Public Provision and Protection of Natural Resources: Groundwater Irrigation in Rural India

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Web Appendix

Additional Selection Issues and Caveats

Migration, Land Distribution, and Crop Choice

Availability of public wells could have induced migration from the villages that were not treated into the treated villages. If it is the case, then this would bias the results. However, this seems unlikely. First, land markets in rural Uttar Pradesh are thin at best. It is highly unlikely for a farmer to sell his or her plot in one village and buy a parcel in another village in response to these public wells. I also check migration patterns in the World Bank Survey data *1997-98 Uttar Pradesh and Bihar Survey of Living Conditions*, which is representative of this area. The most reported reason for out-migration is labor and more than 70 percent of those who migrate, move to another state. Among entrepreneurial work, weaving and brick making are cited as types of work for which inhabitants of the villages migrate. No out-migration is reported for farming. In light of this evidence, it seems unlikely that these public wells caused land owning farmers to relocate to treated areas. Another possible concern might be that the land distribution patterns are different in the treated and control villages across cost categories. The primary data used in the analysis does not have information on land distribution. I impute village level land distribution from block level *Agricultural Census of India*. A comparison of the village level *imputed* land distributions shows that these are not systematically different.[1] Also, there is no systematic difference in crop choice (this too was imputed from the block level data). The program also provided agricultural outreach, but this component was similar in high and low-cost areas.

Water Markets

It is also possible that private markets for water may arise, which are not explicitly addressed in the paper. Most of the existing literature on markets for water points out that these are bilateral trade arrangements among neighbors (Jacoby et al, 2004 ; Foster and Sekhri, 2007). In such a case, a group of buyers and sellers can be thought of as one large farmer. This would only result in a shift of the perceived land distribution for the purposes of the model.[2] Empirically, I examine whether the determinants of the bilateral trade arrangements (as ascertained in Foster and Sekhri, 2007), indicate differences across treatment and control groups that vary by cost category.[3] I regress the plausible predictors of the market activity (bilateral trade among neighboring farmers) on treatment status that indicates whether a village received a public well or not, cost category status that

[1] The results are available on request.

[2] For large-scale farmers to operate in a more integrated market, an extensive distribution network would be needed which is not only very expensive to lay out, but also infeasible due to property rights issues, as the channels would have to pass through privately owned land. A number of case studies point that such permissions in case of unlined field channels result in conflict.

[3] In the absence of transaction data, I cannot test for differences in actual market activity. However, I examine the differences in the determinants of the market activity.

indicates the fixed cost for private extraction is low or high, and the interaction of the treatment and cost category status in the pre-period. [4] The results are reported in Web Appendix: Table WA.II. Column (i) reports the coefficients of the interaction between treatment and cost category status indicators, and the t-statistic is reported in column (ii). None of the coefficients reported in column (i) are statistically significant at conventional levels of significance. As this table shows, the predictors of the market activity are not different across treatment and control villages by the cost category in the pre-period of the public wells program. Hence, it is less plausible that any differential trends in the evolution of the markets confound the results.[5]

Hydrological Externalities

This paper abstracts from addressing externalities arising from well interference.[6] When several pumps irrigate in the vicinity of each other, the extraction from one well affects the extraction of other wells due to underlying hydrological features of the aquifer. This effect arises because the rate of water flow towards a cluster of wells from the other parts of the aquifer depends on how many wells are in the cluster. The proposed mechanism in the paper establishes that the number of private wells in the high-cost areas that received public wells expanded less than in comparison villages. Under this scenario, fewer wells are pumping in the vicinity of each other. The immediate effect of this is a reduction in water usage as the rate of flow of water moving towards fewer wells is smaller. This paper cannot quantify this effect separately.[7] But the magnitude of this effect may not be large if the well reduction occurs in a dispersed rather than spatially concentrated manner in the village.

