Beyond Lights: The Changing Impact of Rural Electrification on Indian Agriculture

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Abstract

In rural India, electricity is important in enabling groundwater irrigation leading to increased agricultural production, productivity and thereby farm incomes, albeit at the cost of depleting groundwater. India pumps more groundwater for irrigation every year than any other country, yet parts of India remain largely unirrigated despite healthy groundwater levels. This paper investigates the contribution of a temporal change in India's rural electrification policy in the uneven development of groundwater irrigation. I construct a district level panel dataset using two broad waves of rural electrification and measure the impact of the rural electrification policy change on groundwater irrigation outcomes with a fixed effects model. I find that the policy change resulted in over 37% lesser growth in electric pump use in districts electrified in the second wave compared to districts electrified in the first wave. The reduction in irrigated area growth was nearly 53% during Rabi (dry cultivation season). These reductions cannot be explained by differences in household wealth, the need for, or the availability of groundwater resource. Even the richest 85% farm households irrigated smaller areas on average in the later electrified districts than did the poorest 15% in the earlier electrified districts. The results suggest a need for India to address the unintended impacts of its current rural electrification policy, particularly as groundwater irrigation will likely continue (and perhaps grow) in its important role in the country's food security. My results also imply an important oversight more broadly in the measurement of electricity access using household electrification. It is possible that governments across the developing world could be limiting electricity-enabled income generating activities by solely targeting domestic electrification.

Keywords Electricity access; Rural electrification; Groundwater irrigation; Fixed effects; India

1 Introduction

Electricity access has been gaining importance as a driver of development even before its adoption among the Sustainable Development Goals in 2015 (See SDG Goal 7.1.1). Electricity access is primarily a rural challenge across the developing world due to high infrastructure costs and low payment rates. In response, government subsidized electrification programs have mushroomed in recent years, often aided by multilateral development funds. The World Bank alone had provided more than USD 5B for electrification programs across 35 countries between 2010 and 2018 (World Bank, 2018).

In most developing countries, the target of electricity access programs has been household electrification. In India, a similar focus on household electrification preceded the announcement of UN SDGs, when the government launched the national electrification program *Rajiv Gandhi Grameen Vidyutikaran Yojana* (RGGVY) in 2005. Progress on electrification has been made at impressive rates since then and the latest government numbers indicate near universal household electrification (see *saubhagya* dashboard). However, little can be conclusively said about the short-run or long-run impacts of RGGVY in particular, and of electrification programs more generally. There is scant evidence to suggest that electrification leads to significant economic gains in newly electrified regions of South Africa (Dinkelman, 2011), Kenya (Lee et al., 2019) and Rwanda (Lenz et al., 2017). While these studies suggest that electrification may not lead to economic gains at previously assumed scales, they also highlight our lack of knowledge about the mechanisms through which electrification impacts household income and other economic outcomes. This paper fills the gap by looking at the impact of rural electrification (RE) on economic development through agriculture, which remains the largest sector of the Indian rural economy.

Electricity plays an important role in the rural economy in India by enabling groundwater pumping for irrigation. Irrigation can have a multiplicative effect on rural incomes by allowing farmers to cultivate multiple crops per year, to grow high-value crops, and to increase the economic returns to labor, machinery, and chemical input use. Irrigation in India is majorly sourced from groundwater through wells (over 60% of irrigated area) and surface water through canals (over 25% of irrigated area) (Ministry of Agriculture & Farmers Welfare, 2019). Groundwater can be accessed during dry cultivation months when surface water flow is diminished, making it a particularly effective source of irrigation. Additionally, wells afford farmers independence as wells unlike canals do not suffer from competing use for generation of hydro-power and riparian rights. The role of groundwater irrigation in Indian agriculture is widely studied particularly in the northwest and southern parts of the country, where electricity subsidies to agriculture are hotly debated and have been the cornerstones of multiple state and national elections.[1] Although the rural electrification policy is set by the national government in India, electricity subsidies and supply to agriculture are determined by state governments and therefore vary regionally. Little attention has been given to how the different policies have cumulatively shaped the widely varying agricultural economies of the 28 Indian states.

This paper makes three main contributions to the literature on the impact of rural electrification. First, I study a specific channel of RE impacts on rural economic outcomes in India. Studies so far have largely focused

[1] See Shah (2000), Shah et al. (2003), Dubash (2002), Mukherji (2008) and Giordano and Villholth (2007)

on measuring the impact of electrification on household and village level outcomes of employment, consumption and income without analyzing the mechanisms driving the impacts (Lee et al., 2017). I study the district level impacts of rural household electrification on two indicators of groundwater irrigation: - (1) change in access to groundwater irrigation captured by the number of groundwater wells, and (2) extent of groundwater irrigation reflected in the area irrigated by groundwater wells. I then link groundwater irrigation to agricultural household consumption. Second, I add to the relatively sparse literature quantifying the long-run impacts of electrification in the developing world with the exceptions of van de Walle et al. (2015), Barnes and Binswanger (1986) and Lipscomb et al. (2013). I link two sources of census data to create a district-level panel dataset extending from 1986 to 2013 to study the long-run impacts of RE in India. Third and finally, I link two different uses of electricity - I study the impact of RE defined by the number of rural electrified households (a commonly used metric of RE) on the use of electricity for groundwater irrigation. My results suggest that household electricity access may be an incomplete measure of RE, particularly when the primary objective of RE is to spur economic development. In the context of this study, electricity connections outside of homes are responsible for providing access to groundwater irrigation. Since a change in the Indian RE policy in the 1990s, increase in household electricity access was decoupled from agricultural electricity access. India now finds itself in a situation where it has provided near universal household electricity access with persisting regional variations in agricultural electricity, the third largest sectoral consumer of electricity in India during 2015-16 (Power Finance Corporation Ltd., 2018).

The remainder of the paper is structured as follows. I begin by providing a brief history of the evolution of rural electrification and its role in groundwater irrigation in India. I review the literature on electrification impacts in India and find that the studies have not explored the specific characteristics of rural electrification policies, which could be driving their divergent results. I provide information about the data and descriptive statistics, followed by the estimation strategy in sections 3 and 4 respectively. Section 5, includes the main estimation results of the impact on groundwater irrigation at the district level. I consider threats to identification in section 6 and conclude in section 7.

2 Background - Rural Electrification and Groundwater Irrigation in India

The legislative powers for electricity governance are divided between the national and state governments in India. Post-independence in 1947, the state governments were given the legislative responsibility of electrifying rural areas with no clear guidance on financing and implementational modalities (Kale, 2004). It was not until the late 1960s that the national government focused on RE. Two large scale famines in 1965 and 1966 coupled with President Lyndon Johnson's short tether policy on PL-480, created an urgent need for India to gain self-sufficiency in grain production (Rudolph and Rudolph, 1987).[2] High Yielding Variety (HYV) seeds along with chemical fertilizers and pesticides formed the pillars of India's Green Revolution (GR). However, reliable and steady sources of irrigation were key to GR's success.

[2]See Barrett (2006) for more on the US Public Law 480 (PL-480)

Areas with assured irrigation which were primarily served by canals were initially targeted as part of the "betting on the strong approach" (Varshney, 1995). However, groundwater irrigation soon expanded in response to the stagnating development of canal irrigation (Singh, 1990). The need for cheap motive power to pump groundwater led to RE's expansion in rural areas which benefited most from GR. Success in GR gave rise to an increasingly politicized agrarian lobby, who demanded better and cheaper inputs to aid agricultural production (Varshney, 1995). In response, not only did agricultural electricity coverage increase, electricity rates were also subsidized by instituting flat tariffs in states which witnessed the greatest returns from GR technology (Shah et al., 2004). Household electrification was secondary to agricultural electricity at this time (Banerjee et al., 2014). Barnes and Binswanger (1986) estimated the impact of rural electrification on agricultural outcomes between 1966 and 1980 using a panel data of 108 villages across three states of Maharashtra, Andhra Pradesh and West Bengal. They found positive impacts of years since village electrification on relative use of electric pump-sets, well-based irrigation and multiple cropping.

