Wells, Water, and Welfare: The Impact of Access to Groundwater on Rural Poverty and Conflict*

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Abstract

This paper evaluates the causal impact of access to groundwater on rural poverty using data from rural India. The estimation exploits the fact that the technology required to access groundwater changes exogenously due to constraints imposed by laws of physics at a well defined cutoff of 8 meters. I compare village poverty rates above and below this cutoff. I find that rural poverty in areas where groundwater is less accessible (depth from surface is below the cutoff) is 10-12 percent higher than in areas where it is easily accessible. Using survey data for a sub-sample of villages, I also show that disputes over irrigation water increase by 27 percent around the cutoff.

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1 Introduction

More than fifty percent of the world's food production is sustained by groundwater irrigation. Groundwater access has the potential to raise agricultural productivity by providing farmers with a more reliable source of crop irrigation than rainfall. By increasing agricultural productivity, groundwater access can address enduring goals in poverty alleviation: stabilizing rural incomes, raising living standards, and enhancing food security. Amid declining groundwater supplies, policymakers the world over debate policy interventions to achieve the optimal allocation of finite groundwater resources and encourage sustainable use. Absent from these debates is a precise assessment of how groundwater access reduces poverty especially in rural areas.

I identify the causal effect of groundwater access on rural poverty based on variation in exogenous technological constraints to groundwater extraction. When groundwater is within eight meters below ground, it can be extracted with a simple, low-cost centrifugal pump that utilizes atmospheric pressure to raise water above ground. Pumps using atmospheric pressure cannot support the weight of groundwater more than eight meters. Costlier submersible pumps are necessary to extract deeper groundwater. I exploit the random variation in the feasibility of technology used to extract groundwater to compare poverty rates in villages with low and high access to groundwater across five Indian districts. Villages whose depth to groundwater is below eight meters have 10-12 percent higher poverty rates than villages with groundwater depth within 8 meters. Groundwater irrigated area as a fraction of total sown area falls by 45 percent, whereas there is no change in surface water irrigated area. These estimates are robust across several empirical specifications and estimation techniques. Survey evidence from a subsample of villages shows that the percentage of farmers that own submersible pumps rises sharply for villages whose groundwater depth from the surface is below eight meters. This further validates the identification strategy that I employ. In other settings, water shortages have been shown to result in escalated conflict (Devoto et al, 2011). Using survey data, I find that self-reported disputes over irrigation water increase by 27 percent around this cutoff in rural India.

This study evaluates the impact of groundwater access on rural poverty in India. India exemplifies developing countries' dependence on groundwater and its promise as a poverty alleviation tool. Nearly 54 percent of India's population is employed in agriculture. Sixty percent of Indian agriculture depends on groundwater crop irrigation. Almost 92 percent of the groundwater that India extracts is used for irrigation (Jha and Sinha, 2009). India also exhibits the challenges to sustainable groundwater supply management. It is the world's single largest user of groundwater. Over the period 1960-2010 there has been a 500 percent increase in area irrigated by groundwater (World Bank, 2010). Across India non-renewable aquifers are rapidly depleting (NASA 2009, Sekhri 2012). Protecting groundwater for future use has taken a center stage at policy discussions. But market or non-market solutions to addressing over-extraction can be meaningfully designed only if the benefits of access to groundwater are well known.

This paper contributes to the literature on groundwater irrigation in the developing world. Most of the existing literature on groundwater in United States has focussed on studying externalities arising from groundwater use (Brill and Burness 1994; Brozovic et al, 2006; Gisser and Sanchez 1980). There is a small but growing body of work that focuses on examination of institutions for groundwater water allocation or inter-sectoral effects of groundwater use in developing countries(Aggarwal and Narayan (2004); Anderson (2011); Banerji et al (2010); Foster and Rosenweig (2008); Foster and Sekhri (2008); Jacoby, Murgai, and Saeed Rehman (2004); Keskin (2009) ; Sekhri (2011, a); Sekhri (2011, b)). A few studies focus on estimating the effect of groundwater irrigation on agricultural output. Sekhri (2011,c) evaluates the impact of groundwater irrigation on agricultural production in India and investigates coping mechanisms to groundwater distress. Hornbeck and Keskin(2011) also focus on agricultural output in midwestern U.S and look at the role groundwater plays in adaptation to climate stress. The impact of electricity subsidies on groundwater extraction and agricultural production has been investigated by Badiani, R. and K. Jessoe (2011). This paper is the first study to provide credible estimates of the effect of groundwater access on rural poverty that are vital for policy design.

This paper also complements the literature on welfare effects of irrigation. The most credible estimates on the effects of irrigation have been established by Duflo and Pande (2007). Their study assesses the effect of dam irrigation on agricultural output and poverty in Indian districts. In contrast, this paper focuses on the impact of groundwater irrigation on poverty using village level data. [1] Since Indian agriculture relies heavily on groundwater, it is important to understand the welfare implications of access to groundwater irrigation.

The findings of the paper have important policy implications.In light of rapid declines in groundwater tables around the world, there is a significant policy debate about whether groundwater irrigation should be constrained completely or innovative policies should be implemented to encourage sustainable use. The estimates of the impact on welfare of access to groundwater are extremely crucial for making informed policy choices. This paper indicates that groundwater irrigation leads to significant reduction in poverty.

Rest of the paper is organized as follows: : Section 2 discusses the naturally occurring variation in the cost of groundwater access that I exploit in the empirical analysis. Section 3 describes the data. Section 4 outlines the estimation strategy. Section 5 reports the results and discusses the robustness tests. Section 6 provides concluding remarks.

2 Spatial Variation in Access to Groundwater

The technology suitable for extracting groundwater depends on the depth from which groundwater is extracted. Mechanized pumps are used to extract water for irrigation. These use electricity or diesel as fuel in India. Centrifugal pumps are the most prominently used mechanized pumps (H. Raghunath, 1982, p. 363). These pumps are installed on the surface. Centrifugal pumps create a low pressure in the tube of a tube well by suction. As a result, the atmospheric pressure pushing down on water outside the well causes the water level in the tube to rise. The weight of the water inside the tube exerts a downward pressure and the water outside exerts an upward pressure.

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[1] Sekhri (2011,c) evaluates the effect of groundwater irrigation on agricultural production.

This process continues till the pressure inside and outside the tube well equalizes. In a perfect vacuum, the water would rise to a height of 34 feet (10.36 meters), as the weight of a column of this height exerts pressure equal to atmospheric pressure (Frank R. Spellman, 2004, p. 122). However, since suction cannot create a perfect vacuum, the accepted practical standard for extracting water using centrifugal pumps is around 8 meters (U. P. Gibson and R. D. Singer, 1969, p. 116).

Therefore, if the depth to groundwater is more than 8 meters, then the centrifugal surface pumps cannot be used to access water. In such a scenario, a submersible pump that is placed inside the well tube is used to extract water (Gibson and Singer, 1969, p.116 and 124). The submersible pumps cost thrice as much as centrifugal pumps.[2] One concern might be that technology has improved since these estimates were published and submersible pumps may have become cheaper. In order to allay this, I obtained recent estimates of the cost of centrifugal and submersible pumps of various horse power from an established pump vendor in this area. These estimates are shown in Appendix Figure A1. The difference in the cost of the pumps continues to persist. For example, the cost of a 1 hp centrifugal pump is rs 6830 whereas the cost of 1 hp submersible pump is rs 16750.

The difference in technology required is induced by the laws of physics and this law generates an exogenous variation in cost as a function of water table depth (changing at 8 meters). In the subsequent analysis, I estimate a reduced form effect of access to groundwater on poverty exploiting the cost of access that changes at 8 meters as source of spatial variation.

3 Data

The paper employs three main sources of data. The groundwater data at the village-level are from two waves (1993 and 2000) of the Minor Irrigation Census (MI Census) conducted by the Ministry of Water Resources, Government of India on a quinquennial

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[2] These details have been outlined in Sekhri (2011 a), which uses this variation in cost of the pumps to estimate the effect of public wells on groundwater in a triple difference approach.

basis. The paper uses the MI data for 5 districts in Uttar Pradesh. Poverty data is cross-sectional, and is from a poverty census conducted by the government of Uttar Pradesh in 2002. This data provides the list of village residents who were determined to be 'below poverty line' using the criterion established by government of India. Primary Census abstract of the Population Census of India 2001, provides the village level demographic variables including literacy rate, percentage of scheduled caste population, number of households, female population, and female literacy rate, and total population. A very comprehensive set of village infrastructure variables are available in the village directory of the Census of India 2001. These include whether a village is electrified, whether it has a school, a medical facility, a bank, and bus service. The village directory also reports distance to nearest town and expenditure of the village council on public goods. These four datasets have been matched at the village level.

Geographical controls, including rainfall and temperature, are from the University of Delaware climate data. This data has been interpolated from station data to 0.5 degree grid cells[3]. The village level annual rainfall and temperature data have been extracted using spatial data for the respective villages. Elevation and slope data has been extracted from the Digital Elevation Model of India (SRTM at 1 km resolution)[4] by superimposing village spatial coordinates on this raster data.

Main sample is restricted to villages where the depth to groundwater has not crossed over 8 meters in either direction since 1993. So, the villages where depth to groundwater was less than 8 meters in 1993, and then exceeded 8 meters in 2000 have been excluded. Also, villages where depth to groundwater was greater than 8 meters in 1993 and then became less than 8 meters in year 2000, have also been excluded. Thus, the sample villages have historically been in a state where groundwater is accessible using the cheap technology or not. This has been done to mitigate the concern that poverty rates may influence depth to groundwater. Also, such switches may arise due to endogenous reasons. Hence, the main sample excludes these villages. Out of 1714 villages, 278 villages were water abundant in 1993 and the depth fell in such villages in 2000. On

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[3] Available at http://climate.geog.udel.edu/~climate/html_pages/archive.html

[4] The source for this data is the Global Land Cover Facility, www.landcover.org.

the other hand, in 265 villages the water tables saw a rise and the depth crossed over to be in the 0-8 mbgl range. In a robustness test, I show that this exclusion does not influence the results. The test and the results are discussed later in Section 5.6.

The final sample has 1171 revenue villages. Table 1 provides the summary statistics. I use headcount as a measure of poverty. Headcount is the fraction of individuals below poverty line in the total population of the village. The average headcount in this sample is 0.13 and the standard deviation is 0.11. Most of the villages are electrified but very few have access to banking facility or a dispensary within the village. Villages with groundwater above the cutoff that determines the feasibility of surface pumps are different than the ones below the cutoff on many dimensions. Most notable characteristics that are different are scheduled caste population, number of households, rainfall, slope, elevation, access to schools, and total expenditure of the village council on public goods. However, one of the concerns for the identification strategy employed in the paper is whether or not these variables are smooth around the cutoff of 8 meters below ground level or not. More rigorous tests of differences in the two groups around the cutoff are presented in a later section.

4 Estimation Strategy

I use the threshold of 8 meters at which technology required to extract groundwater changes, to isolate the causal estimates of the effect of groundwater access on poverty. The reduced form empirical model can be characterized as follows:

$$Y_i = \alpha + \beta\, G_i + \delta X_i + f(w_i) + \epsilon_i \tag{1}$$

Where Y_i is the outcome of interest in village i, G_i is an indicator variable equal to 1 if the depth to groundwater exceeds 8 meters below ground level and β is the parameter of interest. X_i is the vector of village specific characteristics, $f(w_i)$ is a control function (a function of depth to groundwater in village i), and ϵ_i denotes the error term. The design allays selection concerns by comparing otherwise similar observations just above and below a cutoff (the threshold that determines feasibility of cheaper surface pumps in this case).

