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Rural Electrification and the changing energy irrigation nexus in Bihar

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Abstract

Over the past few decades Agricultural irrigation in South Asia has emerged to be dominantly groundwater sourced. The size and structure of a region's groundwater economy is closely intertwined with its energy economy. Until only a few years ago, diesel was the main source of energy for groundwater irrigation in the region while farmers in the rest of South Asia had access to subsidized or free electricity to operate their pumps. With rapid improvements in rural energy supply, this energy-divide is now disappearing. This has potential to change the area's groundwater energy nexus. Farmers in Bihar, a populous state of India, have installed more than 200 thousand electric pumps for irrigation since 2015. We use data from a representative sample of 1440 farmers from the state to assess the pattern of electrification of groundwater irrigation and its impact on pump ownership, water markets, and water use in agriculture. Electrification of irrigation is skewed towards west and south Bihar. On average, electric pump owners have smaller landholdings than diesel pump owners and they charge significantly lower irrigation fees from water buyers. However, three out of four pump owners report not selling water from their pumps. Farmers using electric pumps—owned or rented—irrigate their crops more intensively and have higher cropping intensity. Near free electricity for irrigation may undermine the fiscal and environmental sustainability of the irrigation led agricultural growth in Bihar.

JEL Codes: Energy Irrigation Nexus, Groundwater irrigation, Rural electrification, Electric pump; Bihar

Background

Over the past few decades agricultural irrigation in South Asia has emerged to be the dominant groundwater source. The size and structure of a region's groundwater economy is closely intertwined with its energy economy (Shah, Singh and Mukherji 2006). The years between 1975-2000 was a golden age of smallholder irrigation in South Asia. This is because there was a spontaneous boom in private investment in small borewells and mechanized diesel and electric pumps. This was complemented by the pressure of intensification of farming due to growing population (T. Shah 2009). Different energy pricing and supply policies for agriculture led to an energy-divide across India. Farmers of relatively water-rich eastern regions of country, relied almost exclusively on costly diesel fuel to pump groundwater while farmers in the western and southern parts had access to highly subsidized electricity for irrigation (Shah, Singh and Mukherji 2006).

Since 2000, however, the region's groundwater economy started to shrink in response to the growing energy squeeze. The energy squeeze was factored on deteriorating farm power supply, embargo on new electricity connections, and a rapid increase in diesel prices. The ratio of increase in rice to diesel prices was particularly worse in eastern India. Because the water markets in eastern India are natural oligopolies, pump rentals relative to farm produce prices, which is what matters to the marginal farmers and sharecroppers, have risen even faster than diesel prices relative to rice and wheat prices (T. Shah 2009).

High cost of irrigation, especially in eastern India and for water buyers put pressure on them to economize groundwater use, and this differential pressure increases with every increase in diesel price (T. Shah 2001). Some of the effects of energy squeeze, observed by (T. Shah 2009) includes decline in pump irrigated area, usage of kerosene/crude oil as diesel substitute, cultivation of less water intensive crops etc. Farmers under-irrigate their crops (Briscoe 2006) leading to worse performance in terms of cropping intensity, input use (T. Shah 2001) and yields (A. Kishore 2004). Until 2000s eastern India had observed a trend of electrification, de-metering, over-exploitation, de-electrification and then dieselization/re-electrification of irrigation, some parts earlier than other. Bihar remained electrically under-privileged throughout (T. Shah 2001).

In the last two decades, rural electrification has expanded rapidly in Bihar (Tripathi 2018). We hypothesize that electrification of wells and tubewells will affect agricultural and groundwater outcomes through reduced cost of irrigation for farmer. Studies exploring the effect of electrification in EGP of India, although limited to West Bengal, observe lesser cost of irrigation for electric pump users which enabled farmers to irrigate a bigger area, devote a larger part of their land to water-intensive paddy, leading to a higher cropping intensity. They observe that a high flat tariff in West Bengal, pushed electric pump owners to sell water more actively than diesel pump owners (A. B. Mukherji 2020) (Buisson 2021).

However, there is minimal research exploring change due to electrification of irrigation on Bihar's groundwater economy and its impact on water markets, water use and agriculture. This paper tries to fill this evidence gap using primary data from a representative sample of 1440 farmers spread across all four agro-climatic zones (ACZs) of Bihar in 2023. The paper is structured as follows. Section 2 discusses re-electrification of irrigation in Bihar. Section 3 describes the sampling strategy, data and its collection. Section 4 presents the main results of paper to discuss changes in pump rental markets (commonly called water markets), cost of irrigation for pump owners and water buyers, irrigation use intensity and cropping intensity. Section 5 concludes the paper with a discussion and policy implications.

Electrification and Irrigation

Planned rural electrification of Bihar started in 1958 but it was only after 1972 that the work gained momentum (A. Srivastava 2019). Many rounds of de-electrification and re-electrification, leading from very commonly noticed de-metering and power theft, make it difficult to accurately describe the periodic status of electrification of Bihar (Oda and Tsujita 2013). In 1988 Kutir Jyoti Scheme was implemented nationwide but it also had limited impact in Bihar due to poor institutional and distribution infrastructure for rural electrification. In 2000, the state was bifurcated and the number of villages under Bihar state reduced from 67,503 villages to 39,073 villages. Most of power infrastructure went with the other state of Jharkhand (A. Srivastava 2019).

Bihar’s trajectory for economic performance, including that of the electricity sector changed post 2005. This was facilitated through a national flagship rural electrification program, Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY), launched in 2005, and new state electrification infrastructure promotion schemes (A. Srivastava 2019). With the introduction of RGGVY, a new definition of village electrification was adopted in India and Bihar in 2004. The new definition focuses on electrification of village households and community spaces such as schools, health centers etc. (Ministry of Power 2024). Approximately 90% of villages were reported electrified in 2012 (A. Srivastava 2019) and by 2018, the state of Bihar reported that all inhabited villages in state stand electrified (DDUGJY 2019).

The increase in access to electricity has been accompanied by a significant improvement in supply quality (voltage and frequency). The average duration of power supply in rural areas was 21.8 hours/day and pr capita consumption was 350 kWh/year in 2021, an increase of 3.5 times from 2007 (ADB 2023). Household electrification and its use for individual and agricultural purposes, however, has lagged village electrification. While 90% of villages were reported electrified by 2012, only 10% of rural households were electrified by then (GOI 2015). Approximately two-thirds of Bihar population did not have access to electricity in 2015 (The Economic Times 2015).

The total amount of energy sold to consumers for agricultural purposes has increased from 313 GWH in 2014 to 1140.8 GHW in 2021 (INDIASTAT). This is 3.1% and 4.3% of total energy sold in the state during those years respectively. The growth rate of energy sold for agricultural purposes across the two years (3.6%) is higher than 3%, the growth rate of total energy sold to consumers in Bihar (CEIC 2022). Contrary to rest of India, only 5% of the 0.64 million pump sets in Bihar were electricity powered in 2012 (Minor Irrigation Census 2013-2014). The number of electric pump-sets in the state has increased from 48.5 thousand in 2013-14 to 253 thousand in 2019-20. North Bihar (part of state, north of the Ganga River), however, lags the southern part of the state in the electrification of irrigation wells (Figure 1).

Government of Bihar is providing electricity for irrigation and allied services under two separate sub-categories for private and State-owned tube-wells, with differentiated tariffs for providing benefit of lower tariffs to private consumers. Unmetered supply is only fixed charged based on per HP per month and metered supply has a two-part tariff. Two-part tariff includes fixed charges on connected load plus energy charge per unit. Based on supply voltage of electricity, the total cost of supply is Rs. 9.19/KWH in North Bihar and South Bihar combined (Bihar Electricity Regulatory Comminsion 2024). The approved tariff for irrigation and agriculture service in Bihar for FY 2023-2024 is Rs. 1350/HP per month for unmetered connection. Metered, IAS-I (private owned tube-wells) are charged Rs. 100/HP (fixed) and Rs. 6.89/unit (variable). Metered, IAS-II (state-owned tube-wells) are charged Rs. 500/HP (fixed) and Rs. 7.32/unit (variable) (Bihar Electricity Regulatory Comminsion 2024). In 2017, the average tariff for a metered IAS-I was approximately Rs. 1.3/kWh as compared to the average cost of supply of Rs. 5.8/kWh (Bihar Electricity Regulatory Commision 2017).

Sampling and Data

Sampling

We used stratified random sampling to sample 15 districts of the four agro-climatic zones (ACZs) of Bihar based on share of the net cropped area of ACZ to that of state. Following this, two blocks from each district (Figure 2) and three village from each block were sampled simple randomly. House-listing surveys in sampled 90 villages were conducted to identify families that cultivate land. If the village population was more than 250 households, a random hamlet of village was visited. The average size of a hamlet surveyed for house-listing is 192 households. 16 families that cultivate land between Kharif 2021-2022 to Kharif 2022-2023 were selected simple randomly from the house listing sample for a more detailed household survey (Table 1).