By the early 1990s, the national government was no longer concerned about grain production. Instead, the Planning Commission in charge of setting India's Five-Year Plans, was concerned about increasing groundwater depletion and financial strain on electric utilities due to indiscriminate pumping by farmers.[3] At this time, there were also large inter-state disparities in RE (Palit and Bandyopadhyay, 2017). RE lagged particularly in states which had lost out on GR driven demand for electricity. RE targets shifted towards household electric connections in the laggard states, with a focus on first connecting all villages and followed by all houses within each village. The central government began providing 100% loans to states with less than 65% rural electrified households (Banerjee et al., 2014).

Studying the impact of rural household electrification in India from 1982 to 1999, van de Walle et al. (2015) disentangled the impact of household electrification from village electrification and found an 8.8% increase in per capita consumption with electrification at the household level and 0.8% increase for electrification at the village level. They also found an increase in days of regular work among electrified households suggesting a possible mechanism of substitution away from casual work towards regular work. They conjectured that electrification of domestic lighting allowed shifting of leisure activities from day to night, freeing up the day for regular work. Using a different set of survey data collected during 2005, Khandker et al. (2014) found a much larger impact of 18% increase in per capita consumption compared to 8% by van de Walle et al. (2015). Differences in empirical strategy and data-sets notwithstanding, both papers reported increases in non-farm income and wage rates and statistically insignificant changes in farm income and employment. When seen together with Barnes and Binswanger (1986), the results suggest that the earlier period of RE was positively correlated with proportion of area cropped multiple times a year and proportion of area using GR technology, which are likely positively correlated with days of agricultural employment and increased farm incomes. In later years, the impact RE on agriculture reduced, possibly due to the shift towards domestic connections.

In 2005, focus on increasing consumptive uses of electricity grew with the launch of Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY) targeting 100% rural household electrification in the next 5 years. Two features

[3] See Planning Commission's Five-Year Plans (1-7) Chapters on Irrigation and Flood Control.

of RGGVY made it particularly different from earlier efforts – full capital subsidy for Below Poverty Line (BPL) households and; focus on unelectrified villages with more than 100 residents. Aggregate electricity demand was calculated using estimated number of households to be electrified and a fixed load capacity per household. The aggregate demand served as the basis for the capacity size of transformers. The individual load capacity of a BPL household was initially estimated at 40-60W, less than a fifth of a non-BPL household at 250 W. Both categories were later revised upwards (250W for BPL households and 500 W for non-BPL households) (Ministry of Power, 2013). Even after the revision, the load capacity of an individual non-BPL house was incapable of handling even a 1HP electric pump-set (approximately 745 W). As a result, transformers in many villages electrified under this program are likely incapable of handling more than a handful of electric pump-sets for groundwater irrigation.[4] Further, in at least one such state where rural electrification occurred majorly through RGGVY, farmers are expected to bear the cost of additional poles and wires to use electricity on agricultural fields (Orissa Lift Irrigation Corporation (2014) and Department of Energy (2016)).[5] It therefore is not surprising that Burlig and Preonas (2016) found no meaningful impact of RGGVY led electrification on either change in the number of irrigation wells or, proportion of cultivated or irrigated area at the village-level. They also did not find any impact on male or female employment or household consumption. Literature on RE impacts in India have not considered the specific features of RE policy they study, which may be driving the contrasting results.

Agriculture continues to be the mainstay of India's rural economy employing over 70% of the country's rural working population and 50% of the country's total working population.[6] India's peculiar case of structural transformation over the last three decades, was characterized by a shift from increasing returns to agriculture to tremendous increases in services, skipping manufacturing. Although this shift has been marked by spectacular GDP growth rates at the national level, it has been accompanied by disappointing outcomes in rural employment and low rural-urban migration (Binswanger-Mkhize, 2013). Therefore at least in the near-term, increasing farm incomes will remain important in addressing rural poverty.

Kishore et al. (2012) found wells and surface water lift-based irrigation to be among the most important determinants of prosperity among smallholder farmers in India. Electricity is the cheapest and most reliable source of pumping power for irrigation. Roughly two-thirds of all irrigated land in India is currently based on groundwater (Government of India, 2018). Groundwater is widely used for irrigation because of its relatively low variable cost of extraction (provided the presence of electricity infrastructure) and individual accessibility. Groundwater wells have been increasing in India since data on them was first collected during 1986-87. The most recent round of data indicates that growth between 2005-06 and 2013-14 occurred almost entirely in the number of deep tube-wells, indicative of the increasing depths to water in some parts of India (Rajan and Verma, 2017). Deep tube-wells have depths greater than 70m and therefore require submersible pump-sets that cannot run on diesel (the alternate energy source) and require electric power.

India is often heralded as the poster-child of RE success across the developing world (see IEA, 2017). Over 280M people were connected to the electricity grid between 2000 and 2010 (Banerjee et al., 2014). The latest

[4] Anecdotal evidence from field visits to Orissa during 2016 and 2018

[5] Villages in most of India are organized such that houses are clustered in one part of the village and agricultural fields are contiguous to each other, often separated from the houses by some distance or a road.

[6] Calculated from Census of India 2011, "General Economic Tables B3: Main, Marginal and Non-Workers."

available government data on household electrification indicates complete coverage of rural households in all states except for Chhattisgarh (formerly part of Madhya Pradesh)(see rural electrification dashboard by the Ministry of Power, Government of India). However, access to groundwater irrigation remains regionally concentrated and not reflective of groundwater availability despite the tremendous increase in electrification coverage (see figure 1).

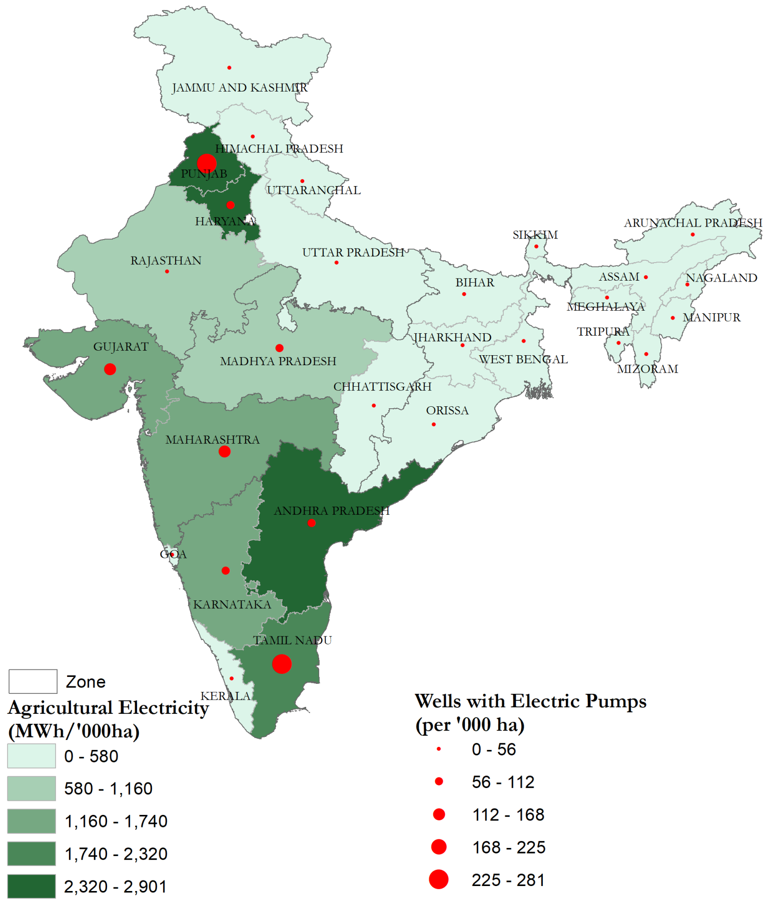


Figure 1: State-wise distribution of wells with electric pumps and electricity consumed by agriculture per 1,000 ha of cultivated land during 2013-14

3 Data and Descriptive Statistics

To understand the disconnect between RE and agricultural electricity, I use four sources of data to analyze the impact of RE on groundwater irrigation in India: 1) Census of India and 2) Minor Irrigation Census collected by the Government of India; 3) Situation Assessment Survey of Agricultural Households 2013 collected by the National Sample Survey Organization (NSSO) and; 4) Rainfall data from the Indian Meteorological Department.

