Pre-Analysis Plan for the Mission Kakatiya RCT: An Impact Evaluation of A Minor Irrigation Tank Rehabilitation Scheme in Telangana*

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March 16, 2019

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*Acknowledgements and disclaimers.

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1 Introduction

1.1 Abstract

Mission Kakatiya (MK) is a large-scale irrigation project initiated by the Indian state government of Telangana (GOT). The project aims to repair and restore roughly 46,000 currently non- or under-utilized water bodies (referred to as "water tanks" or "tanks") throughout the state for local agricultural and other uses. MK was launched in 2015 with the plan to rehabilitate about 1/5 of all tanks in each of 5 phases. We conduct an impact evaluation, comprised of an observational analysis and a randomized controlled trial (RCT), to measure the impact of rehabilitated water tanks on agricultural, economic, and environmental outcomes, as well as identify the different mechanisms through which these impacts may occur. The predicted, immediate, and partial equilibrium impact from MK is an increase in irrigation supply, a reduction in the risks associated with variable rainfall, an increase in the water table through percolation, and an increase in economic opportunities through supplementary uses of the tank such as aquaculture. The study is especially relevant since hyper-local surface irrigation projects are widely considered to be cost-effective and central to climate adaptation and water management policies. In this document we describe our observational analysis, which is partially completed, and we set forth our pre-analysis plan for the RCT.

1.2 Motivation

India has become heavily dependent on irrigated agriculture. The country witnessed a rapid increase in agricultural productivity during the "Green Revolution" in the late 1960s that led to increased adoption of water-intensive, high-yield crop varieties. The dependence of crop productivity on irrigation, especially of the modern high yielding crop varieties that spread gradually across most of India, has been fairly well established in the literature (McKinsey and Evenson, 1999).[1] In India, 55 percent of agricultural output is from irrigated land (Food and Agriculture Organization 2018). While a significant fraction of farmers in India depend on highly variable rainfall (World The World Bank (2012)), the last 30 years have witnessed an increase in irrigated area through increased use of groundwater resources. At the same time, there has been a decline in traditional means of irrigation such as local water tanks (Dayal and Iyengar, 2006).

Due to concerns about the sustainability of groundwater irrigation, India is re-emphasizing water management and careful use of surface irrigation. Rodell et al. (2009) note that water tables are declining rapidly in India, suggesting over-consumption of groundwater for irrigation and other uses as the primary cause. In response, both central and state governments in the past decade have focused on harvesting surface run-off water during the monsoon through local water tanks for irrigation and other uses during the dry season. Farmers tend to use tank water for irrigation whenever possible (Sharma and International Water Management Institute, 2003). Finally, a range of domestic and international agencies, including the European Union (EU), the National Bank for Agriculture and Rural Development (NABARD) and the World Bank (Dayal and Iyengar, 2006), have begun supporting the use of water tanks as a tool for climate adaptation and water management.

Tank irrigation has some notable advantages over groundwater irrigation, particularly their complementary role to the latter. Tanks continue to recharge groundwater through percolation even if the water harvested is insufficient for surface irrigation (Palanisami et al., 2010). An increase in the supply of irrigation through tank restoration is likely to have significant positive effects on agricultural production for not only those in the tank command area but also other farmers in the village through economy wide general equilibrium effects (Bardhan et al., 2012). For instance, they suggest a positive relationship between investment in public irrigation systems and agricultural outcomes through a reduction in water prices across the entire economy.

Tank irrigation also has an advantage of the other main alternative to groundwater irrigation, namely large scale irrigation projects such as dams. The costs of tank irrigation projects tend to be in the INR 60,000 - 98,000 range (per hectare, 2007 prices) compared to average costs of INR 332,000 per hectare for medium to large irrigation projects. Further, frequent unexpected costs in large scale irrigation projects reduce their cost-effectiveness even further (Palanisami et al., 2010).

To our knowledge, there is limited evidence, let alone experimental evidence, of the impacts of local irrigation infrastructure on economic and environmental outcomes, primarily because it is difficult to randomly assign public goods (irrigation goods) that require significant infrastructure creation and public expenditures. There are some carefully executed studies using non-experimental data that measure the impact of increased irrigation supply on farm

[1] This is not unique to India. According to FAO, 2.4 billion people are dependent on irrigated agriculture for sustenance.

productivity and welfare (e.g. Duflo and Pande (2007)) that we draw on. In a series of papers, Sekhri (2011, 2014) use observational data to examine the relationship between groundwater irrigation and a range of outcomes including agricultural production, conflict and poverty. She finds that declines in groundwater levels have significant effects on yields and cropping intensity.