Bihar has fragmented ownership of agricultural land, and hence, a farmer cultivates crops on multiple non-adjacent plots (M. Singh 2009). All questions on agricultural practices such as crop cultivated, source and means of irrigation, level of mechanization, etc. were asked for the largest plot (owned or leased) cultivated by the household. The household survey collected data on land ownership, cultivated area across different seasons, cropping pattern and crop yields. A separate irrigation module is designed to understand ownership, and use of wells or tubewells, different types of pumps (own or rented; centrifugal or submersible), source of energy of the pump (diesel, electric, or solar), pump capacity (in horsepower), and terms of use for rented pumps (irrigation fees and other costs). In addition, we also collected detailed data on exposure to droughts or floods in recent years and the cost of cultivation of the main crop in each season. Agriculture and irrigation modules are answered by the main farmer of household.

Sample characteristics

The houselisting sample consists of 17,620 households. 56.8% of houselisting sample cultivate land at least once between Kharif 2021-2022 and Kharif 2022-2023. Most of these households irrigate their land by sources other than rain-fed irrigation in rabi season and hence have access to pumps for irrigation. 48.3% of all cultivating households use electric pumps and 51.8% use diesel pumps for irrigation. 16.3% of cultivating households own a pump of which 65.6% own a diesel pump and 44.3% own an electric pump, 7.1% owning both diesel and electric pumps. By comparison, 76% of all pumps used in India are electric and 22% are diesel sourced (Minor Irrigation Census 2017-2018). 20% of main farmer respondents are women in our sample. The mean agricultural land owned by a household is 1.05 acres. Paddy is the most grown crop in kharif season and wheat, and maize were the main crops in rabi season. Approximately 25% of farmers cultivate any summer crop, mostly mungbean (Table 2).

Results

The topography of Bihar is fertile alluvial plain. Lying in the Gangetic valley, the state is richly endowed with both ground and surface water resources. The main feature is the River Ganges which flows through it and divides the state into water rich north and south Bihar. The rich endowments of water resources make Bihar India's most flood prone state as well, North Bihar more so than South Bihar. South Bihar is more prone to serious droughts. Average rainfall in the state is around 1,198 mm, but there is considerable variation within the state. Extreme eastern and northern parts receive around 2000 mm while western and southern parts receive less than 1000 mm. As a result, farming in Bihar remains substantially dependent on irrigation, mostly through tubewells and canals. Tubewells/groundwater and canals/surface water contribute around 66% and 28.6% respectively, of the gross irrigated area in Bihar (Hoda, Rajkhowa and Gulati 2017).

Pump and electric pump ownership

The abstraction of groundwater for irrigation is closely coupled with access to pumps through energy economy (Shah, Singh and Mukherji 2006). There are 2312 pumps used by our sample of 1440 households. Close to 88% of pumps used are rented/leased-in and 12% are owned by 17% households. Leased-in pumps are assumed to be different from owned pumps and reported from a village in the sample. (Table 3). Approximately 7% of pumps are owned privately jointly or by more than one individual or farmer, generally members of same family. Only 2% of villages have no household which own a pump for irrigation. The maximum pump ownership rate of farmers who cultivate land is 50%. More pump ownership is noticed in south-west and north-east Bihar (Figure).

Bihar, like India, is also observing an energy-divide upon electrification of irrigation and allied services. Western and southern India depends on subsidized electricity as compared to eastern states which used to depend mostly on diesel pumpset for groundwater irrigation (Shah, Giordano and & Mukherji 2012). West and south Bihar have more access to electrified groundwater irrigation as compared to the rest of the state. This might be because these regions have lower aquifer levels and are more prone to droughts. The political economy of the energy-groundwater nexus might push electrification to more developed South Bihar, but this requires further analysis.

To identify the level of electrification of irrigation in a village we use the density of owned electric pumps (EPO). EPO is the share of households who own electric pumps, of households who own pumps. Density of owned electric pumps is highest (90.7%) in the South-West agrozone and lowest (16.9%) in the South-East agrozone. The calculated density from household data is similar but less than that from the houselisting data. We use the pump densities from houselisting data because of higher sample size between the two datasets. Approximately 54% of all electric pumps in west Bihar are submersible due to the increasingly lower level of aquifers in the region. All electric pumps in north-east Bihar are submersible. Why? and all electric pumps in south-east Bihar are centrifugal.

There are no owned electric pumps by households in 21 of 90 villages in sample. Close to 30% of villages in north Bihar and 10-15% of villages in south Bihar have no households which own an electric pump for irrigation. All pumps used for irrigation run on grid electricity in 16 villages. No village in east Bihar has 100% electrified agricultural services and 43% of villages in south-west Bihar have almost all their agricultural services electrified. Altogether, approximately 40% of villages in Bihar can have a greater number of electric than diesel pumps (Figure 3).

52.1% of households in villages with access to electric pumps report not using them ever for groundwater irrigation. Some of the reasons for it could be excess demand for electric pumps, unavailability of grid connection near the field of irrigation and irregular supply of electricity in the grid. If the grid is far away from farm, delivery pipes, generally made of plastic, are used to transport water or farmers extend informal power lines. However, this adds to the cost of irrigation and is not feasible for every household. Usage of delivery pipe is also dependent on pump capacity and terrain through which water is transported. Sociological reasons such as caste and religion can limit a household's access to assets and act as an impediment to water trade (Anderson 2011).

Access, hence, does not ensure ownership and usage. A household's choice of ownership of a new asset/technology is dependent on multiple geographic and household factors. We estimate four linear probability models, based on equation 1, to identify household characteristics that correlate with the ownership of irrigation pumps and ownership of electric irrigation pumps. The outcome/dependent variable Y*i* in model 1 and 3 is a binary variable identifying if a household owns a pump for irrigation or does not own any pump. For models 2 and 4, the binary variable identifies if a household owns an electric pump or owns a diesel pump.

$$Yi = \beta 0 + \beta 1 Landi + \beta 2 Xi + \alpha i + \varepsilon i \qquad (1)$$

Models 1 and 2 are based on houselisting data and the independent variable *Land* is a continuous variable here represents total land cultivated by household throughout year. Controls used in these models include identification of landless tenant households and whose primary source of income is cultivation. Models 3 and 4 are based on household data and the independent variable *Land* is a continuous here represents total land owned by household. Controls used in these models include education level of main farmer, caste category, religion, and DHS asset index of household. Based on the summary statistics we hypothesize majorly two nulls' hypotheses for models 1/2 and 3/4:

- There is no direction bias in pump ownership/electric pump ownership across Bihar
- Pump ownership does not depend on household's access to cultivation land/ household's ownership of cultivation land in Bihar

Results from Table 4 suggest that households in north-east Bihar is significantly more likely to own a pump compared to their counterparts. Households are least likely to own a pump if located in North-West Bihar, preceded by South-East Bihar (M1). There is no visible direction of pump ownership from M3 as well. Thus, while some regions in Bihar are more likely to own pumps for irrigation there is no single direction to pump ownership in state. Every acre of increased operated land is significantly associated with increase in likelihood of owning the pump by 6% (M1). Similarly, a one acre increase in land owned by household is significantly associated with increase in likelihood of owning the pump by 7% (M3). A landless tenant household is 10% less likely to own a pump. If the main farmer of household is female, then the household is 7% less likely to own a pump. Thus, increased access to agricultural land for cultivation leads to a higher likelihood of owning a pump and so, larger landowners and cultivators are significantly more likely to own an irrigation pump (Figure 4).

Households in north-west Bihar are more likely to own an electric pump than in north-east and south-east Bihar but less than in south-west Bihar. Therefore, ownership of electric pumps is skewed towards western Bihar and most in south-west Bihar. Electric pump owners, on average, have smaller landholdings compared to the farmers who own diesel pumps. This is surprising because electric pumps often cost more than diesel pumps and require additional investment in connecting the pump to the power grid (Shelar, Matsagar and Patil 2024). While an increase in cultivated land by one acre is significantly associated with 1 % reduction in likelihood of owning an electric pump (M2), an increase in agricultural land owned by one acre is non-significantly associated with 0.5% increase in likelihood of owning an electric pump (M4) (Figure 5). Therefore, an increased access to cultivation does not lead to higher likelihood of ownership of electric pumps and so, larger landowners and cultivators are not significantly more likely to own a pump.

Water Markets

Access to irrigation pumps also depends on local groundwater markets. Groundwater markets are an informal arrangement through which well and pumpset owners sell irrigation services to other farmers for consideration. These markets emerge because of two reasons: first, there are farmers who do not have access to a well and a pump due to socio-economic reasons; and second, agricultural lands are so fragmented that investment in a well and pump set for each parcel of land is not feasible(Shah and Ballabh 1997). Pump rental markets or groundwater markets are even more important in Bihar because of small and fragmented landholdings. A farmer on average owns 4 parcels of land at separate locations.

The use of sale of water and leasing-out of pump is made interchangeably ignoring the ownership status of borewell. Mostly, water sellers or pump owners charge a fee in return for pump use. The fee includes the cost of fuel, which gives pump owners the power to modify fee when fuel cost changes. Any breakdown cost, while the pump is leaded-out, is covered by the pump-owner. Close to 17% of households which own pumps sell water (Table 5). Given an active groundwater market, higher pump owner participation as sellers was expected. Sometimes, neighbors, friends and community members are allowed to use pumps free of cost, and inclusion of such cases as water sellers does not change the result much.