3.1 Census of India

India conducts decennial household censuses. I use digitized data from the last three waves conducted in 1991, 2001 and 2011. In each census wave, the key variables include the absolute number of electrified rural households and total rural households. I define RE as the number of electrified rural households similar to the current definition of RE by the Government of India. I match districts across the three waves of the household census, in addition to matching districts in each wave of the household census to each wave in the minor irrigation census. In all, the data includes 323 districts across 18 states in 1986, which increased to 361 districts across 21 states in 2013. New districts are formed in India for many reasons including creation of new states and population increase (although there exists no uniform benchmark for population or population density for formation of new districts).

In all, there were 612 districts during the 2011 census not counting union territories. There were two main reasons for dropping districts. First, if minor irrigation census data were missing for any of the years included. Second, if a district was formed by reorganizing more than one previously existing district.

At an all-India level, rural electrification outpaced population growth. In the first period of assessment, nearly 30% of the rural households had access to electricity compared to over 50% during the last year of assessment (see table 1). I construct a district-level Policy Change (PC) treatment variable. PC is a binary variable and equals 1 for districts with fewer than 50% of total rural households electrified during the 1991 census and 0 for districts that reported 50% or more rural households electrified during the 1991 census. PC helps test whether the impact of household electrification is different among districts that expanded rural electrification infrastructure early (non-PC districts) compared to districts which electrified under the mandate of RGGVY and other similar policies (PC districts) when focus had shifted away from agricultural connections. The overall trend of the results remains the same even when I change the threshold value of PC from 30% to 70% (see appendix figure 2). I also check the validity of PC using a falsification test for the year in which I define PC and find no effect when PC is defined on the basis of proportion of electrified households in 2011 (see table A1).

3.2 Minor Irrigation Census

The Ministry of Water Resources under the Government of India collects Minor Irrigation (MI) census data every five years since 1986. I use the first, third and fifth waves of the census carried out during 1986-87, 2000-01 and 2013-14 respectively. The two main groundwater irrigation outcomes in my analysis are – number of wells using electric pumps and irrigated area. *Kharif* and *Rabi* are the two main cultivation seasons in India. Groundwater irrigation is less important during *Kharif* for mainly two reasons – first, *Kharif* overlaps with the annual monsoons received across the country in varying intensities and second, surface flow is also greater due to rainfall and is an important source of irrigation during this season. Irrigation, particularly from groundwater, is essential for cultivation during *Rabi* when most parts of India don't receive much rainfall, making irrigated area during *Rabi* the outcome variable of interest along with wells operated with electric pumps.

Irrigation structures which irrigate less than 2,000 hectares are included in the MI census (Statistics Division, 2017). They are categorized into three types of groundwater wells and two types of surface water irrigation infrastructures. Surface water irrigation account for little over 10% of total area irrigated by MI structures and have not been included in the analysis. I use data on the three types of groundwater wells, which include dug wells, shallow tube-wells and deep tube-wells. [7] In the last three decades, there has been an increase in the total number of wells from nearly 13M wells in 1986 to over 18M wells in 2013 (see table 1). The greatest growth has been in deep tube-wells which were fewer than 170,000 in 1986 to over 2M in 2013. Deep tube-wells are those with depths in excess of 70m and therefore can only be operated using electric pumps. It comes as no surprise that only a third of all wells used electric pumps in 1986 compared to more than 70% wells in 2013. Wells are mostly owned privately by individual farmers, although a small and shrinking proportion of wells are owned by the government, cooperatives and *Panchayats* (local village governing bodies). Ownership data was not collected

[7] For more information on the different type of wells see (Statistics Division, 2017)

during the 1986 MI census. Perhaps the greatest indicator of the impact of growth in electric pump use is the growth in irrigated area – between 1986 and 2013 while total wells increased by less than 40%, total irrigated area increased by over 270%. In the same period, growth in electric pump use was over 180%.

The years in which MI census was conducted do not match the years of household census precisely. However, my assumptions lead to a conservative estimate of the difference in the impact of electrification on groundwater irrigation pre and post 1990. It is likely that fewer houses were actually electrified in 1986 in the non-PC districts than the reported number in the 1991 household census, leading to a downward bias in the impact of RE in non-PC districts. Following a similar logic, it is likely that more houses were actually electrified in 2013 in the PC districts with a possible upward bias in the impact of RE in non-PC districts. Therefore the estimated overall difference in impact of RE is expected to be downward biased and represents a conservative estimate of the true impact.

3.3 Situation Assessment Survey of Agricultural Households

The National Sample Survey Office (NSSO) operates under the Ministry of Statistics and Program Implementation, Government of India. In its 70^{th} round of survey in 2013, the NSSO collected information from agricultural households on consumption, farming practices, resource availability and awareness about various government supported agricultural schemes. The NSSO defined an agricultural household as one producing cumulative annual value of INR 3,000 or more from agricultural activities and with at least one household member self-employed in agriculture (either as primary or secondary income generating activity). The survey was carried out during two visits – the first visit overlapped with the *Kharif* season and data was collected for July to December 2012 and the second visit roughly overlapped *Rabi* and data was collected for January to June 2013. The main variables of interest from this dataset are per capita consumption in the last 30 days, area irrigated and cultivated during the two cropping seasons and the total land operated in a year (both owned and leased) by a household.

I construct consumption quantiles across agricultural households to tease out the role of wealth in accessing irrigation. I use a subset of the total data and only include households which identify cultivation as their primary source of income to reduce any bias from the impact of income from other sectors on the ability to irrigate. Once again, I match the districts from MI and household censuses to use the same definition of treatment variable PC. Doing this allows me to compare irrigated area among households of similar consumption quantiles in PC and non-PC districts. I use 352 districts of the original panel of 361 - eight of the missing districts were located in Telangana, which was not included in the survey and there were no households who self-reported as mainly cultivators in one district in Tamil Nadu.

3.4 Rainfall Data

There are approximately 3,500 meteorological stations spread across 36 meteorological subdivisions in India. The Indian Meteorological Department (IMD) publishes monthly data at the district and sub-division levels. I use district-level data for the same three years as the Minor Irrigation Census - 1986, 2000 and 2013. I impute missing data by substituting them with sub-divisional data for the few years and districts that were missing.

Panel districts only	1986		2000		2013	
	Number (in '000)	%	Number (in '000)	%	Number (in '000)	%
Total rural households	97,218		120,128		140,569	
Electrified rural households	29,480	30.3	50,088	41.7	74,734	53.2
Total wells	12,929		16,358		18,069	
Dug wells	7,173	55.5	8,012	49	7,417	41
Shallow tube-wells	5,586	43.2	7,879	48.2	8,508	47.1
Deep tube-wells	170	1.3	467	2.9	2,145	11.9
Wells with electric pumps	4,548	35.2	8,978	54.9	12,827	71
Wells with diesel pumps	3,458	26.7	5,503	33.6	4,905	27.1
Wells operated manually or with draft power	1,684	13	1,304	8	242	1.3
Wells owned publicly	na*	na*	2894	1.8	240	1.3
Wells owned by private individuals	na*	na*	14,541	88.9	16,167	89.5
Kharif irrigated area	31,370	39.3	57,063	39.1	128,4339	43
Rabi irrigated area	39,984	50.1	67,846	46.5	129,810	43.5
Total irrigated area	79,788		146,011		298,523	

**Ownership data was not collected during MI-1 in 1986*

Table 1: Descriptive Statistics

4 Estimation Strategy

As grid electricity infrastructure enters districts, it is likely that wealthy households will be the first to connect for both domestic and irrigation purposes because they can afford connection costs. Poorer households are further constrained from accessing electricity for groundwater irrigation due to the additional capital required for well construction and electric pump purchase. Therefore, while the number of electrified households is likely to be positively correlated with groundwater irrigation, the relationship is probably non-linear - greater increase in groundwater irrigation outcomes at lower levels of household electrification. With electricity expansion, this process would repeat across districts. By definition, PC districts had lower electrification rates than non-PC districts in 1986. On average, the rate of increase in household electrification was over 200% in PC districts compared to 80% in non-PC districts between 1986 and 2013, suggesting greater expected growth in groundwater irrigation in PC districts during 1986-2013.