I estimate both parametric and non-parametric functions of depth to groundwater to examine the robustness of the results to a variety of functional form assumptions. For the parametric specifications, I focus on linear, quadratic, and cubic models. For non-parametric specifications, I follow Hahn, Todd, and van der Klaauw (2001) and use local linear regressions to estimate the left and right limits of the discontinuity, where the difference between the two is the estimated treatment effect. The estimation is done in one step using a simple rectangular kernel. Although a triangular kernel puts more weight on observations closer to the cutoff and is boundary optimal (Chang, Fan, and Marron, 1997), I follow Lee and Lemuiex (2010), which argues that a more transparent way of putting more weight on observations close to the cutoff is to re-estimate a model with a rectangular kernel using smaller bandwidths.[5]

The choice of bandwidth can also have a significant bearing on the results. In my parametric approach to estimation, I carry out the regression analysis in two narrow intervals close to the discontinuity (7-10 and 6-11 meters below ground level). For non-parametric RD, I present results for a broad range of bandwidths as there is no consensus on the method to choose the bandwidth. I show results for bandwidths including 10, 7.5, 5, and 2. In addition, I also carry out the estimation in the optimal bandwidth proposed by Imbens and Kalyanaraman (IK) (Imbens and Kalyanaraman, 2009).[6]

By restricting the sample to the villages that stay either above or below the cutoff since 1993, I allay some concern about reverse causality. If poverty effects depth to groundwater, we would expect that in poorer areas, less groundwater is extracted. This implies that such areas would be groundwater abundant. Therefore, I would expect to see a negative correlation between headcount and depth to groundwater. Figure 1 shows the prima facie evidence from the preliminary results that this is not the case. The figure shows the regression function of a local polynomial regression of headcount on depth to groundwater. We observe a positive jump at the threshold of 8 meters

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[5] The results are not sensitive to the choice of the kernel.

[6] The IK bandwidth is designed to minimize MSE.

below ground level.

5 Results and Robustness Tests

5.1 Full Sample Estimation

In Table 3, I report the preliminary results of parametric specifications of equation 1 using the entire sample. Column (i) reports the result of a regression of headcount on the indicator for depth to groundwater greater than 8 without specifying a control function. The coefficient is positive and statistically significant at 1 percent. This indicates that a switch from groundwater depth less than 8 to greater than 8 leads to 5.8 percent increase in poverty. In column (ii), I control for linear depth to groundwater and in Column (iii) I control for squared depth to groundwater. The result holds across these specifications and continues to be statistically significant at 1 percent. This is equivalent to half a standard deviation increase in poverty and is large in magnitude. Adding a cubic control function in column (iv) does not effect the coefficient or the standard error. Thus, I use quadratic control function in the specifications that follow.

Table 4 presents results from robustness tests. In column (i), I add a range of covariates with a quadratic control function of depth to groundwater. These include geographical controls including rainfall and temperature; demographic characteristics of the village including number of households, fraction of literate population, fraction of scheduled caste population, fraction of females in the population and fraction of literate females in the population; geological features like elevation and slope; and infrastructure variables of the villages including electrification status, availability of schools, bus service, medical facilities, banking service, distance to nearest town and total expenditure of village panchayat (council) on public goods. The coefficient on the indicator is 0.041 and is statistically significant at 5 percent.

Lateral velocity of groundwater is very low. Depending on the velocity, it can be a few centimeters to a meter a year(Todd, 1980). Hence, spatial externalities due to interconnectedness of aquifers may not arise over short durations of time. But to allay concerns over this, I allow for spatial correlation across villages in the empirical model. I follow Conley (1999) and estimate the covariance matrix allowing for spatial correlation. The cutoff at which the the correlation is allowed to fall to 0 is 0.025 degrees or 2.78 meters and the control function is quadratic in depth to groundwater. The results are reported in Column (ii) of Table 4. [7] The errors allowing for spatial correlation are reported. The results are unchanged. As in Table 3, the estimates indicate an increase in poverty that are statistically significant at conventional significance levels.

The poverty data are from a survey conducted by the state that identifies the below poverty households based on a criterion. The below poverty line status might be misallocated. However, there is no reason to believe that the status will be differentially accorded above and below the threshold of 8 meters. One concern might be that due to corruption or administrative reasons, the states use some discretion over how to apply rules across administrative blocks, and hence the measurement error is systematic across such areas. In order to address this, I include block fixed effects in the regressions so that villages within same blocks that are above and below the threshold are compared. The results are reported in column (iii) of Table 4. Reassuringly, the results are very similar to the first two columns.

5.2 Falsification Test for the True Discontinuity

If 8 mbgl is indeed the cutoff at which the feasibility of the surface pumps changes, and if there is a relationship between poverty and access to groundwater, then we should see an effect at 8 mbgl. We should not observe an effect at other cutoff values. I perform this falsification test by synthetically changing the cutoff to hypothetical values of 4,5, 6, 7, 9, and 10 mbgl. The identical regression specification for each regression includes demographic, geographical,and infrastructure covariates and a quadratic control function of depth to groundwater. However, the indicator variable indicates depth exceeding a different cutoff in each case. The resulting coefficient from each of the separate regressions is reported in Table 5 and plotted in Figure 2 along with the 95

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[7] These results are not sensitive to the cutoff used. I also use 0.05 degrees and the effects are similar.

percent confidence interval. The coefficient on the indicator for depth exceeding the cutoff is statistically significant for the true value of 8 mbgl and is insignificant for all other cutoff values at 5 percent significance level.

5.3 Regression Discontinuity Estimates

One concern might be that places that are on either side of the threshold differ in other unobserved characteristics that influence poverty and are correlated with depth to groundwater. This would result in omitted variable bias. While this could be true in the tails, such unobserved variables are likely to be similar close to the threshold. Therefore, I estimate the impact of access to groundwater in very narrow intervals around the threshold. I carry out a regression discontinuity analysis using both both parametric and non-parametric procedures. In Table 6, I report the results of the analysis where a parametric control function of depth to groundwater has been specified. I use two intervals: 7-10 and 6-11 around the cutoff. The results for the interval 7-10 are reported in columns (i) and (ii) and those for 6-11 are reported in columns(iii) and (iv). I use linear, quadratic, and a cubic control function. Each cell reports the coefficient from a separate estimation. Columns (ii) and (iv) also control for the demographic, geographical, and infrastructure covariates. The results are statistically significant at conventional levels across all these specifications and range from 8 to 12 percent increase in poverty in moving from below the cutoff to above the cutoff.

The results from the non-parametric analysis are reported in Table 7. I use a rectangular kernel for the estimation. I vary the bandwidths and report the estimated coefficient for different bandwidths. Columns (i) through (iv) show the results for bandwidth 10, 7.5, 5 and 2 respectively. Columns (v) and (vi) show the results for the estimation carried out using the optimal bandwidth as proposed by Imbens and Kalyanaraman (2009).[8] Column (v) reports the results without the covariates and column (vi) includes demographic, geographical, and infrastructure covariates. The results are similar to the parametric estimates reported in Table 6 and are statistically significant

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[8] The code for is available at http://www.economics.harvard.edu/faculty/imbens/files/rdob.ado.

across the various specifications. The preferred specification is column (v)which uses the optimal bandwidth. Including a very rich set of covariates in column (vi) does not change the estimated result. This implies that going from below the cutoff to above increases headcount rate by 11 percent. This is a one standard deviation increase in headcount rate and is very large in magnitude.

In the absence of other credible estimates of impact of access to groundwater on poverty, I rely on contextual information to ascertain if these magnitudes are plausible. Duflo and Pande (2007) estimate a 0.15 percent decline poverty in districts that are downstream from a dam and a 0.77 percent increase in poverty in districts with dams. Relative to dam irrigation, groundwater irrigation is used much more extensively in India. Groundwater is readily accessible relative to surface water. More than 60 percent of Indian irrigation is supported by groundwater and there are close to 20 million wells as of 2000 (Minor Irrigation Census, 2000). Out of a total irrigated area of 55.8 million hectares in India, 34.8 million hectares is irrigated using groundwater (Agriculture Census of India, 2005). (Sekhri, 2011c) evaluates the link between groundwater and agricultural production using data from Indian districts. This study shows that a 1 meter deviation of groundwater around long term mean in Indian districts lead to an 8 percent decrease in food grain production, 5 percent decrease in cash crops and 9 percent decrease in water-intensive crops , whereas dam irrigation increases crop production by 0.34 percent (Duflo and Pande, 2007). Given this large effect on crop production in contrast to dam irrigation, it is not surprising that the welfare effects are also large.

5.4 Smoothness of other Variables

A significant concern about the validity of the the design is the manipulation of the underlying depth to groundwater. No welfare programs are implemented taking into account this cutoff.[9] Therefore, farmers do not have an incentive to manipulate the depth. In addition, in this context, there is very little scope for manipulation of the

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[9] Million Wells Scheme or Free Boring Scheme that subsidized well construction in early 1990's targeted poor populations irrespective of the geography or geology of the village they came from.

distribution as depth to groundwater is objectively measured for the villages at the time of the Minor Irrigation Census survey. Figure 3 shows the distribution of groundwater depth which appears smooth around the cutoff. As is evident from the histogram in Figure 3, there is no systematic pattern that indicates a sharp jump at the cutoff.

One other concern might be whether or not covariates such as the demographic, geographical, and infrastructure characteristics of the villages are smooth around the cutoff, as a jump in these can lead to spurious attribution. Appendix Figure A2 plots local linear regression functions from regressions of these variables on the average value of the normalized groundwater depth bins around the cutoff of 8 meters. While almost all the variables are smooth around the cutoff, elevation exhibits a statistically significant jump as is clear from the Figure. However, results are not sensitive to including or excluding elevation from the regressions. In the non-parametric estimations reported in Table 7, I show that including the demographic, geographical, and infrastructure characteristics of the villages does not significantly change the coefficient or the standard error across columns (v) and (vi). The parametric specifications in Table 6 are also robust to including these control variables.[10]

5.5 Mechanism - Effect on Irrigated Area

I do not directly observe agricultural yield or agricultural production at the village level. Such data for India is not available below district level. However, in order to address whether the effect is being mediated through agriculture, I evaluate how groundwater irrigated area as a fraction of total sown area changes around the threshold. I also

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[10] Although I can control for whether a village is electrified or not, I do not observe the data on number electrical connections by village. But, it is unlikely that this will bias the results. Conditional on the village being electrified, the number of farmers choosing to electrify their pump may be a function of wealth. However, due to lack of data, I cannot test the consequences of poverty -such as not affording electricity- across villages. Personal correspondence with the village residents in the area revealed that an 11 kv feeder is designated for a village if it is electrified. If the 11 kv feeder for a village is established, then the cost of connection to any household or farm within the village is relatively small. It is unlikely that some farmers will be precluded from the village specific grid due to infrastructure concerns.

examine surface water irrigated area. I replicate the parametric specifications used in Table 6 and I present the results for total irrigated area to sown area in columns (i) and (iv); groundwater irrigated area to sown area in columns(ii) and (v); and surface water irrigated area to sown area in columns (iii) and (vi) of Table 8. Each row controls for a different control function. We observe a very large statistically significant reduction in irrigated area as a share of total sown area. This is accounted for by a commensurate reduction in groundwater irrigation. Groundwater irrigated area as a share of total sown area reduced by around 45 percent , whereas there is no change in the surface water irrigated area. [11] Table 9 shows the results from non-parametric regressions in which bandwidth is sequentially changed as in Table 7. The results are remarkably stable across these specifications. Column (v) uses the IK-optimal bandwidth and column (vi) includes co-variates in the IK-optimal bandwidth. As in the previous table, we see a substantial reduction in groundwater irrigated area as a fraction of the total sown area. These results do indicate that groundwater use diminishes when the depth exceeds the cutoff. Total irrigated area does fall. To the extent that returns to irrigation are positive, this would reduce farm profitability. [12]

5.6 Survey Sample Estimation

As mentioned before, the primary data does not have information regarding submersible pumps in the villages. Hence, the analysis is is limited in that we cannot examine the first stage.[13] In order to address this issue, I conducted a very short survey in 400 villages around the cutoff of 8 meters. The villages were chosen from depths between 3 and 12 meters. [14] After restricting to this depth, 400 villages were randomly chosen.[15] Ten farmers were randomly chosen in these villages. Table 2 shows the summary

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[11] These results are robust to including covariates. The table does not report those results for the sake of brevity.