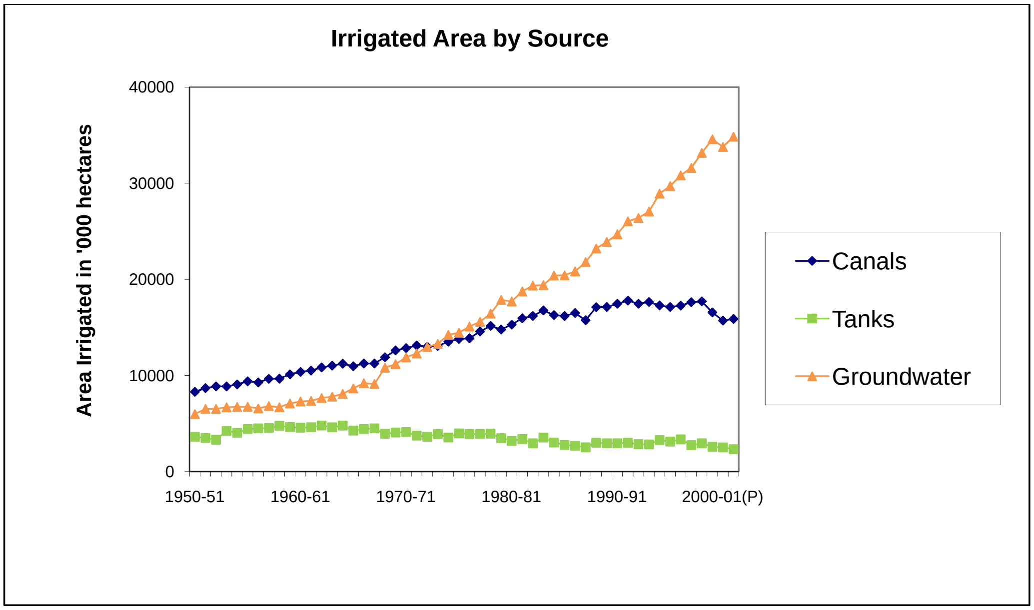
[4]Each regression conditions on the time-varying controls that are included in the main specifications reported in Tables 1 and 2.

[5]Since I directly control for some of the time-varying predictors of the market activity in the main specification used to examine the effects of the public program on water-tables by cost category (reported in Table 2), this further allays any concerns about the confounding effects of differential market activity.

[6]This is an interference emerging from hydrological operations of wells and not because of common pool concerns over aquifers. There seems no reason to think that the incentives to extract due to common pool concerns would vary in treated relative to comparison villages that would differ across cost categories.

[7]The reduced form water savings that I quantify are on account of fewer wells extracting water. This leads to water savings both because there are fewer people extracting water, and because less water is available to extract.

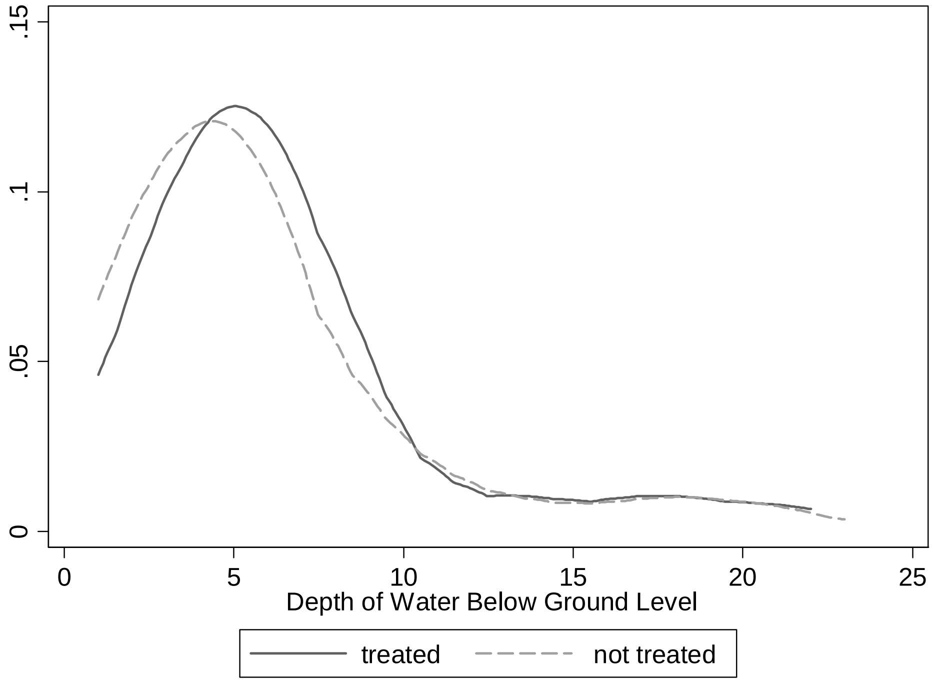
Figure WA.I : Expansion in Groundwater Irrigation in India