However, RE policy changed in the 1990s, with a major shift in focus towards domestic electrification coming in 2005 - the RGGVY program waived domestic connection fees for poorer households. Therefore, I test whether the change in policy reduced the impact of growth in household electrification on growth in groundwater irrigation using a fixed effects estimation strategy on the district level panel data I construct from the Minor Irrigation Census and Household Census. I estimate the impact of RE defined by the log of number of electrified rural households on groundwater irrigation outcomes. The key identifying assumption is that in the absence of the RE policy change, the impact of RE on groundwater irrigation should have been comparable (or rather greater) in PC than non-PC districts.

The basic regression I estimate is:

$$lnY_{it} = \alpha lnRE_{it} + \beta lnRE_{it} \times PC_i + \gamma lnRE_{it-1} + \delta X_{it} + \mu_i + \epsilon_{it} \tag{1}$$

Where, Y_{it} is the number of groundwater wells and area irrigated for district i in time t. RE_{it} captures the number of electrified households in district i and time t. PC_i is the binary treatment variable and categorizes districts into those electrified before 1990 and those that electrified after. The coefficient β is of main interest which captures the difference in the effect of electrification between PC and non-PC districts. γ measures the lagged impact of electrification and X_{it} is a vector of control variables that includes the logged number of total rural households when I measure the impact on growth in wells with electric pumps. X_{it} also includes the cumulative monthly rainfall when I measure the impact on growth in irrigated area. The cumulative monthly rainfall includes only the specific months of cultivation. I do not include cumulative monthly rainfall while estimating the impact on groundwater wells, since I assume the decision to construct wells and buy pump-sets to be a long term investment not impacted by yearly variations in rainfall. μ_i denotes the full set of district level fixed effects to control for time invariant differences between districts. Lastly, ϵ_{it} is the error term. For an unbiased and consistent estimation, there should be no time variant district level effects which are correlated with either household electrification or groundwater irrigation.

5 Results

5.1 District-Level Impacts on Groundwater Wells

Results from equation (1) where Y_{it} is the number of groundwater wells are included in table 2. On average, a 1% increase in electrified households is associated with a 0.6% increase in the total number groundwater wells in a district between 1986 and 2013. There was no significant difference in growth of total wells between PC and non-PC districts suggesting that accessing groundwater is not impacted by the change in RE policy. However upon disaggregating by the type of pump used, I find a difference in the growth rates between PC and non-PC districts. For wells using electric pumps - a 1% increase in electrified households is associated with 1.6% increase in wells using electric pumps in non-PC districts. I find a -0.4% difference in growth of electric pump use between PC and non-PC districts implying an overall increase of 1.2% in PC districts. The results suggest that while the construction of groundwater wells did not significantly differ between PC and non-PC districts, the rate of electrification of wells did at similar rates of household electrification. These estimates translate to an average loss of approximately 18,420 wells with electric pumps in PC districts in 2013 due to the change in policy. The magnitude of effect is rather large - on average, PC districts had a little over 30,000 wells with electric pump-sets in 2013.

The trend in wells using diesel pumps fits the pattern of growth in total groundwater wells and use of electric pumps. With a 1% increase in electrified households, I find a 2.0% decrease in wells using diesel pumps. The difference between PC and non-PC districts is positive for diesel pump use implying an overall increase of 0.3% in diesel pump use in PC districts between 1986 and 2013. As electricity expanded in non-PC districts, not only did more wells electrify, some of them substituted diesel pumps with electric pumps, which makes sense in light of the rising diesel cost.[8] Whereas in PC districts, the number of wells using diesel pumps increased suggesting that farmers had to fulfill their need to irrigate through diesel due to unavailability of cheaper and more reliable electricity supply. It further could be, with increase in domestic electrification in PC districts, farmers were able to spend money on diesel for irrigation which they previously spent on domestic electrification needs such as lighting.

Table 2: Growth in Groundwater Wells since 1986

	Log of groundwater wells		
	Total	With electric pumps	With diesel pumps
Log(Electrified HH)	0.55^{**}	1.63^{***}	-1.99^{***}
	(0.26)	(0.28)	(0.44)
Log(Electrified HH)x PC District	-0.24	-0.42^{**}	2.32^{***}
	(0.17)	(0.20)	(0.41)
Lagged Log(Electrified HH)	-0.08^{**}	0.06	-0.20^{***}
	(0.04)	(0.04)	(0.04)
Log(Total HH)	0.17	-0.33	-0.17
	(0.42)	(0.43)	(0.41)
Observations	968	968	968
R^2	0.19	0.39	0.10

Note: *p<0.1; **p<0.05; ***p<0.01

Standard errors were clustered at the district level.

5.2 District-Level Impacts on Groundwater Irrigation Coverage

Table 3 includes results from estimation of equation (1) where outcome variable Y_{it} is seasonal irrigated area. I find a difference in the growth rate of *Rabi* irrigated area between PC and non-PC districts. Growth in both annual and *Kharif* irrigated areas were not significantly different between PC and non-PC districts and, perhaps is explained by the results from the earlier set of regressions where the growth in total wells did not differ between PC and non-PC districts. Groundwater is often used as a supplementary source of irrigation during *Kharif* with rainfall and canal irrigation serving the primary water requirements for cultivation (Shah et al., 2006).

Average PC district growth in *Rabi* irrigated area was nearly half of the growth in non-PC districts for a similar increase in electrified households. A decrease of 0.5% in *Rabi* irrigated area translates to 71,776 ha of missing irrigated area on average among PC districts which would have been irrigated during *Rabi* in the absence of the policy change. For comparison, in 2013 the average *Rabi* irrigated area among PC districts was less than 65,000 ha, implying doubling of *Rabi* irrigated area in the absence of policy change.

Since change in irrigated area is a second order effect of electrification, I include logged number of wells using electric pumps to capture the latter's mediating role in electrification impact on irrigation in columns (2), (4) and (6) of table 3. I find that the effect of household electrification is not explained entirely by change in wells using electric pumps. The partial mediating effect of electric pumps perhaps alludes to the increased irrigation coverage

[8] See Shah (2007) for more on the impact of diesel prices on diesel based groundwater irrigation.

due to greater hours of electricity supply and larger pump capacity among non-PC districts.[9]

Table 3: Growth in irrigated area since 1986

	Log of irrigated area (ha)					
	Annual		*Rabi*		*Kharif*	
	(1)	(2)	(3)	(4)	(5)	(6)
Log(Electrified HH)	0.96***	0.58***	0.98***	0.60**	1.09***	0.68**
	(0.31)	(0.22)	(0.31)	(0.24)	(0.40)	(0.34)
Log(Electrified HH)xPC Districts	−0.34	−0.26	−0.46**	−0.36*	−0.36	−0.28
	(0.21)	(0.18)	(0.21)	(0.19)	(0.31)	(0.29)
Log(Electric Pumps)		0.26***		0.23***		0.29***
		(0.08)		(0.08)		(0.07)
Lagged Log(Electrified HH)	−0.01	−0.02	0.05	0.03	0.03	0.03
	(0.05)	(0.05)	(0.05)	(0.05)	(0.06)	(0.05)
Log(Total HH)	0.15	0.27	0.17	0.24	−0.04	0.09
	(0.52)	(0.43)	(0.49)	(0.41)	(0.54)	(0.46)
Cumulative Average Monthly Rain†	0.0002**	0.0000	−0.0003	−0.0002	0.0004**	0.0002
	(0.0001)	(0.0001)	(0.001)	(0.001)	(0.0002)	(0.0002)
Observations	968	968	968	968	968	968
R^2	0.26	0.31	0.16	0.20	0.19	0.24

Note: *p<0.1; **p<0.05; ***p<0.01

Standard errors were clustered at the district level.

†Annual rain, average rainfall during November to March and average rainfall during June to October were used for annual, *Rabi* and *Kharif* cultivation seasons respectively.