[12] Using data from India, Duflo and Pande (2007) show that agricultural output for most crops increases with dam irrigation.

[13] I wish to thank Seema Jayachnadran for her suggestions on this issue.

[14] These depths balanced the possible villages on either side of cutoff.

[15] The sample size was chosen in light of the budget available for the survey.

statistics for this sub-sample of villages. The characteristics of these villages look very similar to the ones of the villages in the main sample reported in Table 1.

I estimate the change in submersible pumps, head count rate, and reported conflict over irrigation water in this sample. The results for percentage of farmers with submersible pumps are reported in Figure 4 and Table 10. We observe that percentage of farmers in our sample in the survey villages who report owning a submersible pump rises sharply around the cutoff. Table 10 shows the results from non-parametric regressions. In the first two columns, a bandwidth of 5 has been used. In columns (iii) and (iv), I use the IK optimal bandwidth. Columns (ii) and (iv) include co-variates in the regressions. My most preferred specification from column (iii) yields a 35 percent increase in submersible pump owners, and this is highly statistically significant. In Table 11, I report the results from similar specifications but now for the headcount rate. The results from all specifications are statistically significant. The IK bandwidth results in column (iii) yield a 12 percent increase in poverty around the cutoff. This estimate is remarkably similar to the 11 percent increase estimated from the main sample reported in column (v) in Table 7. Appendix Figure A4 replicates Figure 1 and shows the result graphically. Finally,the results for reported conflict are shown in Figure 5 and Table 12. Figure 5 shows the regression function from a local polynomial regression on either side of the cutoff. We observe a jump around the cutoff. Table 12 reports the results of similar specifications as Table 10 and 11. The estimate using IK optimal bandwidth is reported in column (iii). We see that a jump in the depth escalates disputes over irrigation water by 34 percent. In an urban setting in Morocco, Devoto et al (2011) also find very large reductions of 69 percent in self reported conflict over drinking water. Their study shows that access to piped water completely eliminates such feuds in the treated area. Groundwater used in irrigation is a a vital resource influencing rural livelihood. Consistent with this other study, I find that water scarcity escalates conflict over water in rural settings as well.

5.7 Reverse Causality

Poverty rate can have an effect on groundwater use. [16] In many contexts, poverty has been found to be positively correlated with resource abundance. [17] The data does not bear out evidence for this resource curse hypothesis. In Figure 1 and Appendix Figure A3, we clearly observe an opposite relation than that hypothesized by the resource course literature. We see that poverty rates are higher in areas where water is relatively inaccessible or is scarce. If poverty rates precluded water access, then poverty rates would have been associated with water abundance, or in other words, groundwater would be found closer to the surface due to less depletion.

It is possible that villages which are now water scarce (groundwater depth is below 8 meters from the surface), were once water rich and very affluent. But over time, they used their groundwater and this increased poverty. This is not inconsistent with my findings. In this case, the villages where water is relatively less accessible are on this upward trajectory such that water is less scarce and it is leading to an increase in poverty. Since I have groundwater depth for the villages for 1993 as well, I limit the sample such that villages with transitions in water depth across 8 meters are excluded. Hence, atleast as of 1993 the depth has not shifted across 8 meters in the villages in the main analysis.[18] Also, the results are not sensitive to the exclusion of such villages. In Appendix Table I, I re-estimate the impact of access to groundwater on poverty without any imposed exclusions on the data. The estimated effects on headcount rate are very similar to the ones reported in Table 3. These results are not sensitive to the functional form of the control function, and are highly statistically significant at 1 percent significance level.

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[16] See Alix-Garcia (2011) for a review of this literature and an application showing the effect of poverty alleviation on forest cover.

[17] Several studies posit this is on account of extractive institutions that emerge in these areas.

[18] Note that I do not have village specific poverty rates at an earlier time period. Therefore, I cannot carry out a panel estimation.

5.8 Caveats

Conflict and discrimination can result in residential sorting of households into different types of villages. It is possible that poorer residents are forced to areas with poor groundwater conditions. I include percentage of scheduled caste, who are historically marginalized poor population groups in India, in the regressions. The population shares of different castes in villages have been shown to be very stable in this areas (Anderson, 2011). But to the extent that this is only a crude measure to capture this, the data do not allow me to explicitly address this in more detail.

I do not have village level consumption or income data by household to construct other measures of poverty. The data used is based on a survey that the government conducts. This survey assesses household's income potential and asset holding to assign a score to them. Then the government uses a cutoff score that isolates the poverty threshold. In this sense, the data is a proxy for for poverty. This assigned poverty status is used in the allocations of benefits in all social benefit programs in India. Thus, while the analysis is limited in that I cannot look at other dimensions of poverty, it is informative as most policies are targeted based on this measure.

The data uses a cross section to compare the villages above and below the threshold. The 'above or below the threshold' status in this cross section has been stable since at least 1993. But given this is only seven years, I cannot identify if this is the short run or long run equilibrium. It is possible that this is short run, so that households have not fully adapted yet. If this is the case, and if households can adapt by changing crop mixes or exiting agriculture in long run, then the poverty may reduce over longer horizons. In either case, the results support the policy recommendation that sustainable access to groundwater for rural poor is better from welfare perspective than cutting access altogether at least over medium term periods such as a decade.

6 Conclusion

This paper provides estimates of the Impact of access to groundwater on rural poverty and conflict. A transition from below the cutoff of 8 meters below ground level to above the cutoff results in 11 percent increase in headcount rate. These results are robust to a wide array of functional form assumptions and specifications. I estimate local average treatment effect (LATE) but the estimates do provide insights for policy design. The results imply that depleting groundwater reserves in areas that rely heavily on groundwater irrigation will lead to a substantial increase in poverty. From policy perspective, shutting off access to groundwater in response to rapid depletion will have perverse effects on welfare. Hence, policies that promote sustainable use of groundwater should be at the center stage of discussions to protect groundwater reserves. Compared to other levers of poverty reduction, providing unchecked free access to groundwater results in immediate benefits in terms of increasing welfare but could result in long term costs as the reserves begin to deplete.

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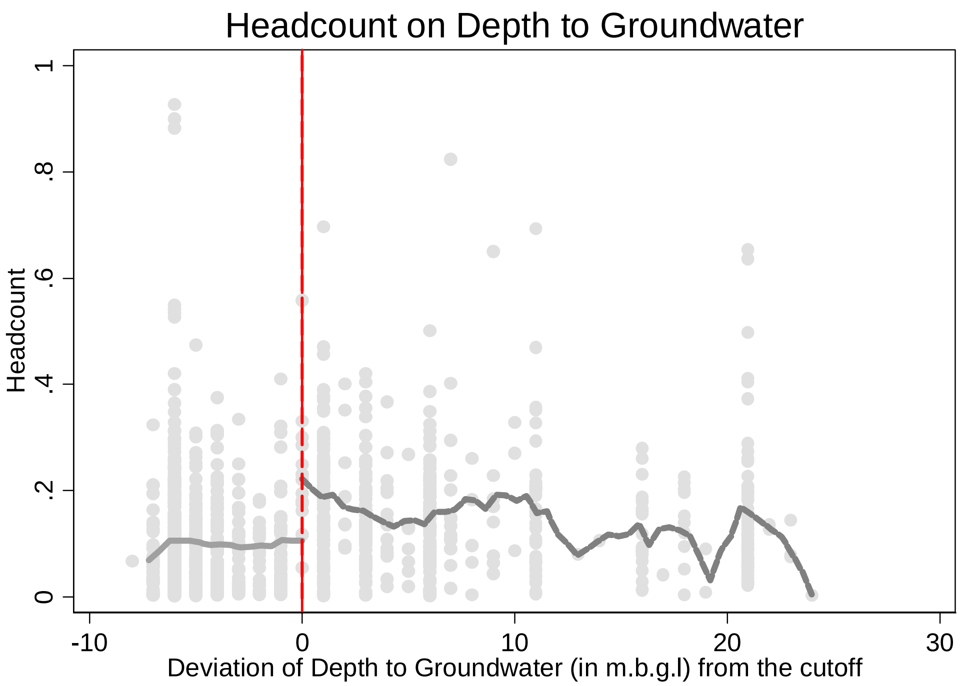


Figure 1: This figure plots the regression functions from a local linear regression of headcount on deviation of depth to groundwater from the cutoff that determines feasibility of surface pumps on either side of the cutoff. The optimal bandwidth proposed by Imbens and Kalyanaraman (2009) designed to minimize MSE has been used in Panel B.

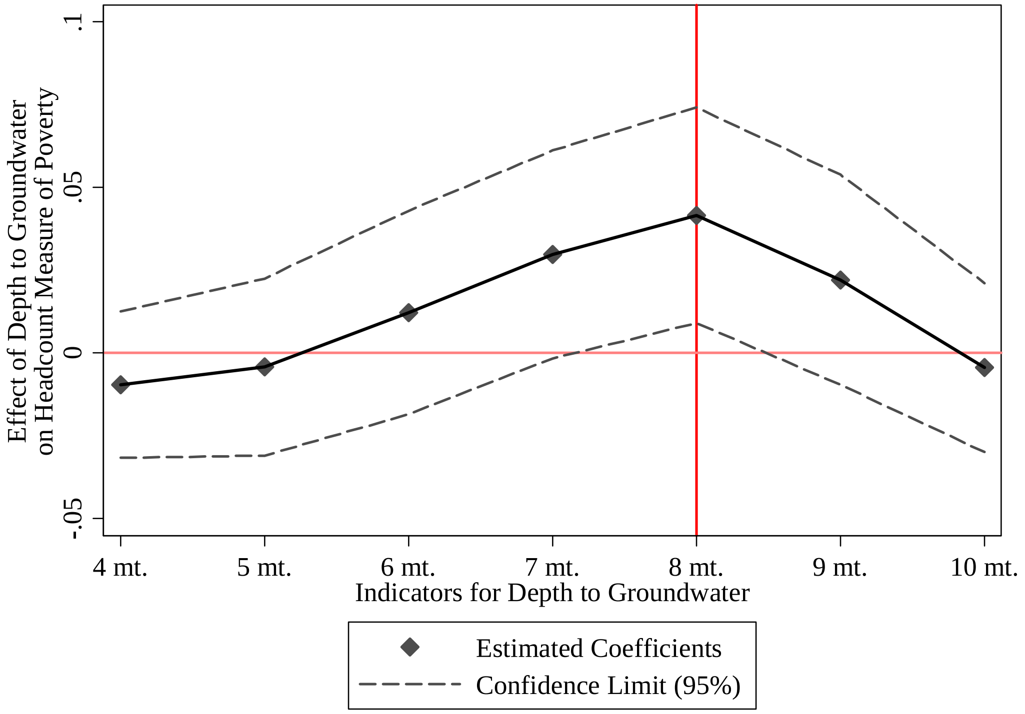


Figure 2: This figure plots the estimated coefficients from separate regressions in which different cutoffs for the feasibility of surface pumps have been used over the entire sample. The dashed lines indicate the 95 percent confidence interval. The estimated effect is statistically significant at the true cutoff.