Approximately 36% of households that sell water own at least one electric pump. The median agricultural land holding size of pump owning households that sell water is 1.4 acres as compared to 0.4 acres for households that do not sell water. This is surprising and counterintuitive. We expected that pump owners with smaller landholdings would be more likely to and more interested in selling water as they have greater spare capacity and perhaps a greater need to supplement their income from cultivating their own lands.

A pump owner, irrespective of pump type sells water to approximately 6 farmers. Approximately 19% of electric submersible pumps owners, 28% of electric centrifugal pump owners, and only 16.5% of diesel pumps owners sold water to other farmers. Since on average a smaller household owns an electric pump and the fixed cost of buying an electric pump is comparatively higher than a diesel pump, it is expected that more electric pump owners would sell water from their pump. The portable nature of electric centrifugal pumps also makes them easier to carry to renter’s field. The existence of inter-village groundwater markets is also noticed. 39 households from villages with no electric pumps report leasing water from an electric pump, probably from nearby villages.

Buying water and leasing-in irrigation pump is used interchangeably. Mostly diesel and kerosene pump renters pay irrigation fees on a per hour basis. Electric pumps are charged at both per hour and per acre/local land unit basis, mostly on per acre/local land unit (Because water markets are most active during the rabi season, we present rabi season results. Similar results from the kharif seasons are available on request). Rental rate responses from water buyers are used due to larger sample size.

Per hour rabi season average rental rate for Electric submersible and Electric centrifugal pumps for wheat are 76.0 Rs and 63.4 Rs respectively. The diesel pump is leased at 169.9 Rs. (Table 6). But the benefits of hugely subsidized farm electricity rate are not translating to similar benefits for electric renters. This is because Bihar's water markets are not competitive and mostly natural oligopolies. Average rental rates for the kharif season are lesser than rabi season, probably due to less demand. Average rental rates for kharif 2021-2022 season are less than average rental rates for kharif 2022-2023 season, probably because of delay in rainfall and severe droughts.

As the number of pumps increases in a water market, it can be expected that ceteris paribus, the equilibrium rental rate of water market will go down. To check this a variable for density of pumps which represents number of pumps owned per 100 acres of agricultural land in a village (A) is used. Graphs of local polynomial regressions of per hour rental rate for wheat on densities of pumps owned (A) depicts that as the number of pumps owned per 100 acres of agricultural land increases the general trend is a reduction in average per hour season rental rates of irrigation pumps in local groundwater market (Figure 6).

If this increase in total number of pumps for water sale is driven by an ownership of electric pumps, and diesel pumps and electric pumps are substitutes, the total average rental rate of market will be less than if the increase was driven by ownership of diesel pumps. It is however difficult to decipher the trend followed by per hour rental rates if share of electric pumps in total owned pumps increases, from graph of local polynomial regression of per hour rental rate for wheat on density of electric pump owned (EPO).

We test the following null hypothesis regarding Bihar's water markets:

- Rental rate of electric pumps is not less than diesel pumps

- Keeping the total number of pumps in a groundwater market constant, diesel rental rates in more electrified groundwater markets are not less than diesel rental rates in less electrified groundwater markets

We estimate two models, based on equation 2 and 4 and run simple ordinary least square estimation Equation 2 corresponds to model 1 and equation 3 corresponds to model 2.

$$Yi = \beta 0 + \beta 1 pumptypei + \beta 2 X2i + \alpha i + \varepsilon i \quad (2)$$

$$Yi = \beta 0 + \beta 1 pumptypei + \beta 3 X3i + \beta 4 X4 * Di + \beta 2 X2 + \alpha i + \varepsilon i \quad (3)$$

The outcome variable for models 1and 2 is per hour rental rate of rabi 2021-2022 season. The independent variable *pumptype* in both models represents the kind of irrigation pump leased-in by the household. The variable takes value 1 if households lease-in a diesel pump. It takes value 2 and 3 if household leases-in an electric submersible or centrifugal pump respectively. The independent variable *X3* represents the owned pump density (A) in M2. The interaction term in M2 is density of electric pumps (EPO) interacted with a binary variable identifying if the leased-in pump is diesel or electric.

Controls include ownership of irrigation source, education level of main farmer, caste category, religion, and asset index of household (exclusive of irrigation infrastructure) and crop fixed effects. For M2 additional controls added include number of ponds available in village, post-monsoon water table depth, and availability of canal as a source of irrigation in village. Both models control for ACZ fixed effects.

(Table 7) Regression results suggest that hourly rates of irrigation from centrifugal electric pumps are the lowest while diesel pumps charge the highest rental rates. Rental rate of an electric centrifugal pump is likely Rs. 98 less and rental rates of an electric submersible pump is likely Rs. 83 less per hour of irrigation as compared to the rental rate of a diesel pump. Thus, we can reject the null hypothesis that electric pumps rental rate is not less than rental rate of diesel pumps. Larger landowners pay marginally higher water rental rates, contrary to expectation. A one acre increase in land ownership is associated with a 4.5 rupees/hour higher pump rental rate. The difference is small but statistically significant.

An increase in number of pumps in local water markets is associated with reduction in reduction in rental rates (Figure 6) but the result is not statistically significant at household level, as in M2.

An increase in the number of electric pumps (EPO) in the local water market, keeping the number of pumps constant is associated with a reduction in water rental rates (Figure 7) but the result is not economically or statistically significant. However, keeping the number of pumps in a water market constant and increasing the density of electric pumps by 10% is associated with a reduction in per hour rental rates of diesel pumps by Rs 2. The result is statistically significant, however not very economically significant.

Controlling the horsepower (hp) of pumps does not change our results significantly but reduces the number of available observations for analysis. Most pumps in our sample are in the 2-8 HP range and larger pumps do not report charge higher water rates of water buyers.

Water, and its use in Agriculture

Irrigation Intensity

Irrigation is one of the main inputs required to increase the productivity of crops (Kishore and Singh 2021) and limitation on irrigation is one reason for agricultural stagnation in Bihar from 2000-2015 Despite its importance to livelihoods and the economy, agriculture in Bihar has stagnated (Najmuddin, et al. 2018). Prevalence of majorly diesel pumps accompanied by deficient rains and fallen groundwater levels has added to increasing cost of irrigation for farmers in Bihar, higher cost being a primary reason for under-irrigation (Hoda, Rajkhowa and Gulati 2017). With decreased cost of irrigation because of electrification of irrigation and allied services, household and its water use can be expected to change.

The average number of irrigations given to wheat in sample is 2 and only 1% of households irrigate 5 or more times. Electric pump users (owners and renters) irrigate their wheat crop a median of 3 times while diesel pump users (owners and renters) irrigate 2 times. We measure the total number of hours of irrigation provided to crops of the largest plot throughout the season. A median of 26 hours of irrigation is provided to the wheat crop throughout rabi 2021-2022 season in our sample (Table 8). Average hours of irrigation given to wheat is more for electric pump owners and renters as compared to both diesel pump owners and renters. This is expected since the cost of irrigation for electric pump owners and renters is less than both diesel pump owners and renters.

We test the following null hypothesis:

- Households which have access to Electric pumps (rented or owned) do not irrigate more as compared to a household that used a diesel pump.

To test the hypothesis, we run OLS estimation for regression equation 4.

$$Yi = \beta 0 + \beta 1 pumptypei + \beta 2X2i + \alpha i + \varepsilon i \quad (4)$$

The outcome variable in is the hours of irrigation provided to crops. The independent variable is the *pumptype* used to irrigate the crop. *Pumptype* variable here takes value 1 and 2 if household uses a rented or own diesel pump for irrigation respectively. It takes values 3 and 4 if the household uses an own or rented electric pump for irrigation respectively. Controls include the area of crop cultivated, soil texture and quality, number of ponds in village, post monsoon water table depth, asset index, caste, and religion of household. Agrozone geographical fixed effects and crop fixed effects are used.

(Table 9) Controlling the land cultivated and crop cultivated, a household which uses own electric pump is associated with irrigating on average approximately 12 hours more than a household which uses rented diesel pump. Similarly, a household which uses an electric rental pump is associated with irrigating 3.5 hours more than diesel rental pump and 4.5 hours more if the household uses an owned diesel pump. Thus, an electric pump user is more likely to irrigate their crop an increased number of hours. Including horsepower from the pump as a control effect gives similar observations for all results but leads to loss in observations. A household which uses its own diesel pump is associated with irrigating 0.95 hours more than a rented electric pump, but the result is not statistically significant. A household which uses its own electric pump is associated with irrigating 7.3 hours more than own diesel pump and the result is significant at 90% confidence interval. Similar findings are found for paddy grown in kharif season.

Cropping Intensity

Another major source of agricultural growth is cropping intensity (Singh, et al. 2014). We notice that electrification of wells and tubewells affect agricultural and groundwater outcomes through reduced cost of irrigation. With the lower per unit cost of pumping, we expect farmers to operate for longer hours and hence, grow crops more intensively. The productivity of crops grown under appropriately irrigated conditions is often higher than that of the same crops underirrigated/unirrigated/rainfed (Hussain and Hanjra 2004). Higher productivity partly stems from higher land use intensity and higher cropping intensity. Increased irrigation affects cropping intensity positively (Dhawan and Datta 1992).