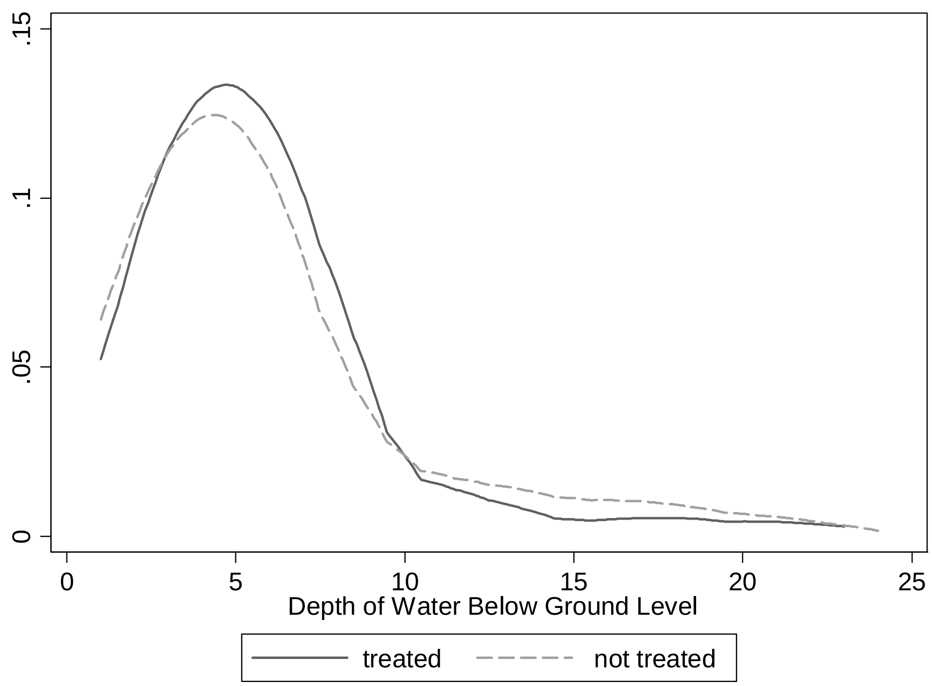
Source: Ministry of Agriculture, Govt. Of India, data provided by Indiastat.com

Figure WA.II: Water Table Depth Distribution

(Non Parametric Kernel Density of Depth of Water below Ground Level in meters-bandwidth= 0.5)