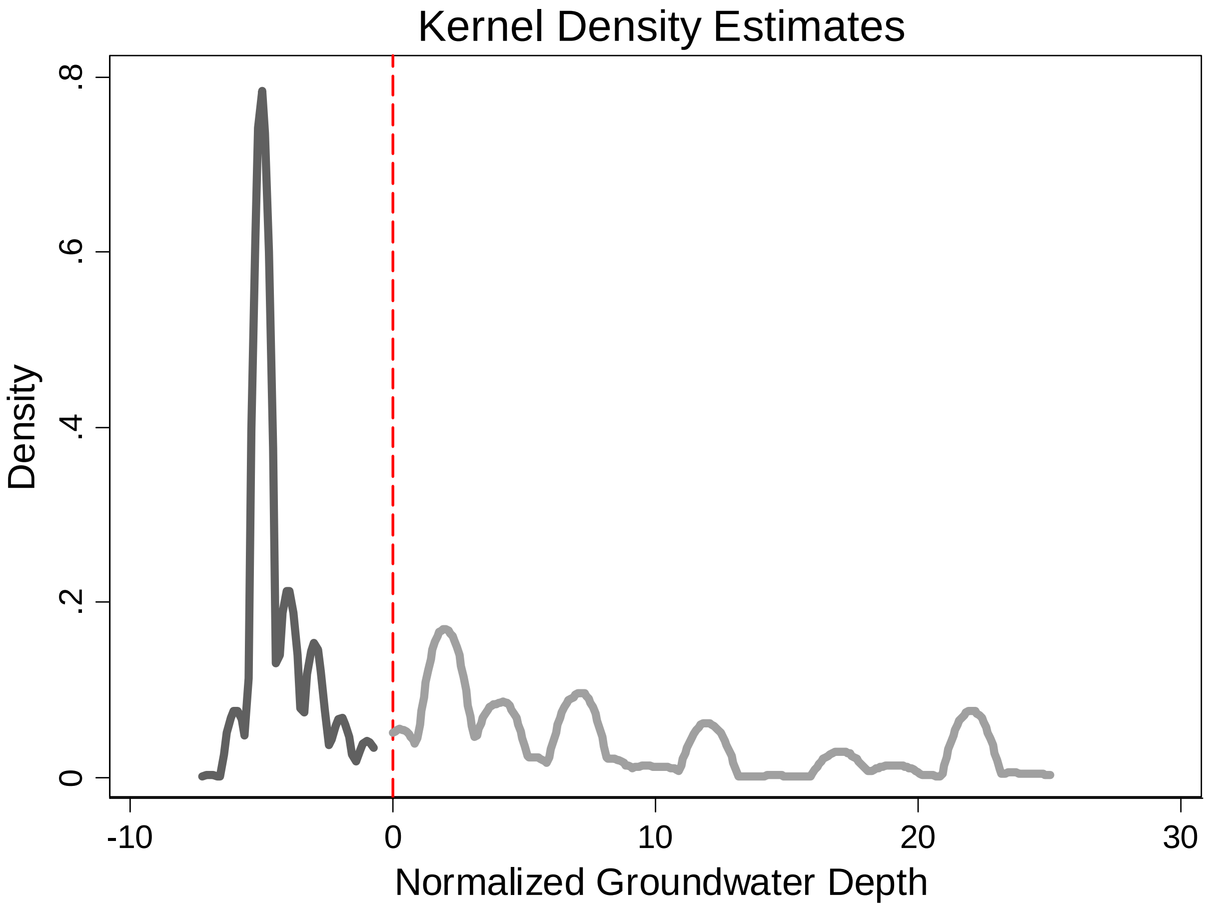


Figure3: This figure shows the distribution of the Depth to Groundwater. The distribution around the cutoff is smooth.

Survey Sample

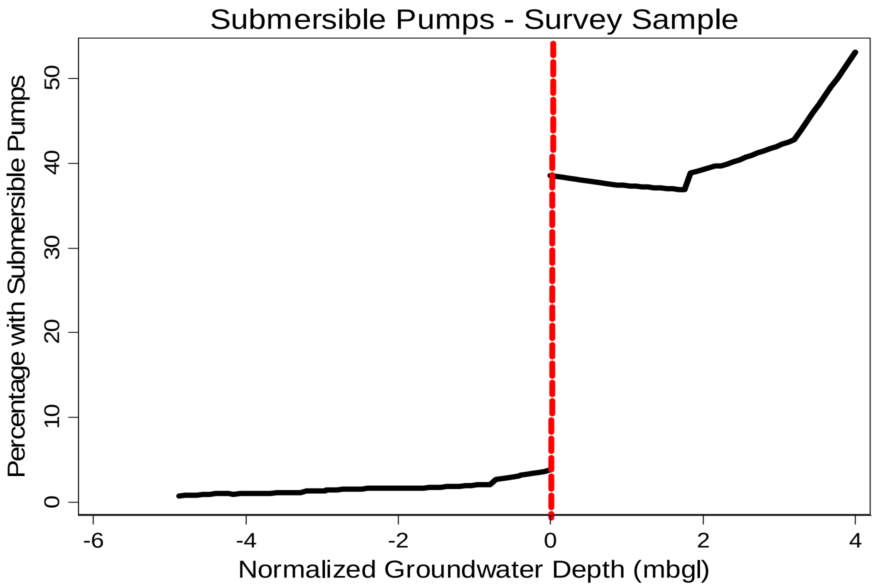


Figure 4: This figure graphs the regression functions from local polynomial regression of percentage of farmers with submersible pumps on deviation of depth to groundwater from the cutoff that determines feasibility of surface pumps on either side of the cutoff.

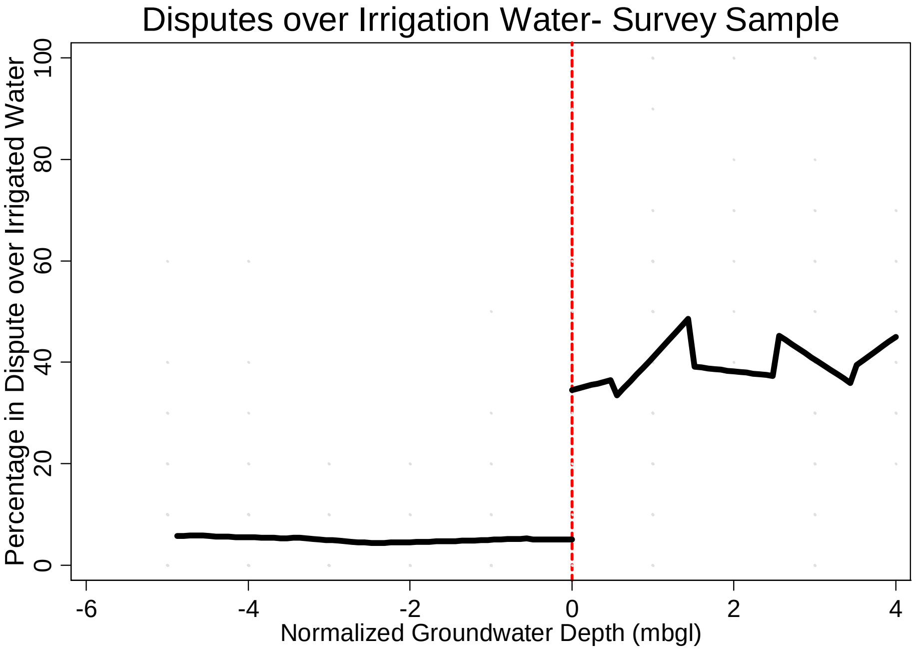


Figure 5: This figure graphs the regression functions from local polynomial regression of percentage of farmers reporting disputes over irrigation water on deviation of depth to groundwater from the cutoff that determines feasibility of surface pumps on either side of the cutoff.

Table 1: Summary Statistics Full Sample

Variable	Observations	Mean	Standard Deviation
Head Count	1171	0.13	0.11
Demography			
Percentage Literate	1171	0.28	0.12
Percentage Scheduled Caste	1171	0.3	0.25
Number of Households	1171	141.24	159.96
Female population	1171	0.48	0.03
Female Literate Population	1171	0.14	0.11
Climate and Geography			
Rainfall	1171	71.66	8.14
Temperature	1171	25.63	0.31
Slope	1171	0.12	0.2
Elevation	1171	107.11	48.92
Village Infrastructure			
School	1171	0.66	0.47
Medical Facility	1171	0.13	0.34
Dispensary	1171	0.03	0.17
Bus Service	1171	0.1	0.3
Distance from Nearest Town	1171	11.47	10.44
Power Supply	1171	0.8	0.4
Bank Facility	1171	0.05	0.22
Total Panchayat Expenditure	1171	29812.94	114889.8

Table 2: Summary Statistics Survey Sample

Variable	Observations	Mean	Standard Deviation
Head Count	400	0.13	0.1
Demography			
Percentage Literate	400	0.26	0.12
Percentage Scheduled Caste	400	0.32	0.25
Number of Households	400	147.6	180.7
Female population	400	0.47	0.03
Female Literate Population	400	0.13	0.1
Climate and Geography			
Rainfall	400	70.3	4.6
Temperature	400	25.6	0.3
Slope	400	0.13	0.18
Elevation	400	115.78	15.4
Village Infrastructure			
School	400	0.65	0.47
Medical Facility	400	0.135	0.34
Dispensary	400	0.03	0.17
Bus Service	400	0.08	0.28
Distance from Nearest Town	400	11.5	11.4
Power Supply	400	0.81	0.38
Bank Facility	400	0.05	0.22
Total Panchayat Expenditure	400	24889.34	66659.45

Table 3: Impact of Access to Groundwater on Poverty

	Dependent Variable: Headcount			
	(i)	(ii)	(iii)	(iv)
Indicator for Depth to Water > 8	**0.058***** **(0.01)**	**0.080***** **(0.01)**	**0.09***** **(0.01)**	**0.09***** **(0.01)**
Water Level Linear	No	Yes	Yes	Yes
Water Level Sqaured	No	No	Yes	Yes
Water Level Cubed	No	No	No	Yes
Observations	1171	1171	1171	1171
R squared	0.06	0.07	0.07	0.07

*** denotes significance at 1 percent level, ** at 5 percent and * at 10 percent.

Notes:

Sample is restricted to villages where depth to groundwater has not crossed over the cutoff that determines feasibility of surface pumps in either direction since 1993.

Indicator for Depth yo Water >8 is an indicator variable which takes the value 1 if groundwater level in year 2000 is at a depth greater than 8 meters below ground level. Robust standard errors are reported in paranthesis.

Robustness Checks

Table 4: Impact of Access to Groundwater on Poverty

	Dependent Variable: Headcount		
	(i)	(ii)	(iii)
Indicator for Depth to Water > 8	**0.041**** **(0.016)**	**0.041**** **(0.017)**	**0.04**** **(0.014)**
Water Level Linear	Yes	Yes	Yes
Water Level Sqaured	Yes	Yes	Yes
Rainfall and Temperature	Yes	Yes	Yes
Demographic Controls	Yes	Yes	Yes
Slope and Elevation	Yes	Yes	Yes
Village Infrastructure	Yes	Yes	Yes
Spatial Correlation in Errors	No	Yes	No
Block Fixed effects	No	No	Yes
Observations	1171	1171	1171

*** denotes significance at 1 percent level, ** at 5 percent and * at 10 percent.

Notes: Robust standard errors are reported in paranthesis. Demographic controls include number of households, fraction of literate population, fraction of scheduled caste population, fraction of females in the population, and fraction of literate females. Village Infrastructure includes availablity of banking facilities, medical facilities, schools, electrification, distance to nearest town and total expenditure of the village panchayat council. Sample is restricted to villages where depth to groundwater has not crossed over the cutoff that determines feasibility of surface pumps in either direction since 1993.

Table 5: Falsification Test -Varying the Cutoff

	(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)
cutoffs	4	5	6	7	8	9	10
Indicator for Depth to Groundwater Above the Cutoff	-0.009 (0.01)	-0.0036 (0.01)	0.012 (0.015)	0.030* (0.016)	**0.041**** (0.02)	0.021 (0.016)	-0.004 (0.01)
Observations	1171	1171	1171	1171	1171	1171	1171
R-Sqaured	0.15	0.15	0.15	0.15	0.16	0.15	0.16

*** denotes significance at 1 percent level, ** at 5 percent and * at 10 percent.

Notes: Each column reports the estimated coefficient from a regression in which the cutoff has been changed to the value reported in the row above. The true cutoff for the feasibility of surface pumps is 8 meters. Robust standard errors are reported in paranthesis. Each also controls for demographic, geographical and infrastructure covariates. Demographic controls include number of households, fraction of literate population, fraction of scheduled caste population, fraction of females in the population, and fraction of literate females. Village infrastructure includes availablity of banking facilities, medical facilities, schools, electrification, distance to nearest town and total expenditure of the village panchayat council. Geographical controls include annual rainfall , temperature, slope and elevation. Sample is restricted to villages where depth to groundwater has not crossed over the cutoff that determines feasibility of surface pumps in either direction since 1993. Control function includes linear and squared groundwater levels.