6 Threats to Identification

Results from section 5 imply a much greater growth in the use of electric pumps and *Rabi* irrigated area associated with increase in household electrification in non-PC districts compared to PC districts. However, electrification in non-PC districts occurred due to GR led demand for irrigation, which could make them systematically different from PC districts lacking similar demand. Therefore the estimates in section 5 could be biased due to non-random assignment of PC and non-PC districts. I investigate the possibility of selection bias through three ways. First, I investigate whether PC and non-PC districts differ in their needs for and presence of groundwater irrigation, both of which could explain the observed muted growth in groundwater irrigation in PC districts. Second, I consider the role that rural poverty may play in accessing irrigation. Perhaps, concentration of rural poverty in PC districts restricts growth in groundwater irrigation which requires additional capital. Third, I run the analysis on a subset of districts which were among the beneficiaries of early targeting of GR by the Indian government. GR targeted districts were selected for the presence of assured irrigation and other characteristics that were thought would lend to the success of GR technology (Frankel, 1971). Therefore, they could have been more similar to one another in late 1960s (when targeting occurred) in factors that led to GR driven demand for electrification, but for reasons other than GR driven demand did not electrify.

[9]The data in MI Census only provides the number of wells with electric pumps and no well specific information on hours of use or pump capacity.

6.1 The Need for and Availability of Groundwater Irrigation

Agriculture still forms a large part of the rural Indian economy, with over two-thirds of the working rural population employed in the sector in both PC and non-PC districts. The working population in agriculture can be of two main types – cultivators and agricultural laborers. Cultivators are workers engaged in cultivation either on their own or rented land, whereas agricultural laborers are essentially waged laborers who work on land owned by others (Census of India, 2011). For this estimation, cultivators are more important than agricultural laborers, since they make decisions related to irrigation. Although the working population in cultivation was larger in PC districts, it was not significantly different from non-PC districts (see table 4).

Irrigation is only needed when potential evapotranspiration (PET) exceeds rainfall. It may be that higher rainfall in PC districts reduced the need for groundwater irrigation compared to non-PC districts. It is indeed the case for long run-average normal annual rainfall, which was greater in PC districts. Across India, the bulk of rainfall is received during the monsoons which overlap with the *Kharif* cultivation cycle. Irrigation, particularly sourced from groundwater is used more intensively during dry season cultivation (*Rabi*). Long run-average normal rainfall during *Rabi* was not significantly different between PC and non-PC districts, suggesting that the need for irrigation does not significantly differ between the two categories of districts. Another reason for not using groundwater irrigation could be due to high depths to water, which significantly increase the cost of groundwater pumping and could also lead to well failures. Data in the most recently available round of Minor Irrigation indicates otherwise. Non-PC districts had a greater number of wells for all categories of depth except for wells with depths between 20-40 m, implying high pumping potential in PC districts.

Canal irrigation is the other dominant form of irrigation which is more useful during *Kharif* when surface flow volume is greater. Groundwater wells constructed within the areas served by canal irrigation could get recharged from surface water and yield more water, changing the economics of groundwater pumping for wells within and outside areas served by canal irrigation. Further, wells within canal irrigated areas also may be supplementary sources of irrigation rather than primary. In 2013, majority of wells were outside the canal irrigated areas in both PC and non-PC districts.

Panel districts only	PC	Non-PC	p Value
Rural working population (in M)	0.87	0.72	0.00
Population in agriculture (in M)	0.62	0.53	0.02
Population in cultivation (in M)	0.26	0.23	0.14
Normal average annual rain (in mm)	1,298.67	1,056.08	0.01
Normal average rain during *Kharif* (in mm)	1,100.67	942.17	0.06
Normal average rain during *Rabi* (in mm)	88.75	76.87	0.24
Well with 0m-20m depth	3,552	6,579	0.01
Well with 20m-40m depth	3,136	2,024	0.00
Well with 40m-60m depth	946	1,299	0.17
Well with 60m-70m depth	476	880	0.04
Well with >70m depth	1,012	2,707	0.00
Wells inside areas served by canal irrigation	2,219	9,352	0.00
Wells outside areas served by canal irrigation	48,146	57,700	0.14

Table 4: Comparison between PC and non-PC districts during 2013

Electric pumps allow more pumping of water from all types of wells but are only required for pumping in deep tube-wells on account of their high depths to water (in excess of 70m). Dug wells on the other hand have depths between 8 to 15 m and can largely be operated on diesel pumps. As part of robustness checks, I estimate the impact of electrification on groundwater wells and irrigated area on data including only deep tube-wells and only dug wells (see appendix tables A2 and A3). I find the difference between PC and non-PC districts to be more pronounced for deep tube-wells, whereas the difference between PC and non-PC districts is not statistically significant and different for dug wells.

6.2 Distributional Effects on Household-level Irrigated Area

There are two features of the RGGVY rural electrification policy which could impact both household electrification and access to electricity for groundwater irrigation – first, there are no longer any domestic connection costs for BPL households. Removal of the one-time connection costs could have led to a jump in domestic electrification with no similar impact on groundwater irrigation. Second, transformer sizing in RGGVY is based on aggregation of the number of households to be electrified and load capacity per household. The highest prescribed load capacity of a single household at 500W is incapable of running even a 1HP electric pump (approximately 745W). For comparison, less than 3% of all wells excluding deep tube-wells were operated using pumps with capacity below 2HP in 2013. It is therefore probable that in districts where electrification occurred under the RGGVY program, even households with the financial means to access electricity for groundwater irrigation were unable to because of constraints imposed by transformer capacity. I conduct a second set of analyses using household level data to test whether both physical (transformer capacity) and economic (household wealth) constraints contributed to the observed reduction in groundwater irrigation in PC districts. I compare *Rabi* irrigated area in 2013 between households in PC and non-PC districts which are in the same wealth quantiles. I estimate the regression:

$$Y_{hi} = \alpha CQ_{hi} + PC_i + \delta X_{hi} + \gamma Rain_i + State_i + \epsilon_{hi} \quad (2)$$

Where, Y_{hi} is *Rabi* irrigated area for household h in district i. CQ_{hi} is the wealth indicator measured by the per capita consumption quantile of household h in district i and PC is 1 for PC districts and 0 for non-PC districts, the same binary variable used in equation (1). X_{hi} is a vector of control variables at the household level and includes the total land cultivated by the household and other household and head of household controls such as household size, expenditure on non-farm activities and education and agricultural training of the household head. $Rain_i$ is the cumulative average monthly rainfall in district i during January to June 2013, when the survey was conducted. Since agricultural policy is a state subject in India, I include $State_i$ to control for state-level differences in agricultural policy which could impact irrigated area.

Table 5 includes the mean per capita consumption of households for each consumption quantile in PC and non-PC districts. Since I construct the consumption quantiles using all households, it is not surprising that they are similar for PC and non-PC districts across the quantiles. Only in the 25^{th} quantile is the difference statistically significant and different from 0 at 95% probability levels.

Quantile	PC	Non-PC	p Value
15^{th}	546.63	540.31	0.47
25^{th}	744.77	753.52	0.04
50^{th}	954.34	952.77	0.71
75^{th}	1,269.68	1,273.05	0.63
85^{th}	2,496.23	2,690.76	0.18

Table 5: Mean monthly per capita consumption across quintiles (in INR)

Estimation results from equation 2 indicate that irrigated area does increase with increasing wealth during *Rabi* (see table 6). However, on average, *Rabi* irrigated area was lower among households in PC districts compared to non-PC district households even after controlling for consumption quantiles. The average loss in irrigated area for PC households is even more than the difference in irrigated areas between the bottom 15^{th} and the top 85^{th} quantiles. In other words, households in PC districts across all consumption quantiles on average irrigated smaller tracts of land than even households in the lowest 15^{th} quantile in non-PC districts. The same was not true during *Kharif*. Although wealth did play a role in the extent of irrigation during *Kharif*, there was a statistically significant difference only between the bottom 15^{th} and the top 85^{th} quantiles, perhaps reflective of the non-essentiality of irrigation for *Kharif* cultivation due to the monsoons. A point to note here is that there is no distinction made between the different irrigation sources in the data set used for this estimation, but it is safe to assume that irrigated area majorly implies groundwater irrigation at least during *Rabi*.