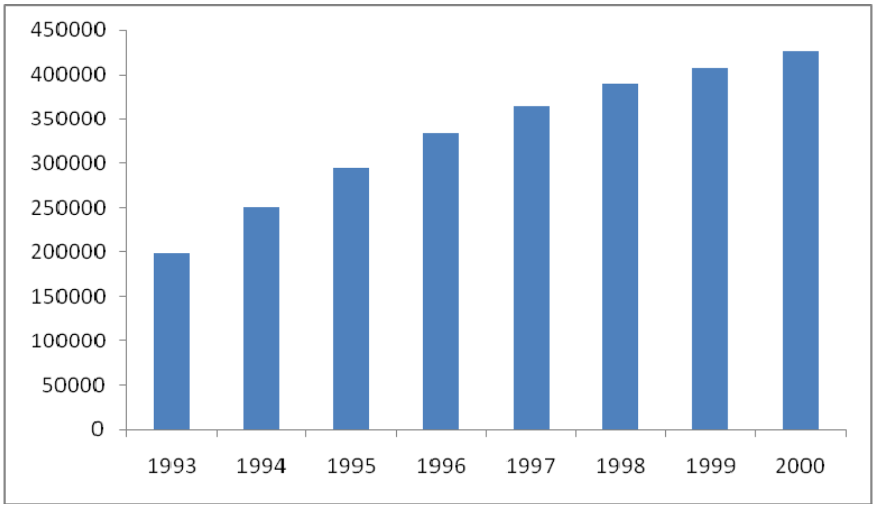


A. For period 1993

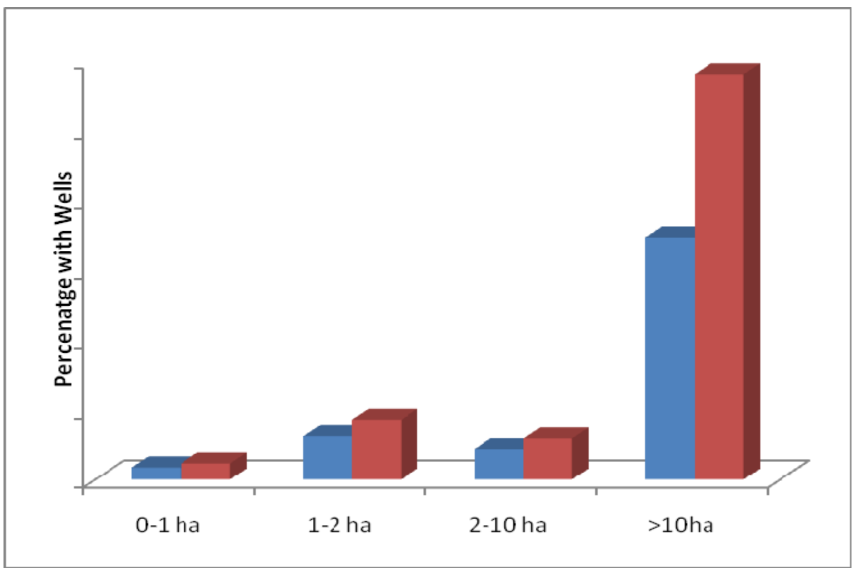


B. For Period 2000

Figure WA.III: **Investment in Private Tube Wells**



A. This figure shows yearly expansion in number of private tube wells in the program districts. New tube wells were installed every year. The sample villages are a subset of the districts.



B. This figure shows expansion between time periods in program districts. The well ownership among farmers with plots bigger than 10 ha rises sharply. The red bars correspond to year 2000.