Table 6: Parametric Regression Discontinuity Estimates of Impact of Access to Groundwater on Poverty

	Estimates for Indicator for Depth to Groundwater > 8			
	Depth to Groundwater restricted to			
	7 to 10 meters below ground		6 to 11 meters below ground	
	(i)	(ii)	(iii)	(iv)
Linear	**0.10****	**0.96****	**0.08*****	**0.06***
	(0.05)	(0.04)	(0.03)	(0.034)
Quadratic	**0.12****	**0.11****	**0.09****	0.06
	(0.055)	(0.052)	(0.04)	(0.041)
Cubic	**0.12****	**0.11****	**0.12****	**0.11****
	(0.054)	(0.051)	(0.06)	(0.05)
Covariates	No	Yes	No	Yes
Observations	199	199	241	241

*** denotes significance at 1 percent level, ** at 5 percent and * at 10 percent.

Notes: Each cell reports the estimated coefficient from a regression of headcount on indicator for depth to groundwater greater than 8 mbgl The parametric specifications of control functions are linear, quadratic and cubic from top to bottom. Columns (ii) and (iv) include demographic, geographical, and infrastructure controls. Demographic controls include number of households, fraction of literate population, fraction of scheduled caste population, fraction of females in the population, and fraction of literate females. Village Infrastructure includes availablity of banking facilities, medical facilities, schools, electrification, distance to nearest town and total expenditure of the village panchayat council. Geographical controls include annual rainfall, temperature,slope and elevation Sample is restricted to villages where depth to groundwater has not crossed over the cutoff that determines feasibility of surface pumps in either direction since 1993.

Table 7: Non-Parametric RDD Estimates of the Impact of Access to Groundwater on Poverty

	Bandwidth 10	Bandwidth 7.5	Bandwidth 5	Bandwidth 2	Optimal Bandwidth	
	(i)	(ii)	(iii)	(iv)	(v)	(vi)
Indicator for Depth to Groundwater > 8	**0.08***** (0.016)	**0.09***** (0.016)	**0.09***** (0.02)	**0.093**** (0.047)	**0.11***** (0.03)	**0.099***** (0.03)
Covariates	No	No	No	No	No	Yes

*** denotes significance at 1 percent level, ** at 5 percent and * at 10 percent.

Notes: Each column reports the estimated coefficient from a regression of headcount on indicator for depth to groundwater greater than 8 mbgl. The non-parametric specifications with different bandwidths are reported in Columns (i) through (vi). Optimal Bandwidth proposed by Imbens and Kalyanaraman (2009) is used in Columns (v) and (vi). Column (vi) includes demographic, geographical, and infrastructure controls. Demographic controls include number of households, fraction of literate population, fraction of scheduled caste population, fraction of females in the population, and fraction of literate females. Village Infrastructure includes availablity of banking facilities, medical facilities schools, electrification, distance to nearest town and total expenditure of the village panchayat council. Geographical controls include annual rainfall, temperature,slope and elevation. Sample is restricted to villages where depth to groundwater has not crossed over the cutoff that determines feasibility of surface pumps in either direction since 1993.

Table 8: Regression Discontinuity Estimates of Impact of Access to Groundwater on Irrigated Area

Estimates for Indicator for Depth to Groundwater > 8

	Depth to Groundwater restricted to					
	7 to 10 meters below ground			6 to 11 meters below ground		
	Total Irrigated to Sown area (i)	**Groundwater Irrigated to Sown** (ii)	**Surface Water Irrigated to Sown area** (iii)	**Total Irrigated to Sown area** (iv)	**Groundwater Irrigated to Sown** (v)	**Surface Water Irrigated to Sown area** (vi)
Linear	**-0.42****	**-0.45****	0.038	**-0.46****	**-0.45*****	-0.005
	(.185)	**(0.18)**	(.039)	**(0.13)**	**(0.13)**	(0.01)
Quadratic	**-0.39****	**-0.42****	0.02	**-0.51*****	**-0.51*****	-0.0008
	(.17)	**(.18)**	(0.024)	**(.14)**	**(.14)**	(.006)
Cubic	**-0.4****	**-0.42****	0.025	**-0.38***	**-0.43****	0.04
	(.18)	(0.18)	(.027)	(.21)	(0.21)	(0.05)
Observations	199	199	199	241	241	241

*** denotes significance at 1 percent level, ** at 5 percent and * at 10 percent.

Notes: Each cell reports the estimated coefficient from a regression of Irrigated Area on indicator for depth to groundwater greater than 8 mbgl. The parametric specifications of control functions are linear, quadratic and cubic from top to bottom.

Sample is restricted to villages where depth to groundwater has not crossed over the cutoff that determines feasibility of surface pumps in either direction since 1993.

Table 9: Non-Parametric RDD Estimates of the Impact of Access to Groundwater on Irrigated Area

	Dependent Variable: Groundwater Irrigated to Sown Area				
	Bandwidth 10	**Bandwidth 7.5**	**Bandwidth 5**	**Optimal Bandwidth**	
	(i)	(ii)	(iii)	(v)	(vi)
Indicator for Depth to Groundwater > 8	**-0.48*****	**-0.46*****	**-0.43*****	**-0.51*****	**-0.42*****
	(0.066)	(0.07)	(0.09)	(0.192)	(0.11)
Covariates	No	No	No	No	Yes

Notes: Each column reports the estimated coefficient from a regression of irrigated area on indicator for depth to groundwater greater than 8 mbgl. The non-parametric specifications with different bandwidths are reported in Columns (i) through (vi). Optimal Bandwidth proposed by Imbens and Kalyanaraman (2009) is used in Columns (v) and (vi). Column (vi) includes demographic, geographical, and infrastructure controls. Demographic controls include number of households, fraction of literate population, fraction of scheduled caste population, fraction of females in the population, and fraction of literate females. Village Infrastructure includes availablity of banking facilities, medical facilities, dispensary, schools, bus service, electrification, distance to nearest town and total expenditure of the village panchayat council. Geographical controls include annual rainfall, temperature,slope and elevation. Sample is restricted to villages where depth to groundwater has not crossed over the cutoff that determines feasibility of surface pumps in either direction since 1993.

Survey Sample

Table 10: Non-Parametric RDD Estimates of the Impact on Percentage of Submersible Pumps

	Dependent Variable: Percentage of Submersible Pumps			
	Bandwidth 5		**Optimal Bandwidth**	
	(i)	(ii)	(iii)	(iv)
Indicator for Depth to Groundwater > 8	**32***** (4.2)	**24***** (5.36)	**35***** (7.87)	**26.1***** (9.8)
Covariates	No	Yes	No	Yes

*** denotes significance at 1 percent level, ** at 5 percent and * at 10 percent.

Notes: Each column reports the estimated coefficient from a regression of percentage of submersible pumps on indicator for depth to groundwater greater than 8 mbgl. The non-parametric specifications with different bandwidths are reported in Columns (i) through (iv). Optimal Bandwidth proposed by Imbens and Kalyanaraman (2009) is used in Columns (iii) and (iv). Columns (ii) and (iv) include demographic, geographical, and infrastructure controls. Demographic controls include number of households, fraction of literate population, fraction of scheduled caste population, fraction of females in the population, and fraction of literate females. Village Infrastructure includes availablity of banking facilities, medical facilities, schools, electrification, distance to nearest town and total expenditure of the village panchayat council. Geographical controls include annual rainfall, temperature,slope and elevation. Sample is restricted to villages where depth to groundwater has not crossed over the cutoff that determines feasibility of surface pumps in either direction since 1993.

Survey Sample

Table 11: Non-Parametric RDD Estimates of the Impact of Access to Groundwater on Headcount

Dependent Variable: Headcount

	Bandwidth 5		Optimal Bandwidth	
	(i)	(ii)	(iii)	(iv)
Indicator for Depth to Groundwater > 8	**0.117***** (0.02)	**0.046**** (0.02)	**0.12***** (0.04)	**0.085**** (0.04)
Covariates	No	Yes	No	Yes

*** denotes significance at 1 percent level, ** at 5 percent and * at 10 percent.

Notes: Each column reports the estimated coefficient from a regression of headcount on indicator for depth to groundwater greater than 8 mbgl. The non-parametric specifications with different bandwidths are reported in Columns (i) through (iv). Optimal Bandwidth proposed by Imbens and Kalyanaraman (2009) is used in Columns (iii) and (iv). Columns (ii) and (iv) include demographic, geographical, and infrastructure controls. Demographic controls include number of households, fraction of literate population, fraction of scheduled caste population, fraction of females in the population, and fraction of literate females. Village Infrastructure includes availablity of banking facilities, medical facilities, schools, electrification, distance to nearest town and total expenditure of the village panchayat council. Geographical controls include annual rainfall, temperature,slope and elevation. Sample is restricted to villages where depth to groundwater has not crossed over the cutoff that determines feasibility of surface pumps in either direction since 1993.

Survey Sample

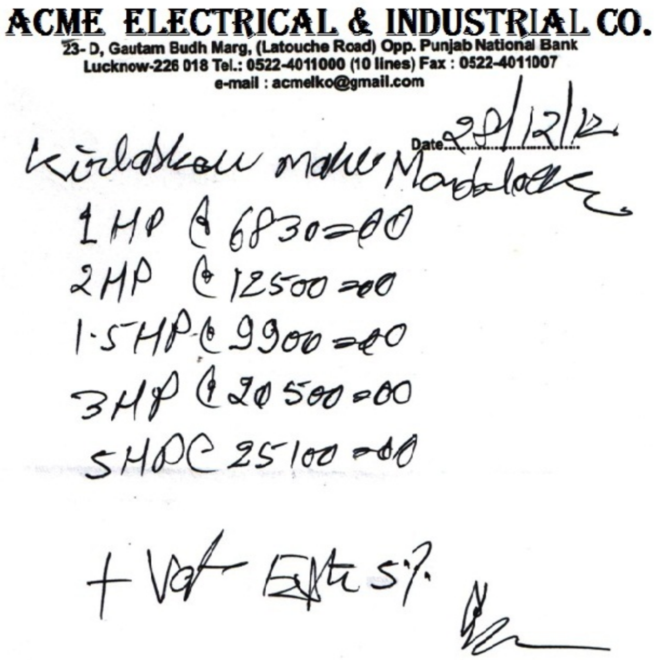
Table 12: Non-Parametric RDD Estimates of the Impact on Disputes over Irrigation Water

	Dependent Variable: Percentage of Farmers in a Dispute over Irrigation Water			
	Bandwidth 5		**Optimal Bandwidth**	
	(i)	(ii)	(iii)	(iv)
Indicator for Depth to Groundwater > 8	**34.5***** **(4.28)**	**26.3***** **(5.3)**	**34.8***** **(5.1)**	**27.7***** **(6.66)**
Covariates	No	Yes	No	Yes

*** denotes significance at 1 percent level, ** at 5 percent and * at 10 percent.

Notes: Each column reports the estimated coefficient from a regression of percentage of reported disputes on indicator for depth to groundwater greater than 8 mbgl. The non-parametric specifications with different bandwidths are reported in Columns (i) through (iv). Optimal Bandwidth proposed by Imbens and Kalyanaraman (2009) is used in Columns (iii) and (iv). Columns (ii) and (iv) include demographic, geographical, and infrastructure controls. Demographic controls include number of households, fraction of literate population, fraction of scheduled caste population, fraction of females in the population, and fraction of literate females. Village Infrastructure includes availablity of banking facilities, medical facilities, schools, electrification, distance to nearest town and total expenditure of the village panchayat council. Geographical controls include annual rainfall, temperature,slope and elevation. Sample is restricted to villages where depth to groundwater has not crossed over the cutoff that determines feasibility of surface pumps in either direction since 1993.