I included a number of control variables which could impact the area irrigated by a household. The Government of India provides floor prices for the sale of rice and wheat in the form of Minimum Support Prices (MSP). At this price, farmers are guaranteed sale regardless of the agricultural produce quantity (at least in principle). I included awareness of MSPs as controls since they could act as incentives for investment decisions. I find that awareness of MSPs does impact the extent of irrigation in seasons when the crops are grown more - majority of the households reported cultivation of rice during *Kharif* (71% households) and wheat during *Rabi* (53% households). Even the extent of irrigation increase associated with awareness of wheat MSP during *Rabi* does not completely negate the loss in irrigated area among PC districts. Whereas, awareness of MSP is the strongest predictor of irrigated area after cultivated area during *Kharif*.

The remaining controls included household and head of the household metrics such as household size to account for unpaid labor that may increase irrigated area (in case manual or draft labor is used for irrigation), education and agricultural training of the household head. Additionally, a small fraction of households reported secondary income generating activities which were mostly related to agriculture or forestry related activities such as fishing, logging etc. I included them to control for wealth indicators not captured by the consumption quantiles. Neither expenses nor output values had any significant impact on irrigated area in either season.

Results in table 6 use the broadest definition of consumption including five categories - (1) purchase, (2) home produced stock, (3) receipts in exchange of goods and services, (4) gifts and loans and (5) free collection (such as free grain distribution by the government). To check the robustness of the results, I also ran the regression with alternative definitions of consumption, leaving out free collection, gifts and loans and even home produced stocks. The statistically significant and negative effect of PC districts remained even when I used the most parsimonious definition of consumption including only goods purchased and money received for goods and services. The results for the alternate specifications are in appendix table A4.

Table 6: Impact on Irrigated Area

	Irrigated area (ha)	
	Rabi	*Kharif*
25^{th} Quantile	0.02	−0.06
	(0.03)	(0.04)
50^{th} Quantile	0.06***	0.02
	(0.02)	(0.03)
75^{th} Quantile	0.07***	0.04
	(0.02)	(0.04)
85^{th} Quantile	0.09***	0.18***
	(0.02)	(0.05)
PC District	−0.13***	−0.07
	(0.05)	(0.06)
Cultivated Area	0.76***	0.44***
	(0.04)	(0.05)
Awareness about rice MSP	−0.01	0.19***
	(0.02)	(0.03)
Awareness about wheat MSP	0.12***	−0.003
	(0.02)	(0.04)
Agricultural produce value	0.0000***	0.0000**
	(0.0000)	(0.0000)
Household size	0.01**	0.03***
	(0.003)	(0.01)
Middle school or higher education	−0.02	0.02
	(0.01)	(0.02)
Received agricultural training	−0.07	−0.01
	(0.05)	(0.05)
Non-farm expenses	−0.0000	−0.0000
	(0.0000)	(0.0000)
Non-farm produce value	0.0000	0.0000
	(0.0000)	(0.0000)
Constant	−0.06	0.01
	(0.07)	(0.10)
State controls	Yes	Yes
Rainfall controls	Yes	Yes
Observations	11,182	11,182
R^2	0.84	0.55

Note: *p<0.1; **p<0.05; ***p<0.01

Standard errors were clustered at the district level.

Results from the household level analysis indicate that even similarly wealthy agricultural households irrigated less in PC districts than non-PC districts. Thus implying that physical constraints due to transformer sizing may have a role to play in the reduced groundwater irrigation observed in PC districts compared to non-PC districts.

6.3 Results from GR Targeted Districts

GR technology was initially targeted to 7 districts starting in 1961 and later expanded to 12 more by 1968 (Sen and Expert Committee, 1969). The districts were selected for their potential of increasing production of wheat or rice through cultivation using high yielding variety seeds, chemical fertilizers and pesticides. One of the primary factors governing their selection was the presence of assured water supply. Other factors included the presence of village institutions such as cooperatives and *Panchayats*. The initial set of districts called the Intensive Agricultural Development Program (IADP) districts served as the training grounds for GR expansion in India which occurred during the 1970s. Subsequently, more districts were chosen for similar concentration of efforts to distribute GR package of HYV seeds, chemical fertilizers and pesticides. The districts selected later were part of the Intensive Agricultural Areas Program (IAAP) (Frankel, 1971). Together IADP and IAAP districts were early beneficiaries of GR targeting and could perhaps be systematically different from the districts not included in the two programs, in ways that could have long-term impacts on groundwater irrigation expansion.

Table 7 includes estimates from equation 1 for impact on growth in wells with electric pumps in GR targeted districts and the full sample of districts. The greater impact of electrification among GR districts is perhaps expected since the districts were chosen for their relative agricultural advancements. However, the penalty of later electrification is also greater within GR districts than the PC penalty in all districts - impact of electrification in PC districts is less than half the impact of electrification in non-PC districts for GR districts, compared to about three-fourths in the full sample.

Table 7: Growth in Electric Pump Use - Only IAAP and IADP Districts

	Log of wells with electric pumps	
	All districts	GR districts
Log(Electrified HH)	1.63^{***}	2.73^{***}
	(0.28)	(0.56)
Log(Electrified HH)x PC District	-0.42^{**}	-1.39^{***}
	(0.20)	(0.47)
Lagged Log(Electrified HH)	0.06	0.15^{*}
	(0.04)	(0.09)
Log(Total HH)	-0.33	-1.73^{**}
	(0.43)	(0.86)
Observations	968	128
R^2	0.39	0.40

Note: *p<0.1; **p<0.05; ***p<0.01

Standard errors were clustered at the district level.

Interestingly, there is no longer a difference between PC and non-PC district growth in *Rabi* irrigated area after controlling for growth in electric pump use. More analyses on the terms of agricultural electricity supplied is required to fully understand how agricultural electricity differs between GR targeted districts and the remaining districts.

Table 8: Growth in Irrigated Area - Only IAAP and IADP Districts

	Log of *Rabi* irrigated area (ha)	
	All districts	GR districts
Log(Electrified HH)	0.60^{**}	0.21
	(0.24)	(0.43)
Log(Electrified HH)xPC Districts	-0.36^{*}	0.17
	(0.19)	(0.33)
Log(Electric Pumps)	0.23^{***}	0.59^{***}
	(0.08)	(0.11)
Lagged Log(Electrified HH)	0.03	0.14^{**}
	(0.05)	(0.07)
Log(Total HH)	0.24	-0.32
	(0.41)	(0.71)
Cumulative Average *Rabi* Rain	-0.0002	0.001
	(0.001)	(0.001)
Observations	968	128
R^2	0.20	0.53

Note: *p<0.1; **p<0.05; ***p<0.01

Standard errors were clustered at the district level.

7 Conclusion

Tremendous strides have been made in the world of energy innovation in the last two decades with the development of increasingly efficient and cost-effective renewable energy technology and supporting infrastructure. Yet governments across the developing world struggle to provide universal energy access. As governments and aid agencies spend billions to increase electrification coverage, there has never been a greater need to build consensus on what is meant by electricity access. Academics studying the impact of electrification in different geographic contexts have found inconclusive evidence to support the claim that electricity access aids development measured by household income, employment and expenditure in the near and long terms. They predominantly focus on domestic electricity access. Perhaps, the primary benefits of electricity access are more intangible constructs that improve aspects of life quality and cannot be measured by household income and employment metrics. Yet another reason for the inconclusive results could be that we are missing the bigger picture of electrification benefits by measuring electricity access solely through domestic electricity connections. In this paper I investigate the latter by looking at the impact of electrification measured by domestic electricity connections on groundwater irrigation, a major driver of the Indian rural economy.

