 and Table A1 in Appendix A) that metering caused a significant decline in hours pumped in the economically crucial summer season, but 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 based on this liberal interpretation.

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

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 data set) may help validate or negate our 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 current 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 a larger set of impact variables. We expect to have defensible policy implications once these additional analyses have been completed.

Appendix A

Table A1 Difference-in-differences estimates of impact (co-efficient on impact or interaction variable), using alternative definitions of treatment

	Village was metered (Vtmt)	**Farmer received metered bill in 2009–2010 (F9tmt)**	**Farmer received metered bill in 2008–2009 (F8tmt)**	**F9tmt*Electric submersible pump set (F9tmt*ES)**	**F8tmt*Electric submersible pump set (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 irrigating own farm in summer 2010	23 (63) [0.72]	−14 (95) [0.88]	−93 (73) [0.22]	16 (87) [0.86]	−71 (116) [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 2009–2010	−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	(0.03) [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]

Note: Co-efficients of regression of the difference in the impact variable between follow-up and baseline on:

a) Village-level treatment dummy (column 2)
b) Village-level treatment dummy interacted with ownership of either electric submersible or electric centrifugal pump set
c) Village-level treatment dummy interacted with ownership of either electric submersible pump set only

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

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