The average cropping intensity of households in our sample is 170 (Table 10). We have calculated cropping intensity as the ratio of gross cropped area across the three cropping seasons to net cultivable land operated by the household. Average cropping intensity is higher for smaller landholders which is expected because smaller household grow minimize risk through diversification (Singh, et al. 2014). Growing a summer crop is suggested to increasing cropping intensity of state since the increasing contribution of pre-monsoon rainfall in annual rainfall for all agroclimatic zones indicate that there is a possibility of summer crop in the region (Kumar and Kumar 2015). Three out of four households in our sample did not cultivate any summer crops.

We test the following null hypothesis on our sample in Bihar:

- Electric pump user does not have more cropping intensity than diesel pump users
- Electric pump users are not more likely to cultivate a summer crop than diesel pump users

We run two models of OLS regressions based on education 6. The outcome variable in model 1 is the household cropping intensity and in model 2 it is probability of cultivating a summer crop. The variable *pumptype* used for irrigation (own electric, rented electric, own diesel, or rented diesel) is the main independent variable of interest and farmers renting diesel pumps are the reference group in both models. We control agricultural land owned, caste, religion, and asset index of the household. In addition, both models include controls for the number of ponds in the village, availability of canal irrigation, and the depth to groundwater table in the village and the ACZ fixed effects.

$$Yi = \beta 0 + \beta 1 pumptypei + \beta 2 X2i + \alpha i + \varepsilon i \quad (6)$$

(Table 11) Farmers using electric pumps—owned or rented—are associated with significantly higher cropping intensities and are significantly more likely to grow summer crops as compared to the farmers who use only diesel pumps in all seasons. Electric pump owners have is associated with having 28% higher cropping intensity than a household which rents diesel pumps, and they are 27% more likely to grow a summer crop in at least some of their land. Farmers who rent electric pumps are associated with having 12% higher cropping intensity and they are 12% more likely to grow a summer crop compared to households which rent diesel pumps. The difference between diesel pump owners and renters is statistically not significant. While the difference between electric pump owners and renters is both economically and statistically significant.

Discussion

Our analysis shows early evidence of positive impacts of electrification of irrigation on agriculture. Access to an electric pump is associated with reduction in the cost of irrigation, higher irrigation frequency and irrigation use intensity, increasing cropping intensity and greater likelihood of growing a summer crop. Although a more rigorous analysis is needed to assess causality and magnitude of these impacts with greater accuracy. We also need to measure the impact of improved access to more affordable irrigation on crop yields and net profits from agriculture.

Two findings from our analysis require deeper understanding. First, nearly three in four pump owners in our sample do not sell water to any other farmer even when most pump owners themselves own a mean of 1.5 acres of agricultural land. The non-sellers include both diesel and electric pump owners. This pattern is not unique to Bihar. An independent survey of 6592 farmers in 6 districts of North Bangladesh also found that 75 percent of all pump owners did not sell water to other farmers (Reference). While water markets in Bihar have been natural oligopolies, it was expected that increased access to pump ownership facilitated through electric pump ownership will make markets more competitive. A typical 3 horsepower centrifugal electric pump costs $150-200 and can last up to 10 years (Reference). With an increased share of farmers owning an accessible pump, water markets will be less competitive if most pump owners do not choose to sell water to other farmers. It will also result in lower capacity utilization of pumps and sub-optimally high investments in pump sets. Low fixed costs allow pump ownership to be financially viable even if the pump is used sparingly.

Second, in both Bangladesh and Bihar, pump owners with smaller landholdings are less likely to sell water. This is even more surprising. This finding contrasts with our expectation that a pump owner with smaller cultivated areas would be more likely to sell water because their own irrigation requirements are smaller, and they have more spare capacity to rent their pumps out. We need deeper interactions with pump owners in Bihar (and Bangladesh) to understand their reluctance in selling water to other farmers.

Policy Implications of our Findings

Farmers in Bihar are responding to improved rural power supply in the state by investing massively in electric pumps. The smallholder farmers in state have invested more than $40-50 million in electric pumps over the past decade. This investment has resulted in access to more affordable irrigation for pump owners, and to some extent, for water buyers too. How do we leverage public investment in rural electrification and power supply to ensure access to affordable irrigation to all farmers in the state without threatening the aquifers? Evidence from West Bengal, where the electrification of irrigation started a few years earlier than Bihar, shows that switching from diesel to electric pumps alone may not lead to a transformational change in agriculture (A. B. Mukherji 2020). This leads to a second but related policy question: how do we maximize the irrigation surplus from widespread access to affordable irrigation in Bihar? Finally, how can Bihar (and other areas in the EGBM) avoid the economic and environmental problems created by irrigation with cheap or free electricity in other parts of South Asia?

All three questions are relevant not only to Bihar but also to other parts of the EGBM basin in Eastern Uttar Pradesh, Bangladesh, and Nepal Terai where rapid electrification of irrigation is underway. Unfortunately, we do not have answers to these very important questions. However, we want to conclude the paper with a brief discussion on the potential pitfalls of heavily subsidizing electricity for irrigation in Bihar.

Government of Bihar, like many other states governments in India, is subsidizing electricity for irrigation heavily. According to our calculation, farmers pay only about 10 percent of the cost of electricity they use. Access to affordable irrigation does not require such high subsidies.

Electricity, even if charged at its full cost of supply, is a much cheaper fuel for pumps compared to diesel. A 5-horsepower electric pump uses 4 units of electricity per hour of operation which will cost a farmer about Rs. 30 without any subsidy. In comparison, a diesel pump of the same capacity will use 1 liter of diesel in one hour costing the farmer Rs. 94 excluding the cost of bringing the diesel from the gas station to her farmgate. Instead of subsidizing electricity, the state government should ensure that farmers get reliable and uninterrupted power supply throughout the year.

Money used to subsidize power tariffs for irrigation can be better used to finance public investments to expand the grid to distant farms, further away from the main roads where the existing grid lines are. It will help all farmers access electricity for irrigation. At present, farmers whose fields are further away from existing grid lines are investing in long thin wires to connect their pumps to the main grid lines. This *ad hoc* solution leads to significant waste of energy (following ohm's law, the thinner the wire, the higher the distribution loss in electricity) and voltage drop for pumps. Public investment in grid expansion will also reduce the capital investment farmers need to install and use an electric pump. Lower capital outlays will lower the barriers to entry and make water markets more competitive. Making water markets more competitive is essential to ensure universal access to affordable irrigation in Bihar.

A tariff subsidy on electricity for irrigation is not only a burden on the taxpayers, but it is also regressive. Resourceful pump owners benefit much more from it than the less well-off water buyers. Cheaper electricity also leads to inefficient use of energy and groundwater.

Only 46% of the available groundwater is extracted in Bihar, implying an under-utilization of available groundwater resources at the aggregate level (Board 2021) and there is a huge scope to accelerate sustainable use of groundwater for harnessing a positive groundwater-agricultural development linkage. Though secular decline in groundwater level is not a problem in most areas of Bihar, aquifers in 72 of the 534 blocks in the state are classified as semi-critical, 18 blocks are critical, and 2 blocks are overexploited. Temporary decline in water tables below 8-9 meters in the pre-monsoon season is more widespread, especially in South-West Bihar. Centrifugal pumps no longer work when the water table recedes more than 8-9 meters below the ground level. More expensive submersible pumps are needed to pump water from such depths. Very few farmers in Bihar can afford to invest in submersible pumps. Unlike centrifugal pumps, submersible pumps are not portable. Water markets can become less competitive and access to groundwater more unequal in areas if farmers must switch from centrifugal to submersible pumps for groundwater irrigation. This technological switch can even impoverish farmers (Sekhri 2014) and reduce their resilience to droughts and dry spells in rice-wheat systems where lack of access to affordable to irrigation in the pre-monsoon season can affect the system level yields, especially if there is a delay in the onset of monsoon rains.

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Figure captions

Figure 1. Number of electrified tubewells in North and South Bihar (2014-15 to 2020-21)

Figure 2. Sampled Districts and Villages for Primary Survey in Bihar

Figure 3. Density map of pump ownership and electric pump ownership

Figure 4. The number of villages belonging to different electric pumps owned density ranges in the sample.

Figure 5. Scatter plot of probability of ownership of pump for each decile of agricultural land owned by households.

Figure 6. Scatter plot of probability of ownership of electric pumps for each decile of agricultural land owned by households.

Figure 7. Twoway Lpoly graph of density of per hour rental of wheat during Rabi 2021-2022 on pumps owned per 100 acres of cultivated land in a village.

Figure 8. Twoway Lpoly graph of density of per hour rental of wheat during Rabi 2021-2022 on electric pumps owned per 100 pumps owned in a village.

Table Captions

Table 1. The Sampling Plan

Table 2. Household Characteristics

Table 3. Percentage share of pumps owned with each agrozone. Figures in brackets represent percentages.

Table 4. OLS regression models of ownership of pumps and ownership of electric pumps across both houselisting and household datasets.