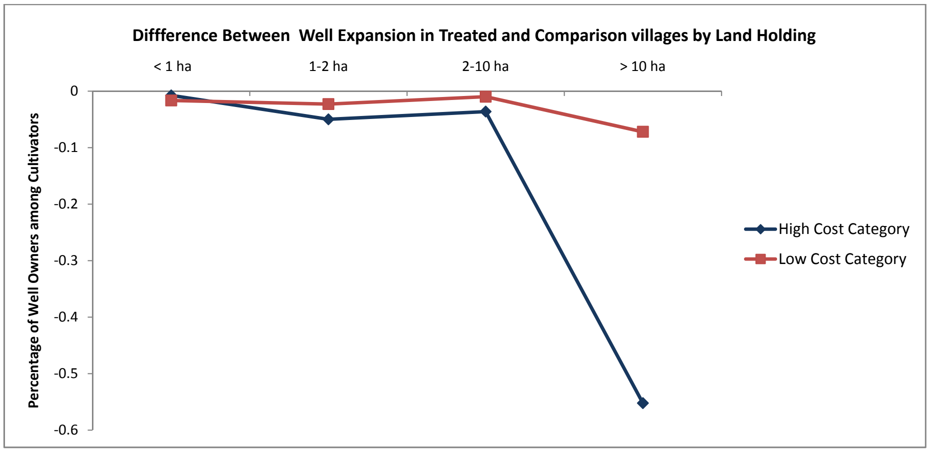


Figure WA. IV: Difference Between Well Expansion in Treated and Comparison villages by Holding Size: This figure shows the difference in Well Expansion over time between Treated and Comparison villages by size of land holding. In the low cost villages, the difference is negligible irrespective of land holding size. However, in the villages characterized by high cost, the difference is negligible for smaller farmers. In contrast, there is a sizable negative impact on the sinking decision in treated villages for relatively larger farmers. This is consistent with the hypothesis that the publicly available water crowds out investment for larger farmers in high cost areas.

The model suggests that relatively large farmers would forgo sinking their own wells when public provision is available. The data classifies the holding size of well owners into 4 categories : less than 1 ha, between 1-2 ha, 2-10 ha and greater than 10 ha [1]. The last category comprises all farmers of holdings greater than 10 ha irrespective of scale. I compute a difference-in-difference estimate of the expansion in private wells [2] by holding size across both cost categories. This figure shows the estimate for each of the 4 land size categories. We observe that in low cost category, there is no difference in the number of private wells between treated and comparison villages irrespective of the scale. However, in high cost category, the larger farmers sink fewer wells. This evidence is also consistent with the predictions of the model.

[1] Due to this classification of data, I cannot show that the intermediate farmers sink fewer wells and very large farmers are unaffected

[2] The number of cultivators in each of these holding size categories was imputed for the villages using block level data from the Agricultural Census of Uttar Pradesh for 1995-96. I then computed percentage of cultivators who own wells in each of the holding size categories. There is little evidence of change in land distribution over this period.

Table WA.I : Robustness Check for the Validity of Shift in Cost between High and Low Cost Category at 8 meters

	5 mbgl	**6mgl**	**7mbgl**	Break Point	**9mbgl**	**10mbgl**	**11mbgl**	**12mbgl**	**13mbgl**
Public Tube Well *	-0.55	-1.25	-1.1	**-0.54**	-0.96	-0.8	-0.8	-0.85	-0.87
Post * Low Cost	(1.01)	(.8)	(.75)	**(.78)**	(.78)	(.75)	(.75)	(.75)	(.75)
Public Tube Well *	-1.37	-1.93	-2.93	**-5.14**	-5.1	-5.06	-4.62	-3.8	-3.9
Post * High Cost Category	(1.31)	(1.77)	(2.07)	**(2.25)**	(2.32)	(2.58)	(2.6)	(2.7)	(2.81)
Difference	**-0.82**	**-0.68**	**-1.83**	**-4.6**	**-4.14**	**-4.26**	**-3.82**	**-2.95**	**-3.03**
F statistic	0.24	0.12	0.69	**3.73**	3.87	3.1	1.98	1.1	1.08
significane level	**0.62**	**0.72**	**0.4**	**0.05**	**0.09**	**0.11**	**0.15**	**0.3**	**0.3**

Notes:
std errors are reported in parantheses and are clustered at village level .
All Regressions are based on the baseline groundwater depth common support sample described in data appendix.
Low Cost category is charaterized by the depth below ground level upto which low cost surface pumps are physically feasible.
'Break Point' indicates a depth of around 25 meters below ground level which is the actual practical cutoff at which fixed cost to access aquifers changes .
Each Column corresponds to a separate regression where the cutoff of water table depth at which the change in fixed cost occurs is arbitrarily shifted from 8 meters in increments of 1 meter.