Web Appendix: Not for Publication



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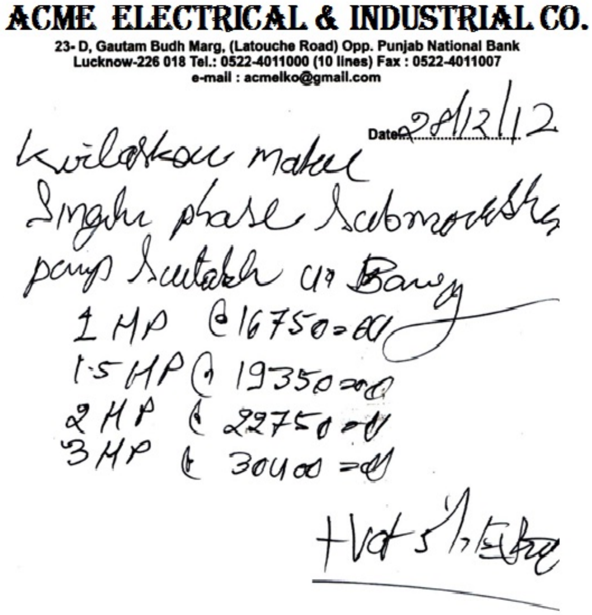
Costing –Centrifugal Pumps



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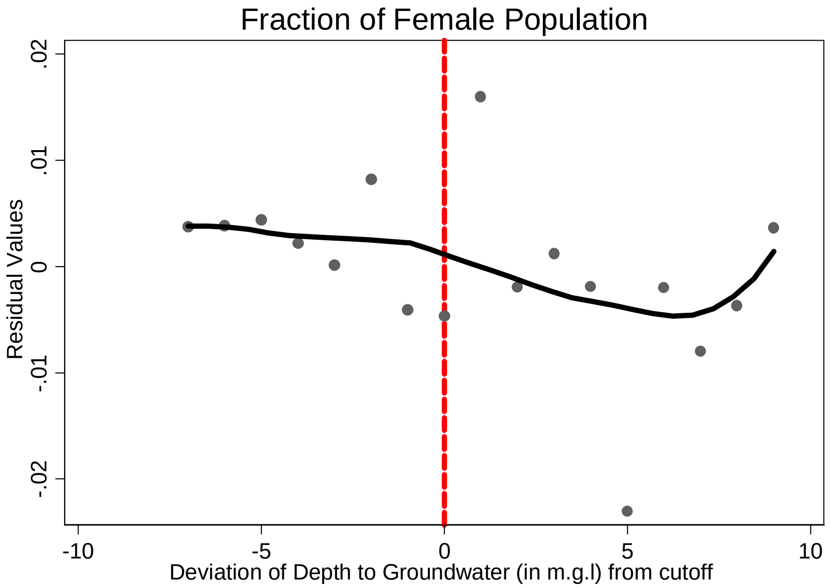
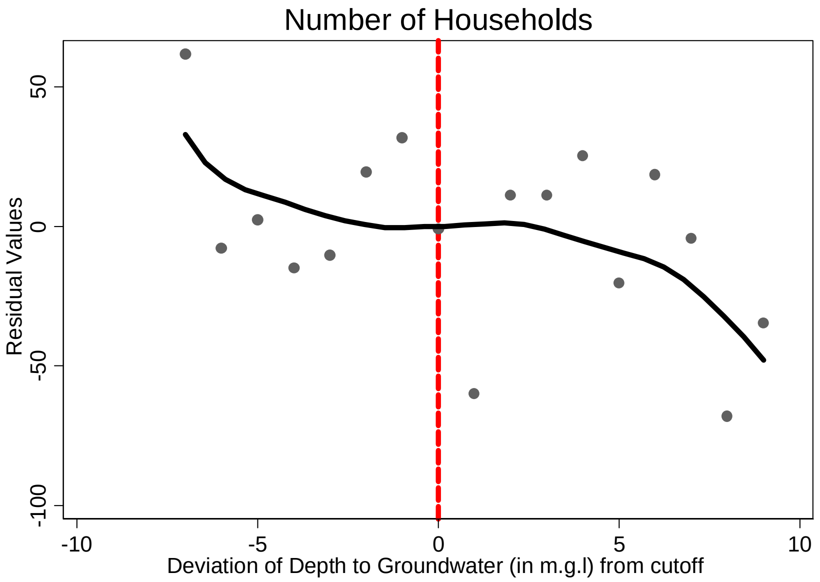
Costing- Submersible Pumps

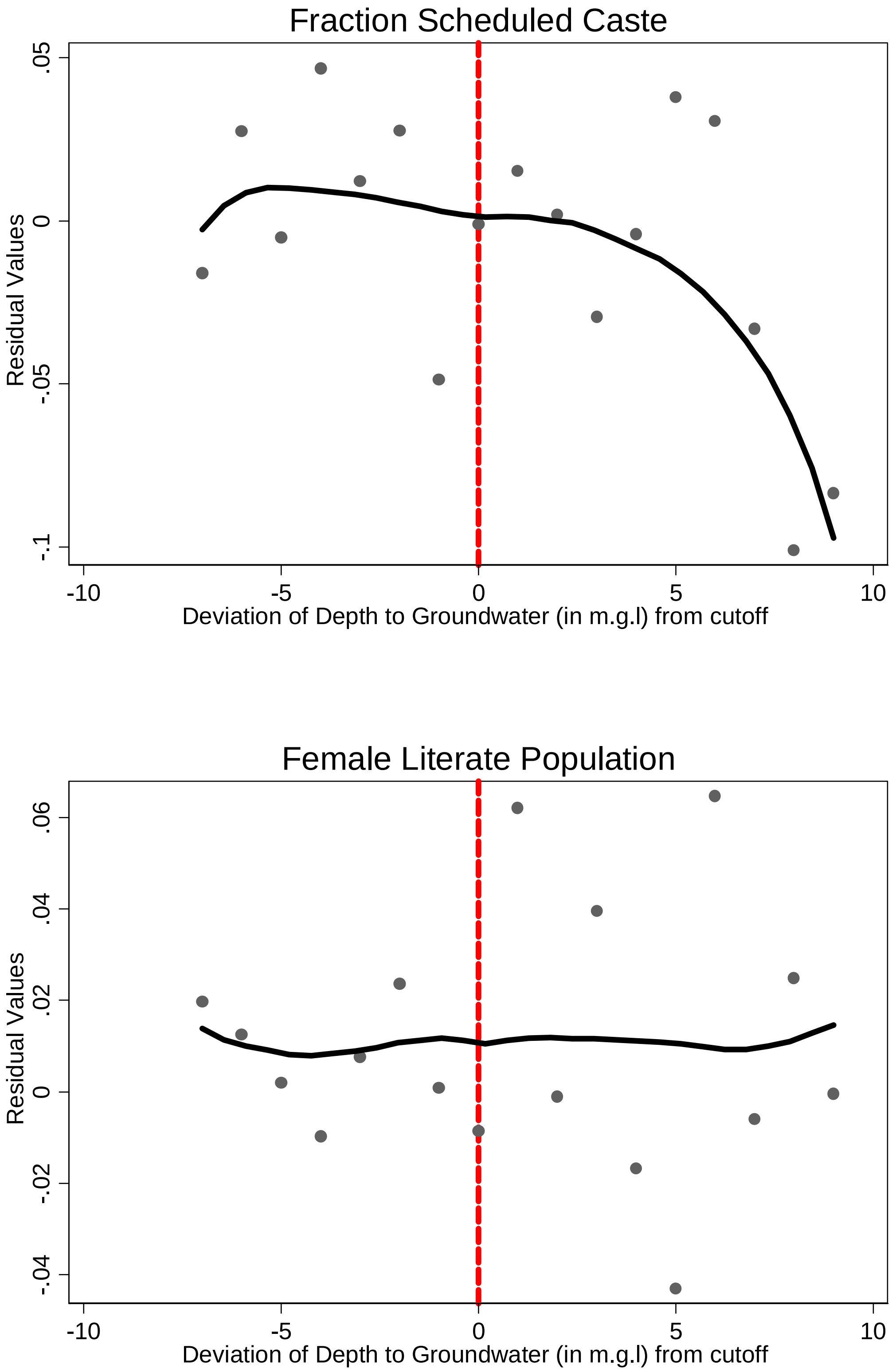
Appendix Figure A1: Recent Estimates of Pump Costs

Appendix Figure A2: This figure examines the continuity of control variables at the cutoff