Table 5. Descriptive statistics, pumps that sell water of pumps owned in sample

Table 6. Per hour rental rate of leased-in pumps for wheat crop cultivated during season Rabi 2021-2022

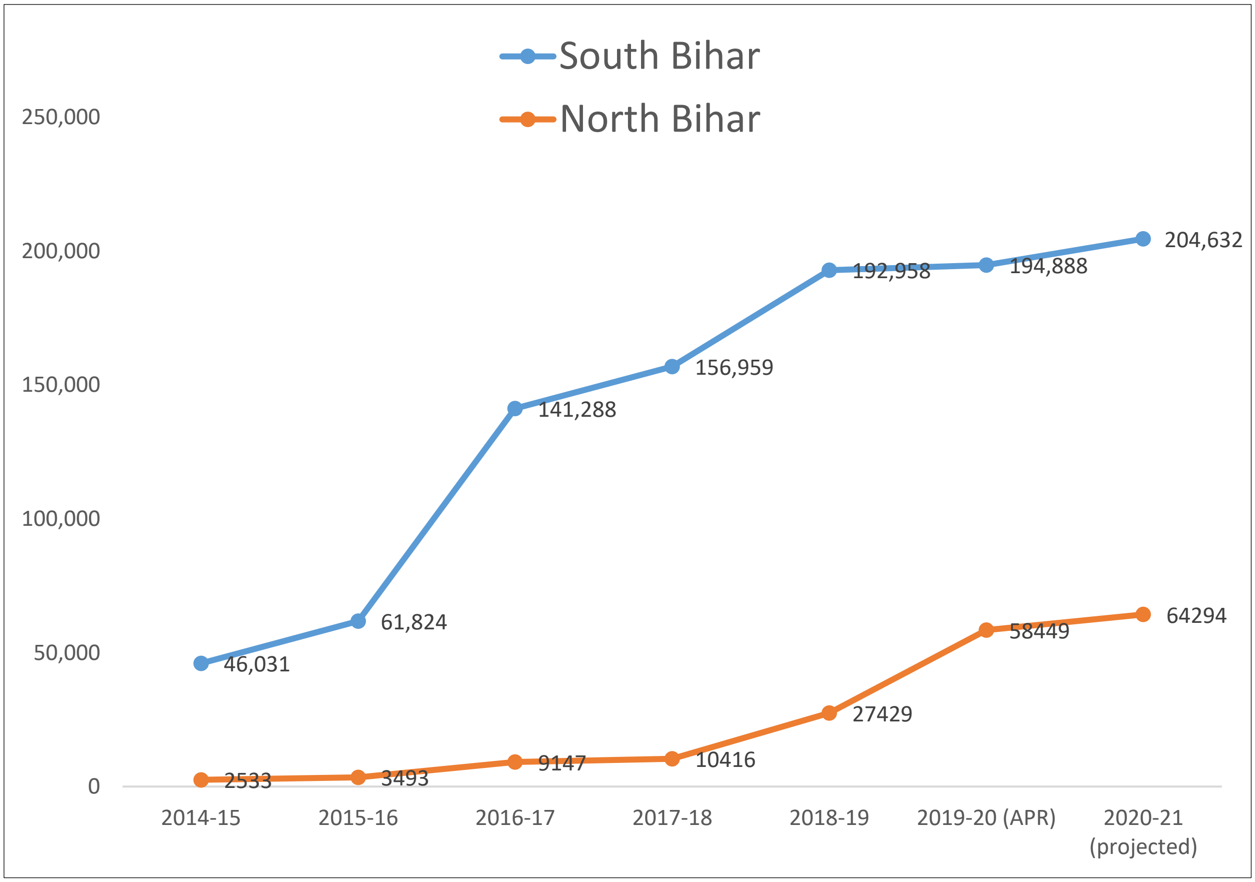
Table 7. OLS regression models for Rental rate of irrigation pumps

Table 8. Median hours of irrigation provided by each kind of pump

Table 9. OLS regression for hours of irrigation provided to under each kind of irrigation pump

Table 10. Average cropping intensity of different types of households categorized on the kind of irrigation pump they have access to

Table 11. OLS regression of cropping intensity on households using different means of irrigation



Figures

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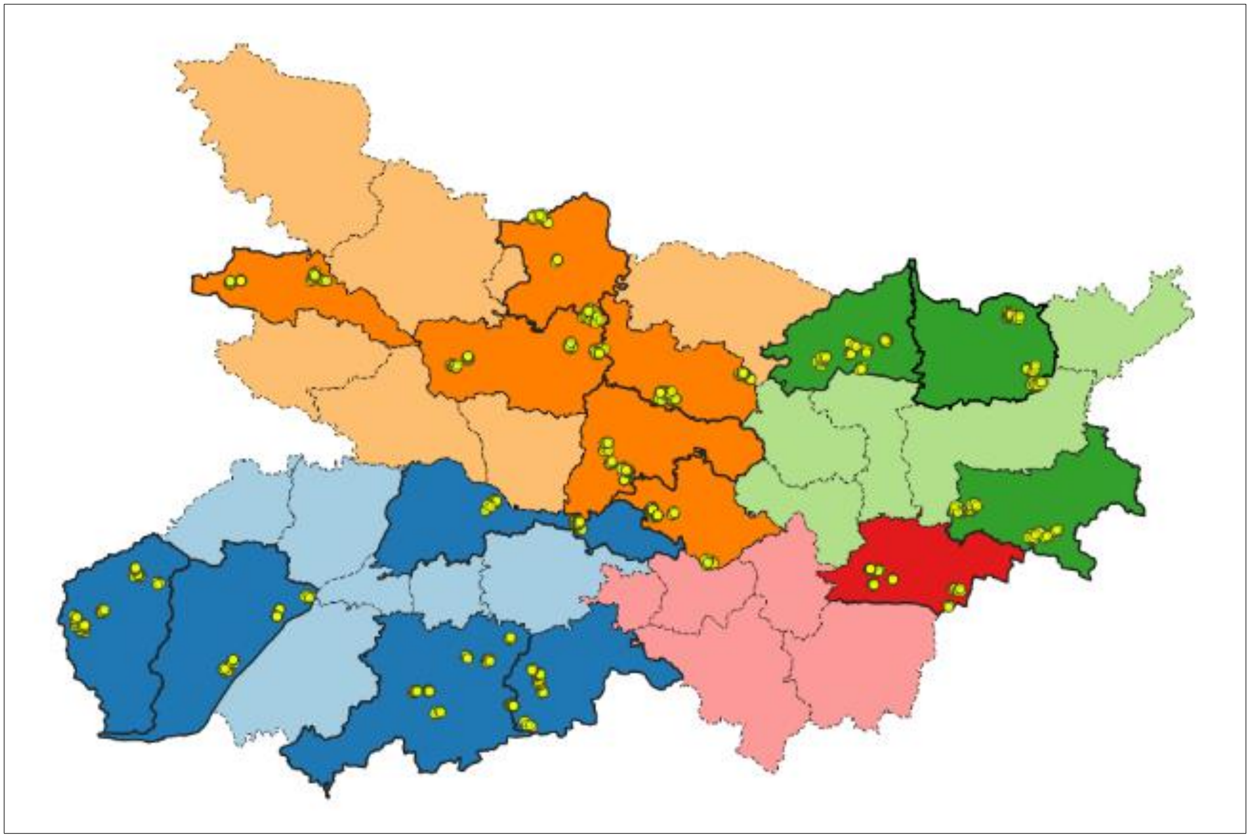
Number of electrified tubewells in North and South Bihar (2014-15 to 2020-21)

Figure 2.

Sampled Districts and Villages for Primary Survey in Bihar.



Note: Districts in the 4 agro-climatic zones of Bihar are shown by 4 different colors. The 15 districts in our sample are shown by darker shades. Yellow circles show the locations of the 90 villages sampled for our study.