Table WA.II: Variation in the Determinants of Water Markets by Treatment Status and Cost Category Status

Pre-period OLS Estimates of the Interaction between Treatment Indicator and the Low Cost Category Indicator

	(i)	(ii)
Dependent Variables	**Coefficient**	**T-Stat**
Percentage of SC Population	0.021	1.33
Slope of the Terrain	-0.3	-0.26
Area of the Village	14.1	1.11
Number of House Holds	-22.8	-1.3
Sown Area	-4.37	-0.2
Government Canals	0.007	0.17
Electrification	0.05	1.42

Note: Each Row reports results from a separate regression. The dependent variable is regressed on the indicator for treatment status, indicator for low cost category, and the Indicator for the interaction of treatment status and low cost category. Each regression conditions on the time varying regressors included in the benchmark specifications reported in Table 1 and Table 2. The variables included are fraction of population that works, fraction of literate population, fraction of SC Population, Population density of the village, annual mean rainfall and temperature in period 1. The regressions are based on the sample described in the Web Appendix : Data Appendix.

Data Appendix

Variable	Definition	Source
Average Ground Water Level for the Village	Depth in meters below ground level at which water is found	Minor Irrigation Census, 1993 and 2000
Average Number of Private wells	Average number of shallow tube wells owned by farmers	Minor Irrigation Census, 1993 and 2000
Ground Water Irrigated Area	Ratio of area irrigated by ground water to the total sown area	Minor Irrigation Census, 1993 and 2000
Total Population	Total Population of the village	Census of India, 1991 and 2001 *Primary Census Abstract*
Number of Households	Number of residing households in the village	Census of India, 1991 and 2001 *Primary Census Abstract*
Percentage Workers	Main workers as percentage of total population in the village	Census of India, 1991 and 2001 *Primary Census Abstract*
Percentage Scheduled Caste	Percentage of total population that is classified as scheduled caste	Census of India, 1991 and 2001 *Primary Census Abstract*
Percentage Literate	Percentage of the Population that is literate	Census of India, 1991 and 2001 *Primary Census Abstract*
Density	Total Population over the total area of the village	Census of India, 1991 and 2001 *Primary Census Abstract*
Power	Dummy variable=1 if the village is electrified, and 0 otherwise	Census of India, 1991 Village Directory
Primary	Dummy variable=1 if the village has a primary school, and 0 otherwise	Census of India,1991 Village Directory
Community Health Workers	Dummy variable=1 if the village has Community health workers, and 0 otherwise	Census of India,1991 Village Directory
Government Canal	Dummy variable =1 if the village has Government canal irrigation, and 0 otherwise	Census of India,1991 Village Directory

(cont.)

Tubewell	Dummy variable=1 if the village has tube well irrigation, and 0 otherwise	Census of India,1991 Village Directory
Tank	Dummy variable=1 if the village has tank irrigation, and 0 otherwise	Census of India,1991 Village Directory
River	Dummy variable=1 if the village has river irrigation, and 0 otherwise	Census of India,1991 Village Directory
Elevation	Elevation of the village above sea level in meters	Digital Elevation Model, SRTM 1km (India)
Slope	Slope of the village terrain	Digital Elevation Model, SRTM 1 km (India)
Rainfall	Average Annual Rainfall in mm	UEA CRU TS2p1 monthly prcp
Temperature	Mean monthly temperature	UEA CRU TS2p1 monthly mean
Number of Holdings (< 1 ha) (1-2 ha) (2-10 ha) (>10 ha)	Number of Holdings of various sizes in administrative blocks of the program districts	Agricultural Census of Uttar Pradesh, 1995-96

<u>Working Sample (common support of baseline groundwater depth)</u>

1) There are three observations for treated villages for which there are no comparable comparison villages in terms of water table depth at the time when the public tube wells were put into operation. These are in the extreme right tail of the baseline depth distribution. Also, there are 43 comparison villages for which there are no comparable treated observations.
I exclude these observations in the regressions to detect heregenous impact following Heckman et al. 1996 and Heckman et al. 1997. These observations are 0.6 percent of the total.

2) In the regressions controlling for covariates, 93.2 percent of the sample is retained as around 6.8 percent of the observations did not match across various data sources.