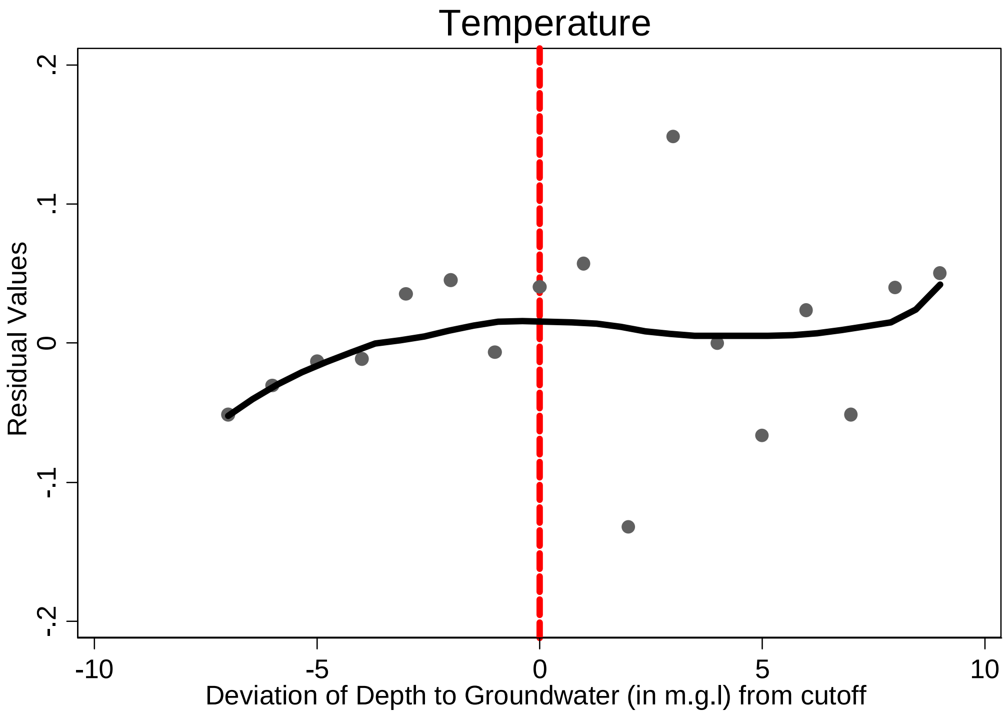
a. Demographic Controls







b. Geographical Controls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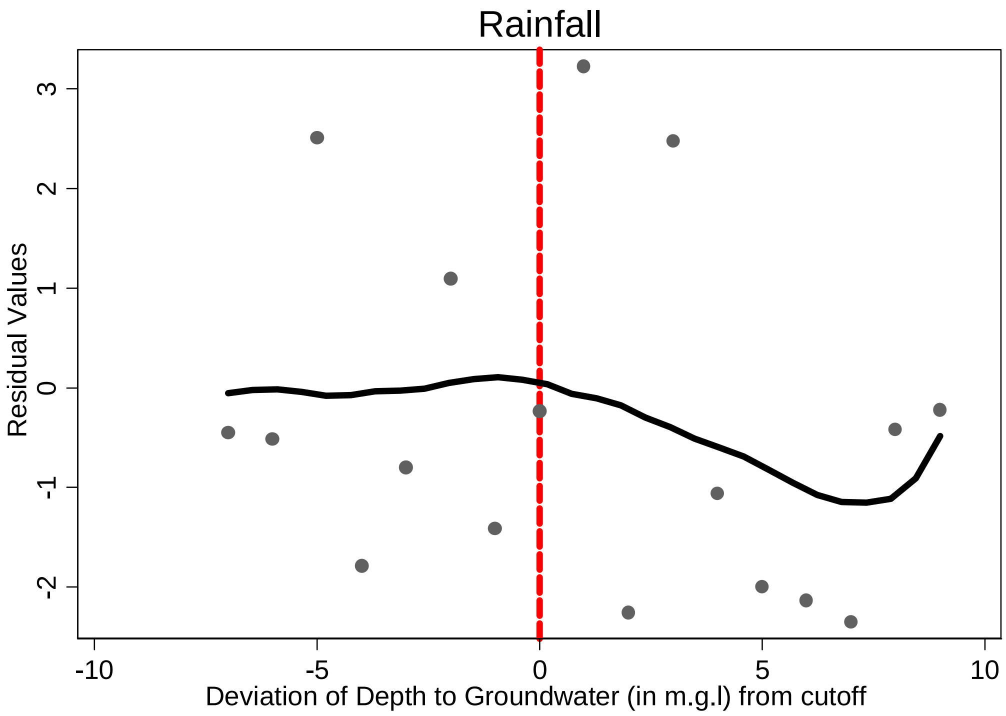
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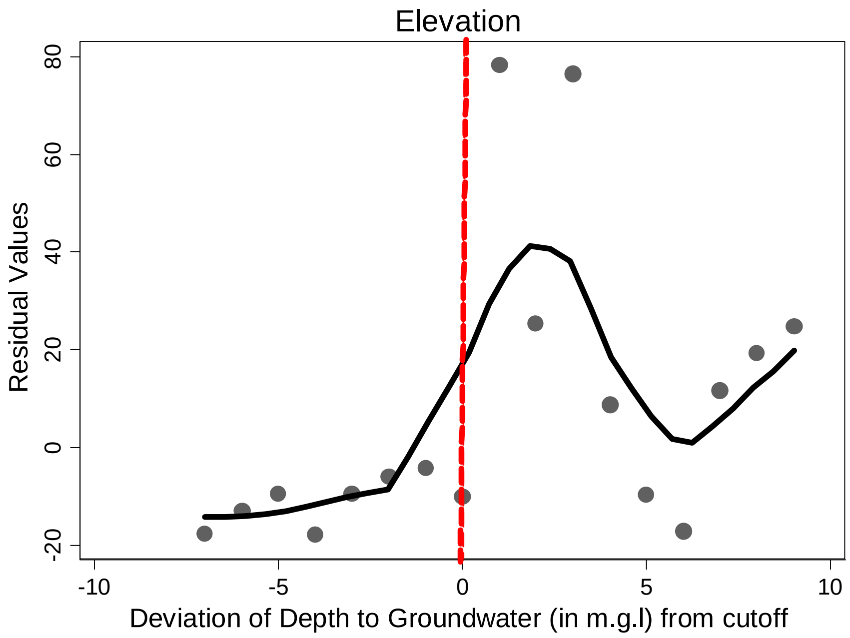
Elevation
Residual Values
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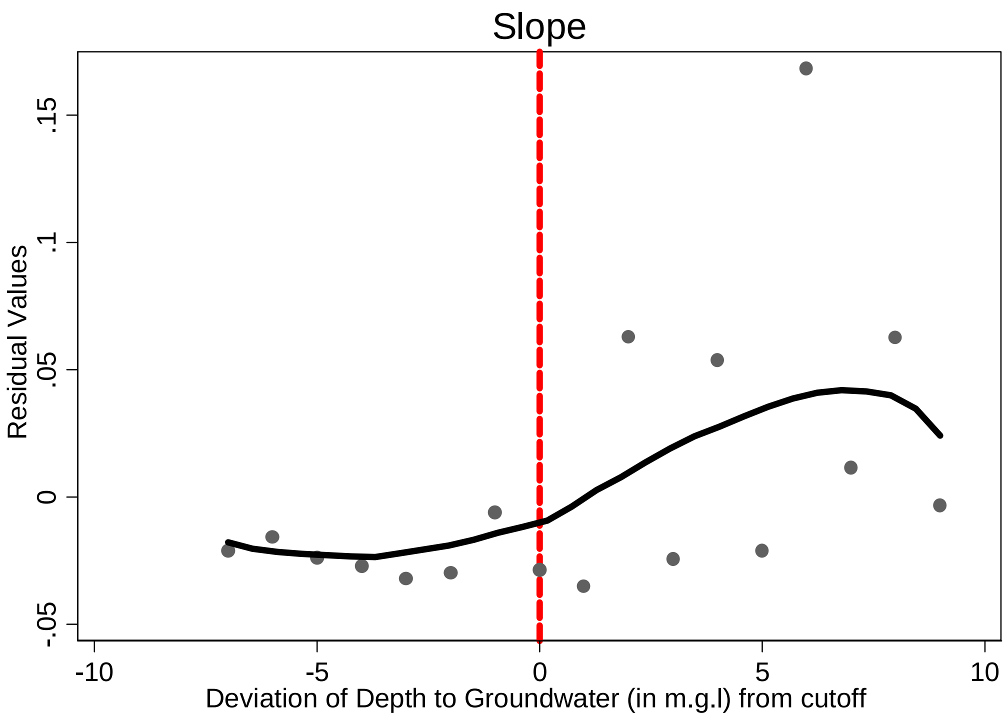
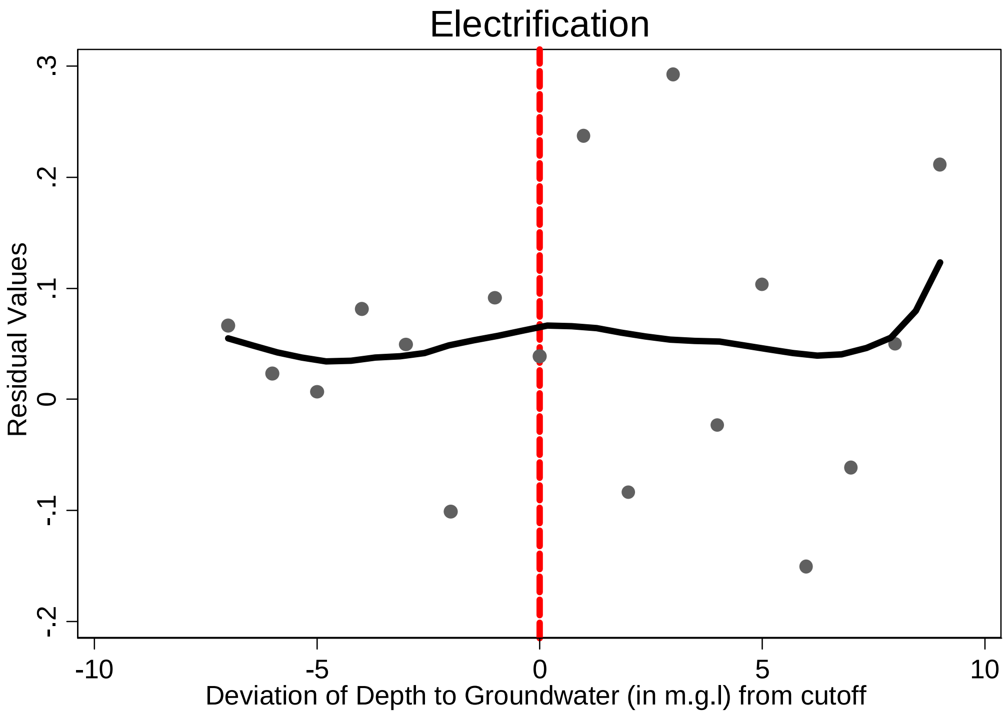
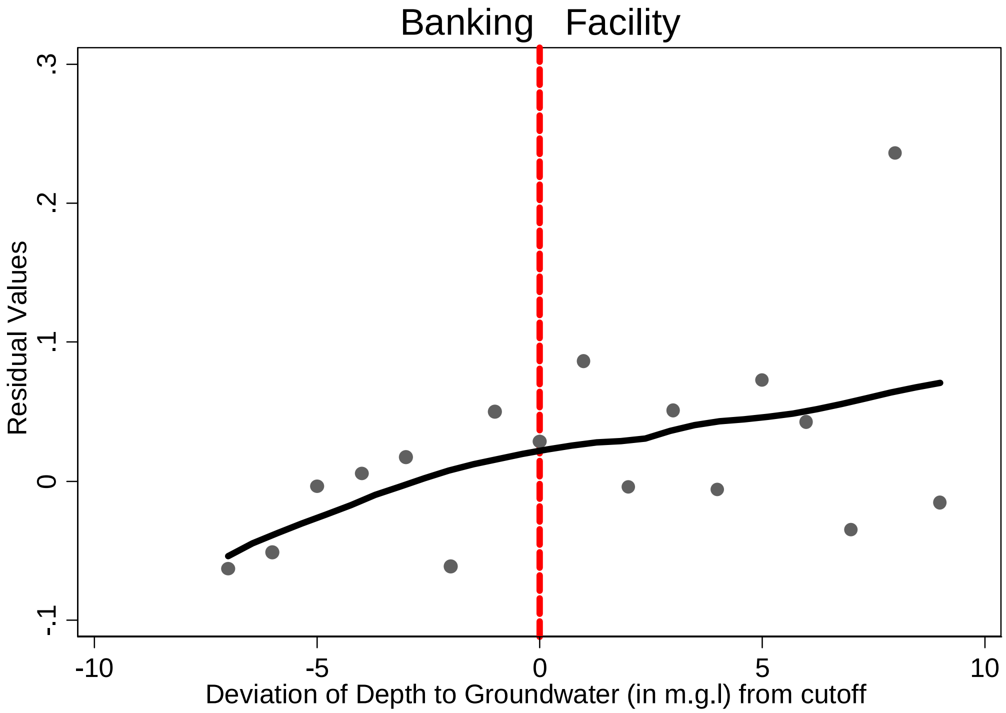
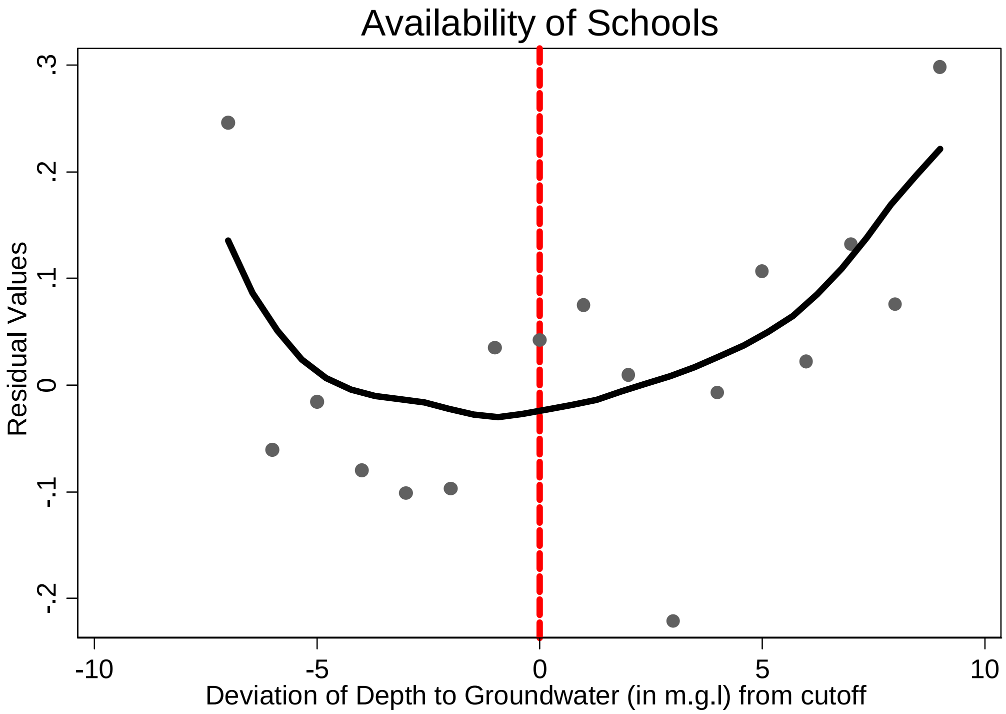
0
20
40
60
80
-10
-5
0
5
10
Deviation of Depth to Groundwater (in m.g.l) from cutoff