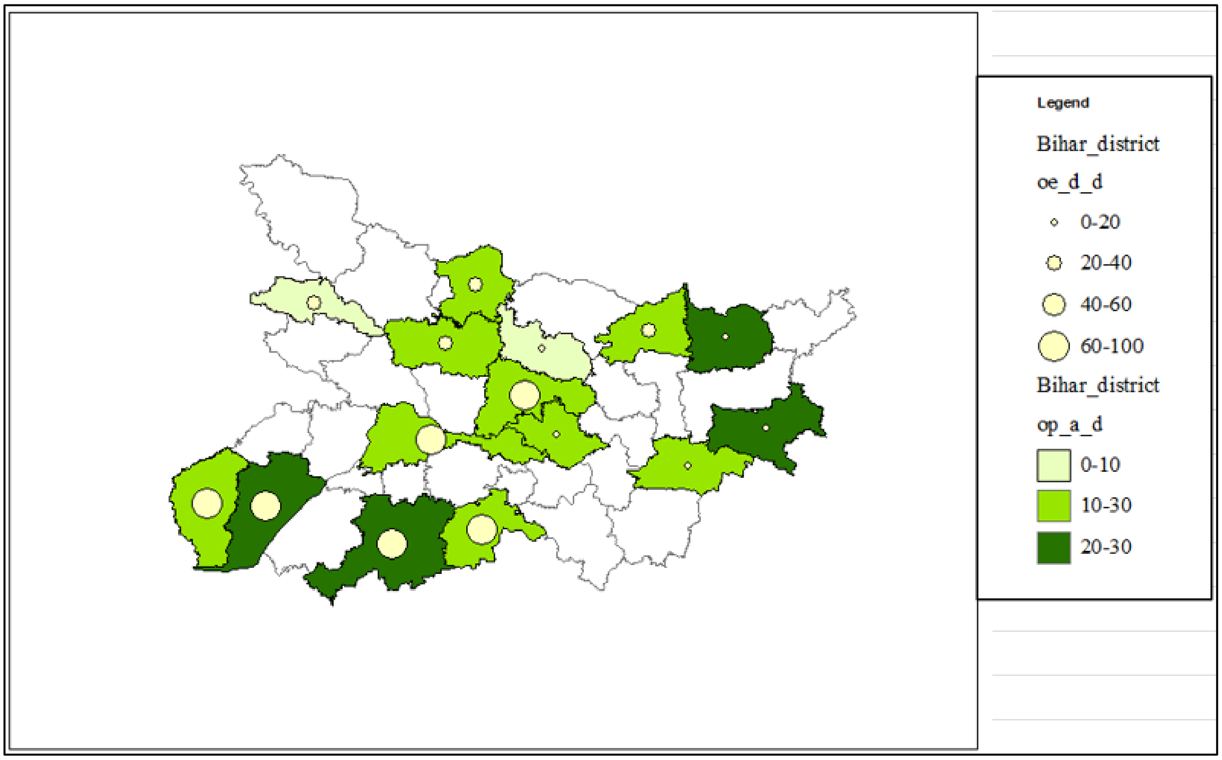


Figure 3.

Density map of pump ownership and electric pump ownership.

Note: Oe_d_d stands for electric pump density (EPO)in a village. Op_a_d is the pump ownership density (A) in a village.

Figure 4.

The number of villages belonging to different electric pumps owned density ranges in the sample.

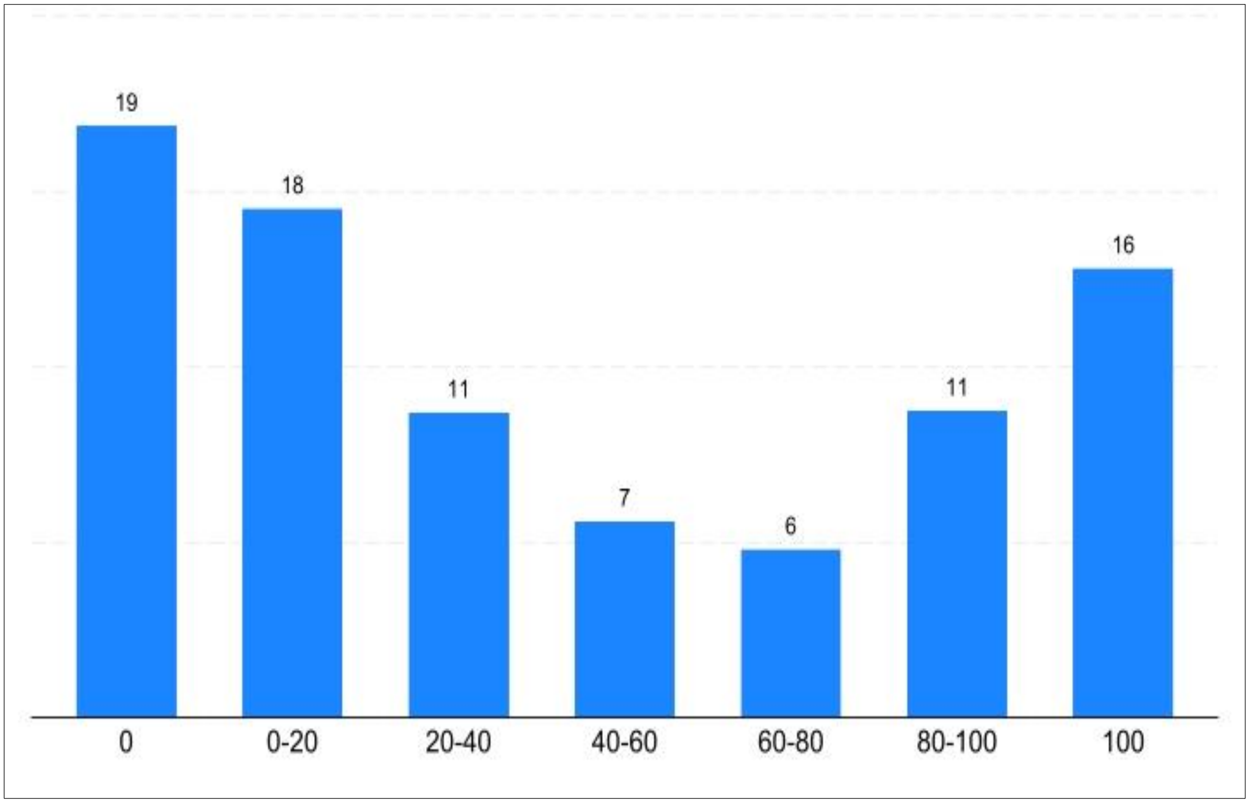
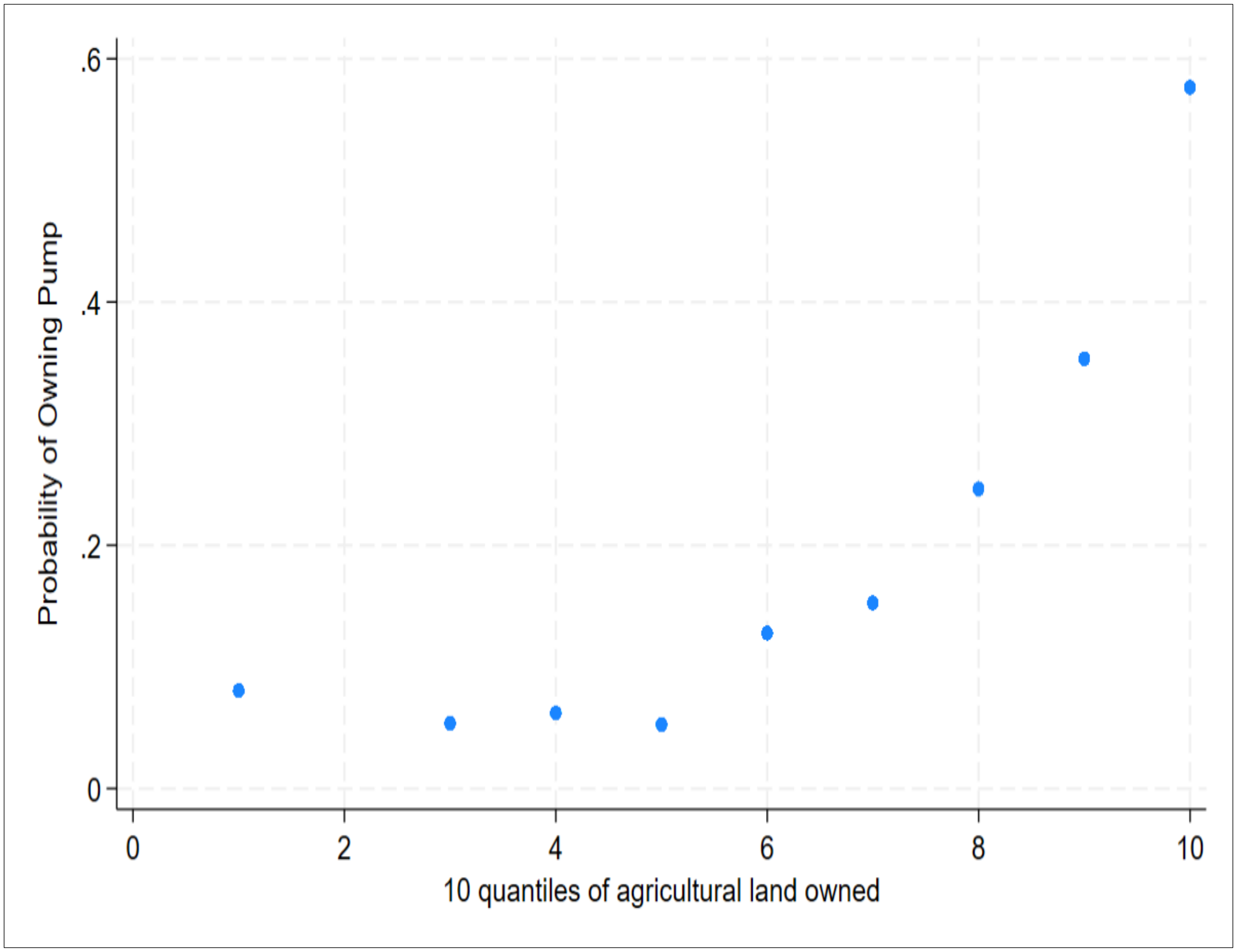


Figure 5.