I use household electrification, the commonly used definition of electricity access to study the impact of growth in electricity access on the use of electric pumps in groundwater irrigation from 1986 to 2013. I also study second order impacts through growth in irrigated area. I find that districts which witnessed major electricity expansion post 1990 did not experience similar growth in electric pump use or groundwater irrigation coverage during dry season cultivation, compared to districts which electrified before 1990. These results cannot be explained by differences in the need for irrigation, presence of groundwater resource or household wealth. Households in the top 85% of household consumption on average irrigated smaller areas in newly electrified districts than did bottom 15% households in districts that electrified before 1990. The reduced growth in groundwater irrigation also persists among newly electrified districts which were among the early beneficiaries of Green Revolution targeting. The reduction in electricity use in groundwater irrigation can be partly attributed to a shift in the Indian electrification policy that began in the 1990s and crystallized in 2005 with RGGVY, India's flagship program in rural electrification. Rural electrification demand was driven by well energization with household electrification as a secondary beneficiary until the 1990s. Household electrification became the primary target of rural electrification beginning in the 1990s. The RGGVY went a step further and removed barriers of entry by waiving domestic electricity connection costs for the rural poor and set up electricity infrastructure to support limited domestic loads. The resulting infrastructure is likely unable to support agricultural electricity use due to limited transformer capacity and distance from electricity distribution infrastructure.

India now finds itself in a situation where despite near universal household electrification, access to electricity for groundwater irrigation remains regionally concentrated and not reflective of groundwater availability. India needs to, therefore, rethink its current rural electrification policy if it wants to provide equitable access to groundwater irrigation and optimize groundwater use. Groundwater irrigation is expected to grow in its importance in ensuring future food security with rising uncertainty in rainfall and temperature due to climate change, making its judicious use a necessity. Access to irrigation also has implications for poverty alleviation of rural agrarian households.

My results imply an important limitation more broadly in the current definition of electricity access measured solely by household electrification. Just as the Indian government's focus on household electrification has constrained the use of electricity in groundwater irrigation, it may be, other parts of the rural economy also similarly suffer. More broadly, the unintended consequences of targeting solely domestic electricity access and the constraints created for electricity use in potential income enhancing activities merits further study across the developing world. Perhaps the time has come to reconsider uniform prescriptive electricity loads and uses in the formulation of electrification policies.

References

Banerjee, S. G., Barnes, D. F., Mayer, K., Samad, H. A., and Singh, B. N. (2014). Chapter 4: History of Rural Electrification and Institutional Organization. In *Power for all : electricity access challenge in India*. World Bank Group, Washington, DC.

Barnes, D. F. and Binswanger, H. P. (1986). Impact of Rural Electrification and Infrastructure on Agricultural Changes, 1966-1980. *Economic and Political Weekly*, 21(1):26–34.

Barrett, C. B. (2006). U.S. Food Aid: It's Not Your Parents' Program Any More! *Journal of Agribusiness*, 24(1):16.

Binswanger-Mkhize, H. P. (2013). The Stunted Structural Transformation of the Indian Economy: Agriculture, Manufacturing and the Rural Non-Farm Sector. *Economic and Political Weekly*, 48(26/27):10.

Burlig, F. and Preonas, L. (2016). Out of the Darkness and Into the Light? Development Effects of Rural Electrification. *Energy Institue at Haas Working Paper*, page 54.

Census of India, G. o. I. (2011). Census of India 2011: Metadata.

Department of Energy, G. o. O. (2016). Office Memorandum - Amendment of Biju Gram Jyoti-Rural Electrification programme of the State Government.

Dinkelman, T. (2011). The Effects of Rural Electrification on Employment: New Evidence from South Africa. *The American Economic Review*, 101(7):3078–3108.

Dubash, N. K. (2002). *Tubewell Capitalism: Groundwater Development and Agarian Change in Gujarat*. Oxford University Press, New Delhi ; New York.

Frankel, F. R. (1971). Introduction. In *India's Green Revolution: Economic Gains and Political Costs*, pages 3–11. Princeton University Press, New Jersey.

Giordano, M. and Villholth, K. G., editors (2007). *The agricultural groundwater revolution: opportunities and threats to development*. Number 3 in Comprehensive assessment of water management in agriculture series. CABI, Wallingford, UK ; Cambridge, MA. OCLC: ocm70167525.

Government of India, Ministry of Agriculture & Farmers Welfare, D. o. E. . S. (2018). Agricultural Statistics at a Glance 2017. Technical Report 500-2019 (DSK-III), Government of India, Controller of Publications, New Delhi.

Kale, S. S. (2004). Current Reforms: The Politics of Policy Change in India's Electricity Sector. *Pacific Affairs*, 77(3,):467–491.

Khandker, S. R., Samad, H. A., Ali, R., and Barnes, D. F. (2014). Who Benefits Most from Rural Electrification? Evidence in India. *The Energy Journal*, 35(2).

Kishore, A., Lamba, S., Shah, T., and Tewari, N. P. (2012). How Do Some Small Farmers Become Prosperous? Technical Report 48, International Water Management Institute.

Lee, K., Miguel, E., and Wolfram, C. (2017). Electrification and Economic Development: A Microeconomic Perspective. Technical report, Energy and Economic Growth: Applied Research Programme.

Lee, K., Miguel, E., and Wolfram, C. (2019). Experimental Evidence on the Economics of Rural Electrification. *Journal of Political Economy*.

Lenz, L., Munyehirwe, A., Peters, J., and Sievert, M. (2017). Does Large-Scale Infrastructure Investment Alleviate Poverty? Impacts of Rwanda's Electricity Access Roll-Out Program. *World Development*, 89:88–110.

Lipscomb, M., Mobarak, A. M., and Barham, T. (2013). Development Effects of Electrification: Evidence from the Topographic Placement of Hydropower Plants in Brazil. *American Economic Journal: Applied Economics*, 5(2):200–231.

Ministry of Agriculture & Farmers Welfare, G. o. I. (2019). Agricultural Statistics at a Glance 2018. Technical report, Department of Agriculture, Cooperation & Farmer Welfare, New Delhi.

Ministry of Power, G. o. I. (2013). Implementation of Rajiv Gandhi Grameen Vidyutikaran Yojana: Forty First Report. Technical report, Fifteenth Lok Sabha 2013-14, Lok Sabha Secretariat, New Delhi.

Mukherji, A. (2008). Spatio-temporal analysis of markets for groundwater irrigation services in India: 1976–1977 to 1997–1998. *Hydrogeology Journal*, 16(6):1077–1087.

Orissa Lift Irrigation Corporation, G. o. O. (2014). Detail Information about Jalnidhi-I.

Palit, D. and Bandyopadhyay, K. R. (2017). Rural electricity access in India in retrospect: A critical rumination. *Energy Policy*, 109:109–120.

Power Finance Corporation Ltd. (2018). Report on the Performance of State Power Utilities for the years 2013-14 to 2015-16. Technical report, Power Finance Corporation Ltd. (A Government of India Undertaking).

Rajan, A. and Verma, S. (2017). Evolving Nature of India's Irrigation Economy: Insights from the Fifth Minor Irrigation Census. Technical Report 7, International Water Management Institute.

Rudolph, L. I. and Rudolph, S. H. (1987). Chapter 12: Policies and Politics of the Agricultural Sector. In *In pursuit of Lakshmi : the political economy of the Indian state*. University of Chicago Press.

Sen, S. and Expert Committee, o. A. . E. (1969). Modernising Indian agriculture: report on the intensive agricultural district programme 1960-68. Technical report, Department of Agriculture, Government of India, New Delhi.

Shah, T. (2000). Wells and Welfare in the Ganga Basin: Essays on Public Policy and Private Initiative. *Paper presented in the Workshop on Poverty, Gender and Water in South Asia*.

Shah, T. (2007). Crop per Drop of Diesel? Energy Squeeze on India's Smallholder Irrigation. *Economic and Political Weekly*, 42(39):4002–4009.

Shah, T., Roy, A. D., Qureshi, A. S., and Wang, J. (2003). Sustaining Asia's groundwater boom: An overview of issues and evidence. *Natural Resources Forum*, 27(2):130–141.

Shah, T., Scott, C., Kishore, A., and Sharma, A. (2004). Energy-irrigation nexus in South Asia: improving groundwater conservation and power sector viability. Technical Report Research Report 70, International Water Management Institute, Colombo.