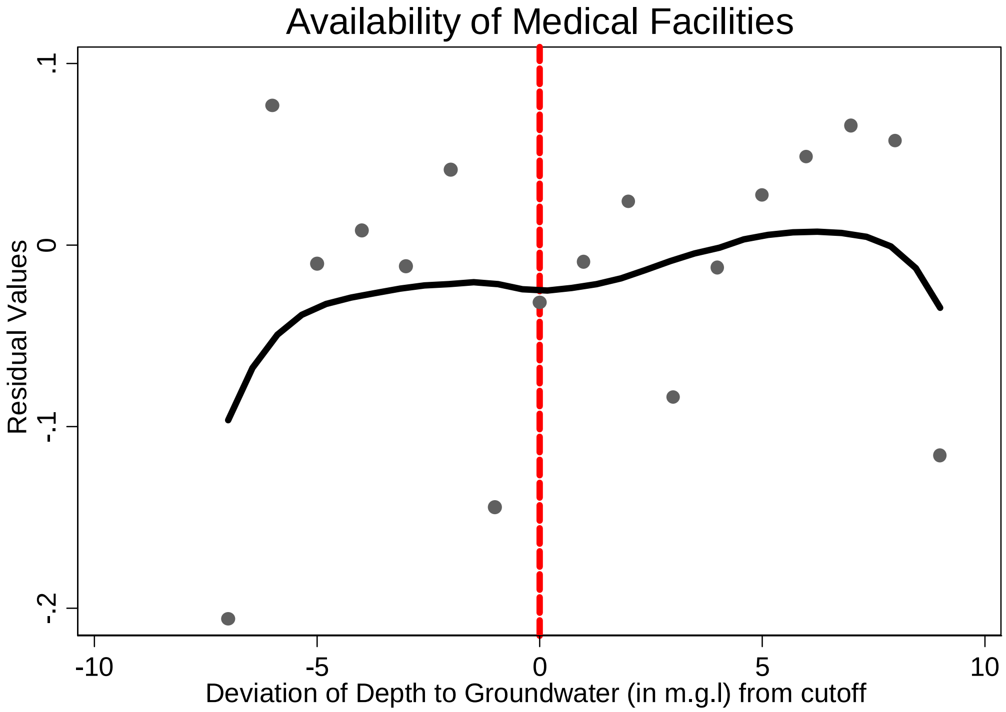

Slope
Residual Values
-.05
0
.05
.1
.15
-10
-5
0
5
10
Deviation of Depth to Groundwater (in m.g.l) from cutoff

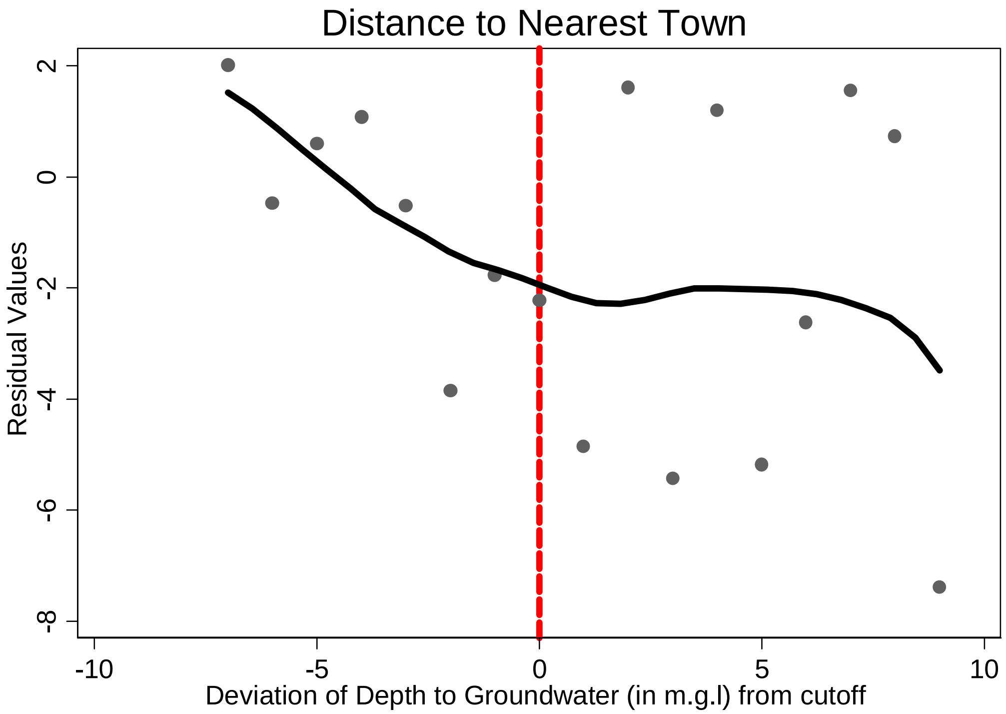
c. Village Infrastructure

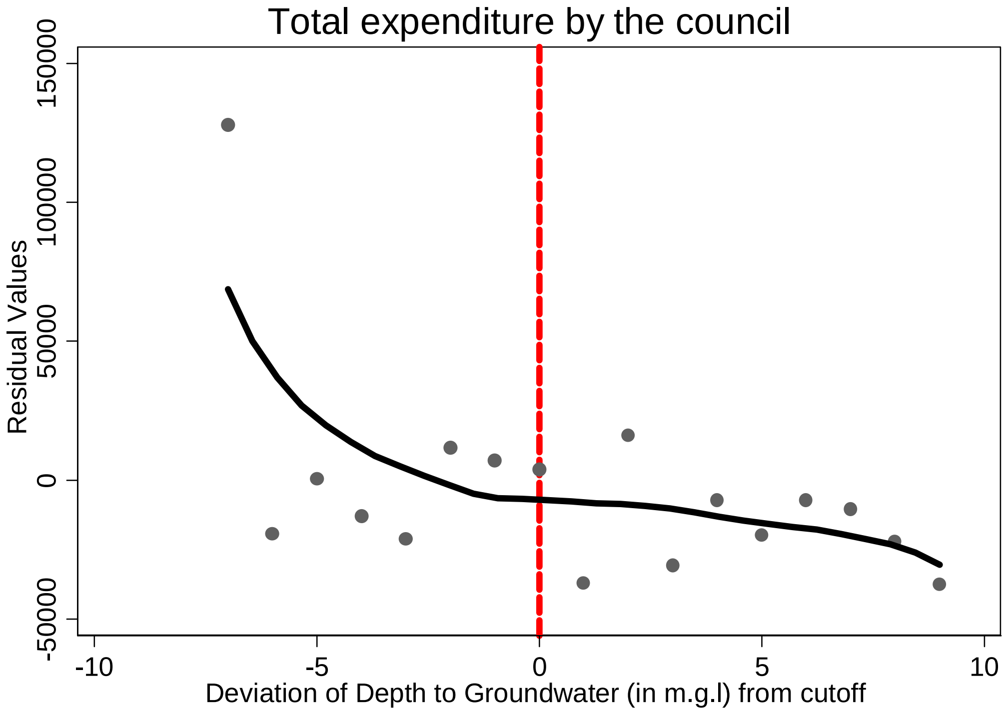

Electrification


Banking Facility


Availability of Schools


Availability of Medical Facilities


Distance to Nearest Town


Total expenditure by the council

Appendix Figures

Sensitivity Analysis

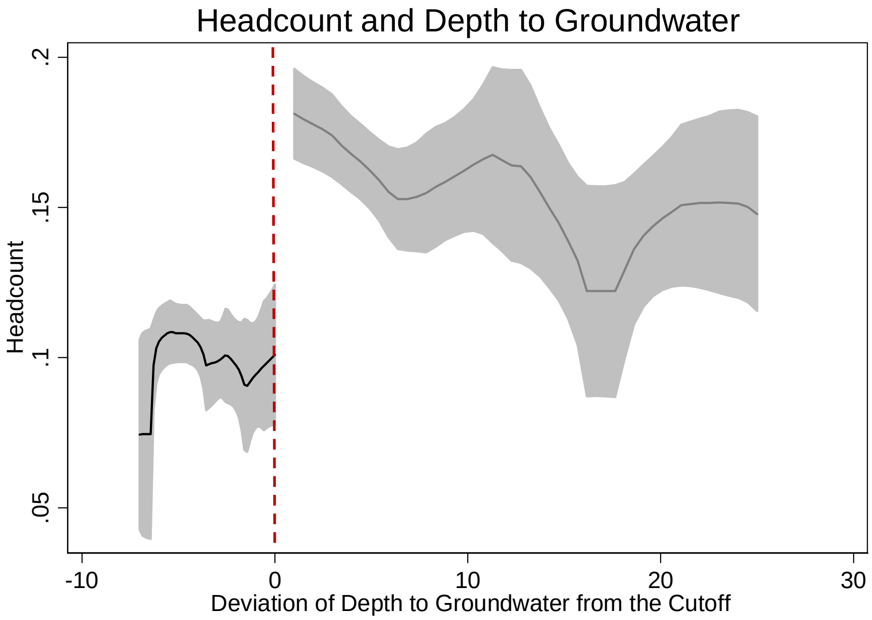


Figure A3: This figure graphs the regression functions from local polynomial regression of headcount on deviation of depth to groundwater from the cutoff that determines feasibility of surface pumps on either side of the cutoff. The 5 percent confidence bands are included.

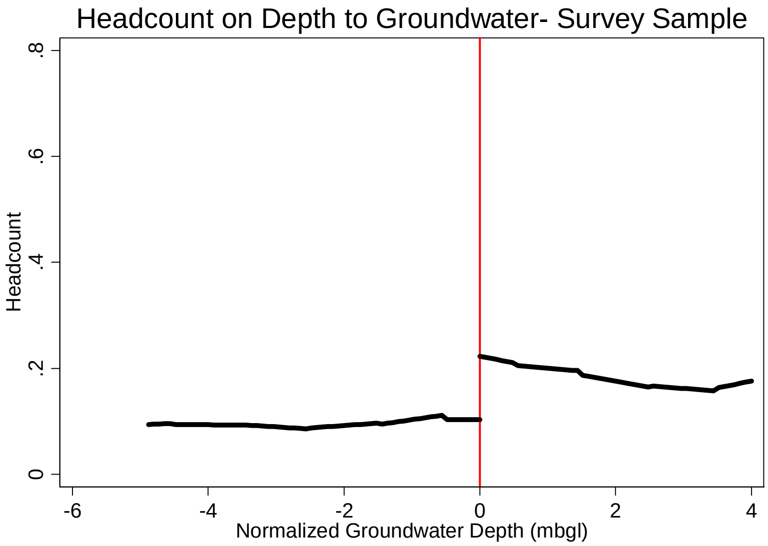


Figure A4: This figure graphs the regression functions from local polynomial regression of headcount on deviation of depth to groundwater from the cutoff that determines feasibility of surface pumps on either side of the cutoff for the *survey sample*.

Online Appendix Tables

Unrestricted Sample including villages that transitioned over 8 meters in either direction between 1993 and 2000

Appendix Table I: OLS Estimates of Impact of Access to Groundwater on Poverty

	Dependent Variable: Faction of Individuals Below Poverty Line		
	(i)	**(ii)**	**(iii)**
Indicator for Depth to Water > 8	**0.03*** (.0050)**	**0.04*** (.0080)**	**0.035*** (.0100)**
Water Level	No	Yes	yes
Water Level Squared	No	No	Yes
Water Level Cube	No	No	Yes
N	1714	1714	1714
R- squared	0.017	0.02	0.02

*** denotes significance at 1 percent level, ** at 5 percent and * at 10 percent.

Notes:

Indicator for Depth yo Water >8 is an indicator variable which takes the value 1 if groundwater level in year 2000 is at a depth greater than 8 meters below ground level. The regressions are based on an unrestricted sample. Robust standard errors are reported in parenthesis.