Scatter plot of probability of ownership of pump for each decile of agricultural land owned by households



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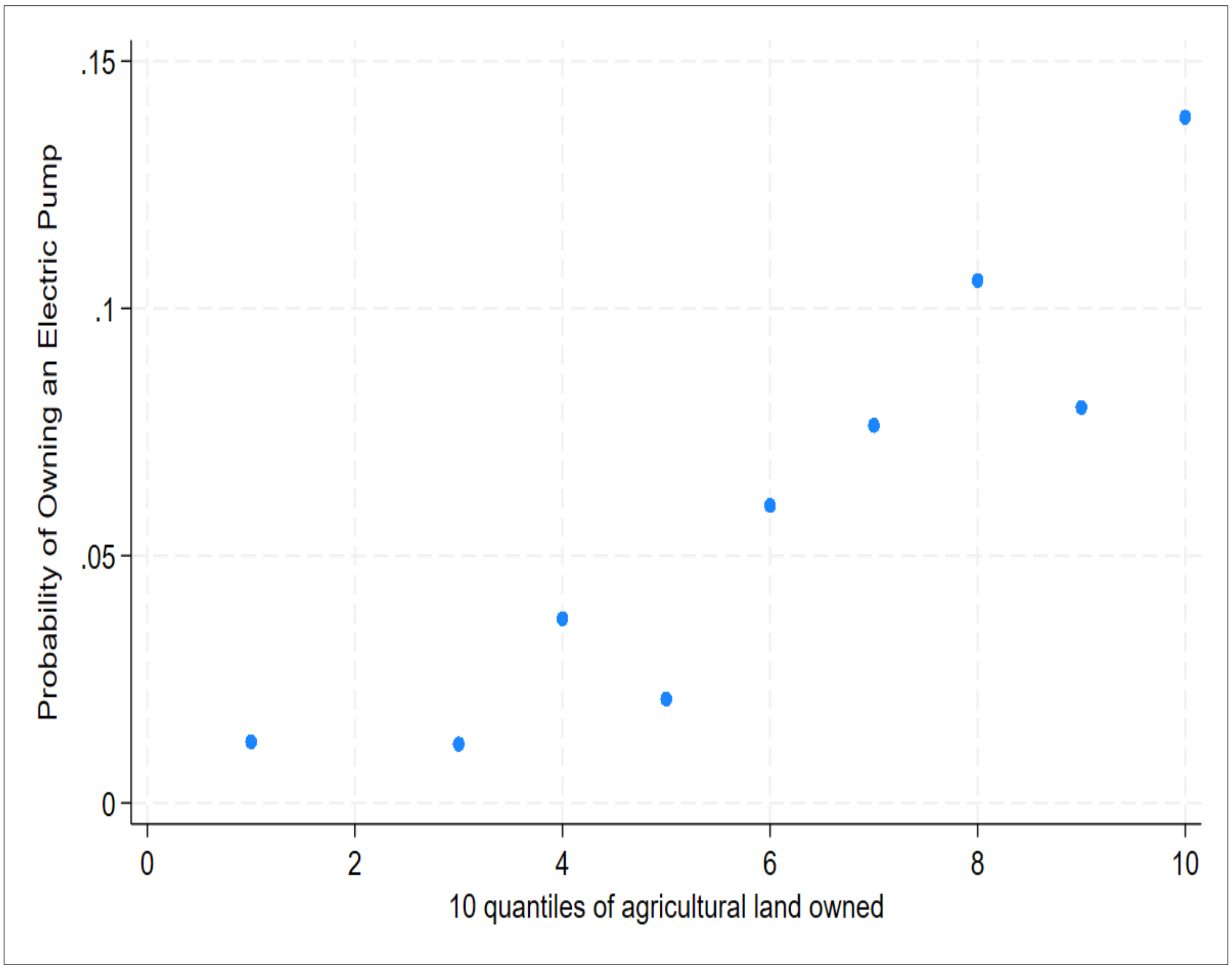
Scatter plot of probability of ownership of electric pumps for each decile of agricultural land owned by households.



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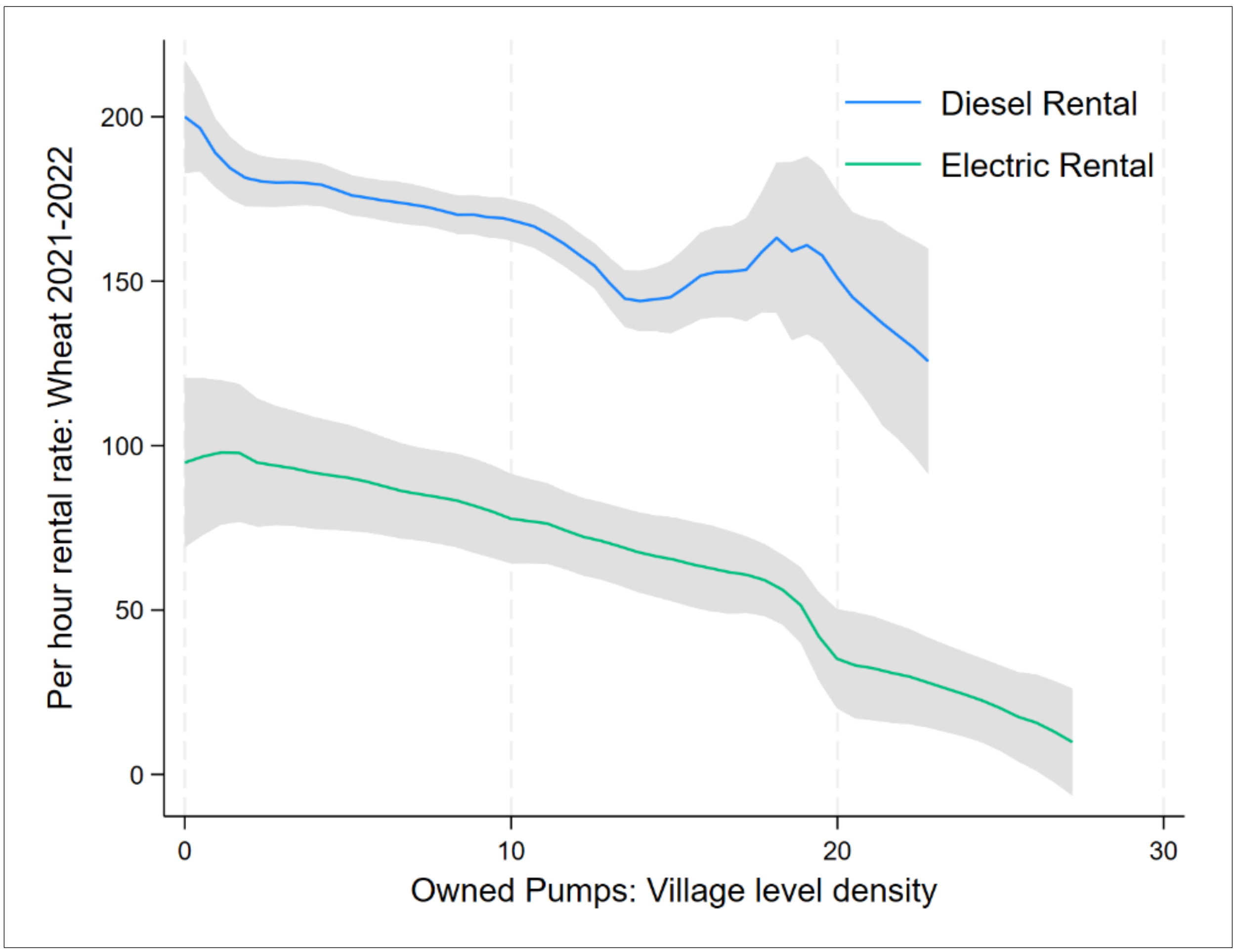