Shah, T., Singh, O. P., and Mukherji, A. (2006). Some aspects of South Asia's groundwater irrigation economy: analyses from a survey in India, Pakistan, Nepal Terai and Bangladesh. *Hydrogeology Journal*, 14(3):286–309.

Singh, S. K. (1990). Evaluating Large Dams in India. *Economic and Political Weekly*, 25(11):15.

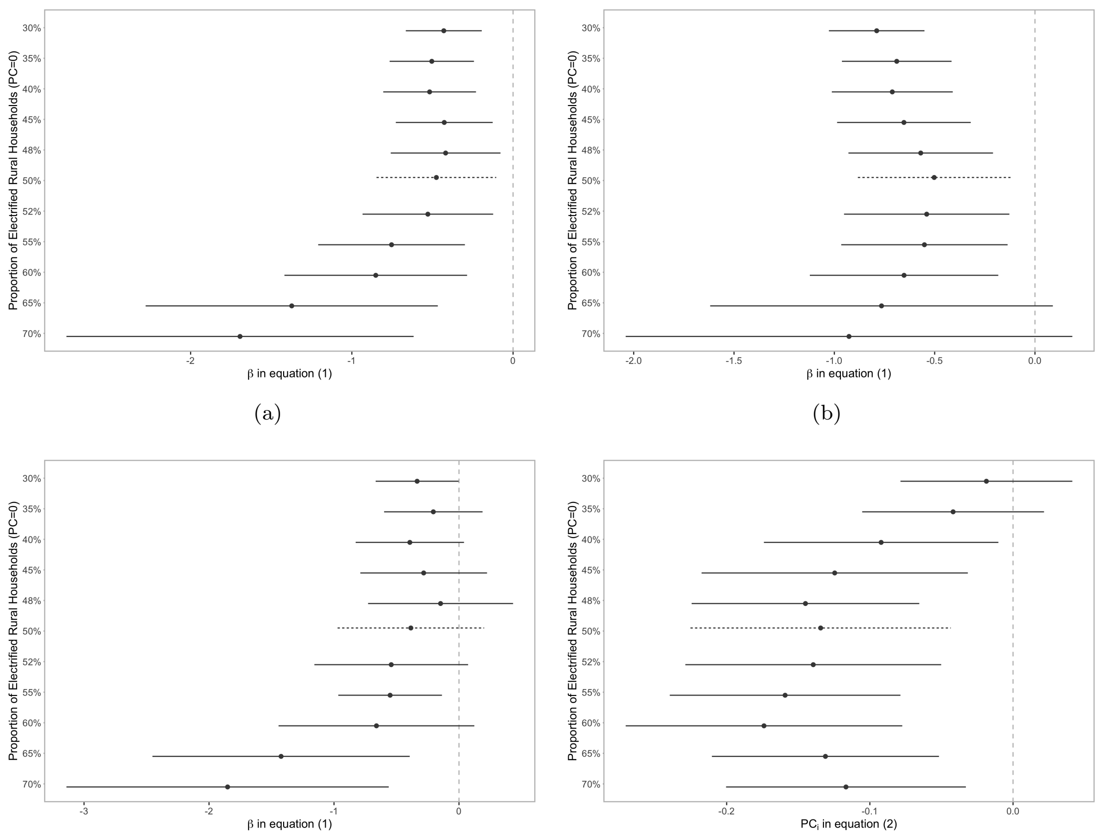
Statistics Division, M. I. (2017). Manual For Data Collection in the Census of Minor Irrigation Schemes 2013-14. Technical report, Ministry of Water Resources, Government of India, New Delhi.

van de Walle, D., Ravallion, M., Mendiratta, V., and Koolwal, G. (2015). Long-term gains from electrification in rural India. *The World Bank Economic Review*, 31(2):385–411.

Varshney, A. (1995). Organizing the Countryside in the 1980s. In *Democracy, Development, and the Countryside: Urban-Rural Struggles in India*, Cambridge Studies in Comparative Politics, pages 113–145. Cambridge University Press.

A Appendix: Robustness Checks

A.1 Sensitivity to PC Threshold Value



(a) (b)

(c) (d)

Figure 2: Robustness checks of PC threshold for: (a) Growth in electric pump use; (b) Growth in *Rabi* irrigated area; (c) Growth in *Kharif* irrigated area; and, (d) Distributional impacts on *Rabi* irrigated area

A.2 Falsification Test for PC Year

Table A1: Growth in electric pump use since 1986

	Log of wells with electric pumps	
	PC Year 1991	PC Year 2011
Log(Electrified HH)	1.63***	1.30***
	(0.28)	(0.16)
Log(Electrified HH)x PC District	−0.42**	−0.16
	(0.20)	(0.13)
Lagged Log(Electrified HH)	0.06	0.06
	(0.04)	(0.04)
Log(Total HH)	−0.33	−0.19
	(0.43)	(0.40)
Observations	968	968
R^2	0.39	0.39

Note: *p<0.1; **p<0.05; ***p<0.01

PC Year 1991 is the original specification and is defined on the basis of proportion of electrified rural households in 1991. PC Year 2011 includes PC binary variable defined for 2011.

A.3 Deep Tube-wells and Dug Wells

Table A2: Growth in electric pump use since 1986 - Only Deep Tube-wells and Dug Wells

	Log of wells with electric pumps	
	Deep tube-wells	Dug wells
Log(Electrified HH)	4.77^{***}	-0.10
	(0.74)	(0.48)
Log(Electrified HH)x PC District	-3.42^{***}	0.52
	(0.72)	(0.45)
Lagged Log(Electrified HH)	0.35^{***}	0.01
	(0.08)	(0.06)
Log(Total HH)	0.32	-0.10
	(0.65)	(0.46)
Observations	968	968
R^2	0.22	0.02

Note: *p<0.1; **p<0.05; ***p<0.01

Standard errors were clustered at the district level.

Table A3: Growth in *Rabi* irrigated area since 1986- Only Deep Tube-wells and Dug Wells

	Log of *Rabi* irrigated area (ha)	
	Deep tube-wells	Dug wells
Log(Electrified HH)	1.32^{**}	-0.64^{*}
	(0.64)	(0.35)
Log(Electrified HH)xPC Districts	-1.37^{**}	-0.35
	(0.63)	(0.31)
Log(Electric Pumps)	0.73^{***}	0.94^{***}
	(0.04)	(0.05)
Lagged Log(Electrified HH)	0.21^{***}	0.08
	(0.07)	(0.07)
Log(Total HH)	-0.06	0.50
	(0.57)	(0.40)
Cumulative Average Monthly *Rabi* Rain	-0.002	-0.002^{**}
	(0.001)	(0.001)
Observations	968	968
R^2	0.63	0.48

Note: *p<0.1; **p<0.05; ***p<0.01

Standard errors were clustered at the district level.

A.4 Consumption Quantiles

Table A4: Impact on Irrigated Area

	Rabi irrigated area (ha)		
	Full	Specification #2†	Specification #3†
25^{th} Quantile	0.02	0.02	0.01
	(0.03)	(0.02)	(0.02)
50^{th} Quantile	0.06^{***}	0.07^{***}	0.01
	(0.02)	(0.02)	(0.02)
75^{th} Quantile	0.07^{***}	0.07^{***}	0.05^{**}
	(0.02)	(0.02)	(0.02)
85^{th} Quantile	0.09^{***}	0.09^{***}	0.06^{***}
	(0.02)	(0.02)	(0.02)
PC Districts	-0.13^{***}	-0.14^{***}	-0.13^{***}
	(0.05)	(0.05)	(0.05)
Cultivated Area	0.76^{***}	0.76^{***}	0.76^{***}
	(0.04)	(0.04)	(0.04)
Constant	-0.06	-0.06	-0.03
	(0.07)	(0.07)	(0.07)
Full Controls	Yes	Yes	Yes
Observations	11,182	11,182	11,182
R^2	0.84	0.84	0.84

Note: *p<0.1; **p<0.05; ***p<0.01

Standard errors were clustered at the district level.

† Specification#2 excludes free collection and specification#3 excludes free collection, gifts and loans and; own produce.