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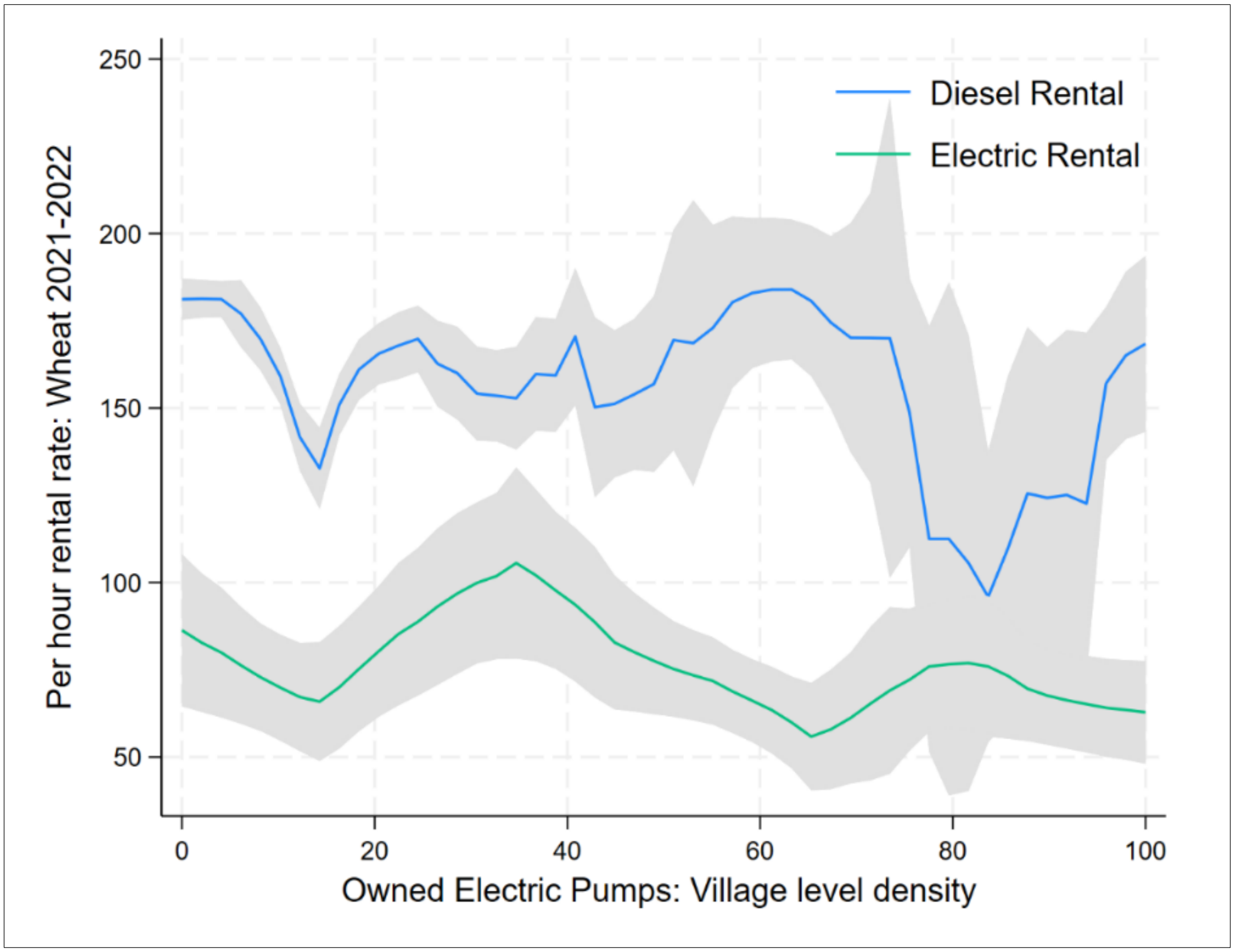

Tables

Table 1.

The Sampling Plan

Strata	**Numbers**
Districts	15
Blocks	30
Villages	90
# households in the house listing	17,620
# farming households in house listing	9980
Number of households in the final sample	1440

Table 2.

Household Characteristics

	Sample
Houselisting Sample	N = 17,620
# Farming households (HHs)	9980
# Farming households which use pumps for irrigation	9717
Median operated land (acres)	0.89
	Percentage
Share of pump owners in farming households	16.3
Share of pump owners with a diesel pump	65.6
Share of pump owners with an electric pump	44.3
Share of farming households who rely on rented diesel pump	54.9
Share of farming households who rely on rented electric pumps	41.7
Household Sample	N = 1440
Household Characteristics	
Median agricultural land owned by households (acres)	0.4
Average household size	6.09
Caste Category of household	*Percentage*
General	17
Schedule Caste	19
Other Backward Caste	64
Religion of household	*Percentage*
Hindu	91.4
Muslim	8.5
Irrigation Infrastructure	*Percentage*
Owns a tubewell	14.4
Owns pump	17.6
% pump owners with an electric pump	35
% pump owners who sell water to other farmers	18.5
Irrigated Area/Net Cropped Area	*Percentage*
Wheat	99.3
Paddy	92.3

Table 3.

Percentage share of pumps owned with each agrozone. Figures in brackets represent percentages.

	Sample	NE	NW	SE	SW
Pumps used	2312	416	1080	134	682
(Pumps Owned of pumps used)	(11.8)	(18.5)	(7.7)	(17.1)	(13.1)
Pumps Owned	275 (100)	77 (100)	85 (100)	23 (100)	90 (100)
% Share in total pumps owned in the zone					
Electric submersible pumps	21.8	9	5.8	0	53.3
Electric centrifugal pumps	9.8	0	3.5	0	26.6
Diesel pumps	68.3	90.9	91.6	100	20

Table 4.

OLS regression models of ownership of pumps and ownership of electric pumps across both houselisting and household datasets.

	Owns Pump (Ref: Does not own pump)	Owns Electric Pump (Ref: Owns Diesel Pump)	Owns Pump (Ref: Does not own pump)	Owns Electric Pump (Ref: Owns Diesel Pump)
Dataset	Houselisting		Household	
	(M1)	*(M2)*	*(M3)*	*(M4)*
Cultivate Land	0.06*** (0.003)	-0.01*** (0.003)		
Landless Tenants	-0.001*** (0.0001)	-0.09* (0.05)		
Agricultural Land Owned			0.07*** (0.013)	0.005 (0.017)
Main Farmer Female			-0.07*** (0.01)	0.1 (0.07)
Agrozone (Ref: NE)				
NW	-0.08*** (0.009)	0.17*** (0.02)	-0.06*** (0.02)	-0.12** (0.06)
SW	-0.008 (0.01)	0.78*** (0.02)	-0.03 (0.02)	0.53*** (0.08)
SE	-0.05*** (0.01)	0.04 (0.03)	-0.007 (0.03)	-0.15 (0.06)
Constant	0.08*** (0.009)	0.17*** (0.02)	0.05 (0.03)	1.2*** (0.11)
Adjusted R^2	0.13	0.46	0.32	0.58
Fixed Effects	Agrozone	Agrozone	Agrozone	Agrozone
Controls	Yes	Yes	Yes	Yes
Observations	9821	1610	1417	247

Table 5.

Descriptive statistics, pumps that sell water of pumps owned in the sample.

Pumps Owned: 275	Sample
Pumps that sell water of pumps owned	17.4%
Electric submersible pumps that sell water of ES pumps owned	16.6%
Electric Centrifugal pumps that sell water of EC pumps owned	29.6%
Diesel Centrifugal pumps that sell water of DC pumps owned	15.9%

Table 6.

Per hour rental rate of leased-in pumps for wheat crop cultivated during season Rabi 2021-2022.

	Wheat 2021-2022	Rice 2022-2023
Rental rate (Rs)	149.4	114.2
Rental rate: Electric submersible	76.0	48.2
Rental rate: Electric centrifugal	63.4	33.9
Rental rate: Diesel centrifugal	169.9	163.8

Table 7.

OLS regression models for Rental rate of irrigation pumps.

Rental rate of Rabi 2021-2022 season		
	(M1)	*(M2)*
Ref: Diesel Centrifugal		
Electric Submersible	-82.9***	-86.4***
	(4.8)	(6.02)
Electric Centrifugal	-97.0***	-100.2***
	(5.1)	(7.6)
Agriculture land owned	4.3*	4.73**
	(2.4)	(2.4)
Pumps owned per 100 acres of cultivated land		-0.35
		(0.25)
% share of electric pumps in the village		-0.09
		(0.08)
Share of electric pumps*Diesel		-0.2**
		(0.1)
Constant	123.9***	130.1***
	(5.6)	(6.4)
Adjusted R^2	0.56	0.60
Crop Fixed Effects	Yes	Yes
Area Fixed Effects	Agrozone	Agrozone
Controls	Yes	Yes
Observations	826	824

Table 8.

Median number of hours of irrigation provided by each kind of pump.

Median numbers	Wheat 2021-2022	Paddy 2022-2023
Hours of Irrigation per acre	26.1	32
Rented Diesel	23.4	26.6
Own Diesel	24	25.6
Own Electric	38.4	64.5
Electric Rental	32	46.3

Table 9.

OLS regression for hours of irrigation provided to under each kind of irrigation pump.

Hours of Irrigation: Rabi 2021-2022	
Ref: Rented Diesel	*(M1)*
Diesel Own	4.5**
	(1.7)
Electric Own	11.8***
	(3.5)
Electric Rental	3.5***
	(0.99)
Constant	4.9**
	(2.4)
Adjusted R^2	0.46
Crop Fixed Effects	All crops
Area Fixed Effects	Agrozone
Controls	Yes
Observations	1224

Table 10.

Average cropping intensity of different types of households categorized on the kind of irrigation pump they have access to.

	Sample
Cropping Intensity	170%
Household Leases Diesel Pump	170%
Household Owns Diesel Pump	160%
Household Leases Electric Pump	180%
Household Owns Electric Pump	180%

Table 11.

OLS regression of cropping intensity on households using different means of irrigation.

	Cropping Intensity	*Grows Summer Crop*
Ref: Rented Diesel	*(M1)*	*(M2)*
Owns Diesel Pump	3.5	-0.03
	(5.3)	(0.04)
Leases Electric Pump	12.1***	0.12***
	(4.0)	(0.02)
Owns Electric Pump	27.8***	0.27***
	(7.4)	(0.06)
Agriculture land owned	-8.8***	-0.02*
	(1.6)	(0.01)
Constant	200.1***	0.4***
	(6.4)	(0.05)
Adjusted R^2	0.12	0.10
Area Fixed Effects	Agrozone	Agrozone
Controls	Yes	Yes
Observations	1352	1353