In this document we set forth the design for two studies of GoT's MK project. The first, observational study, compares outcomes from 580 treatment tanks slated to be rehabilitated prior to Summer 2017 (prior to the start of phase 3) with 119 control tanks slated to be rehabilitated later than that date. We address the endogeneity of rehabilitation decisions in two ways. First, we instrument for the actual rehabilitation using the assignment to phases 1 or 2 of MK conditional on tank features. We believe this is a plausibly exogenous instrument that hastens the time at which a tank is rehabilitated. Second, we condition on phase 1 or phase 2 assignment. This is a reasonable strategy if phase assignment is thought to be endogenous, but actual completion of rehabilitation post assignment is exogenous, depending only on idiosyncratic factors uncorrelated with the allocation to a specific phase.

The second, experimental study randomizes a subset of tanks that were not rehabilitated prior to summer 2018 to rehabilitation under phase 4 (treatment group) or to rehabilitation in phase 5 (control group). This analysis provides an intent-to-treat estimate of the impact of assignment to rehabilitation in phase 4 of MK and a treatment-on-treated estimate of the impact of rehabilitation using random assignment to phase 4 as an instrument for rehabilitation.

Although this document describes our strategy for both studies, we had access to and performed preliminary analysis on the data from the first study before we posted this document. Therefore, this document is only a pre-analysis plan for the second, experimental study. We consider our preliminary analysis under the observational component as an input into the design and analysis of the RCT, specially for power calculation and sampling strategy.

Our strategy to evaluate GOT's scheme to rehabilitate irrigation tanks under MK is innovative on two levels. First, we will examine the causal effects of access to irrigation on agricultural production using a combination of observational and experimental strategies. Second, we hope to shed light on both direct and indirect channels through which increased access to irrigation affects production and welfare outcomes. Under the direct channel, we hypothesize that tank rehabilitation will increase surface irrigation from the renovated tank. We also hypothesize an increase in overall irrigation through indirect channels, arising out of improved groundwater tables (from increased percolation arising from the renovated tank) and an increase in water trade. Both of these channels are complementary and likely to augment the effects of rehabilitation. To distinguish indirect and direct effects, we will decompose the impact by plot size and the presence of bore-wells.

Our study also has immediate policy relevance. Since the restoration under Mission Kakatiya is across the universe of tanks in Telangana, an evaluation of the impact would also be useful for deciding on a policy for on-going maintenance given that the GOT has already committed huge sums of money for rehabilitation but none yet on maintenance. Additionally, a systematic evaluation can provide valuable insights to other southern and western states that account for 60% of the 3.2 million hectares of tank irrigated area in India (Palanisami et al., 2010).

1.3 Research questions

The main research question is whether and to what extent rehabilitation of water tanks impacts key outcomes – irrigation use; water table levels; water distribution patterns and local water markets; and crop yields (paddy, cotton, and maize), crop mix and agricultural incomes more generally. We will also examine corollary questions, such as the mechanisms for the observed effects and the persistence in outcomes across multiple cropping seasons. We predict the effects of tank rehabilitation will manifest on the following margins:

1. **Extensive margin**: The command area ("ayacut") that is irrigable with water from tanks may increase. We believe that de-silting and repair of field channels will increase considerably the area irrigable by the tanks. We measure this using the official records maintained by the village inspectors and revenue assistants as well as undertaking GIS mapping of the ayacut.

2. **Intensive margin**: Plots in the pre-existing command area will have access to a greater volume of irrigation water due to the increase in tank storage capacity through the rehabilitation.

3. **Crop choice and cropping intensity**: Farmers make cropping decisions based on their expectations of rainfall and/or access to irrigation. Farmers with access to irrigation will tend to grow water-intensive crops like paddy, whereas farmers relying on rain-fed irrigation tend to grow millets/subsistence crop.[2] Also, farmers with access to irrigation will cultivate "second paddy", i.e., cultivate paddy during the Rabi season (dry season between Jan-Apr), whereas those without irrigation leave their land fallow. For farmers owning multiple plots, changes in the water availability of a plot in the command area can also affect investment decisions in other plots and we will be able to measure these directly.

4. **Indirect effects through water-markets**: Prices for irrigation water in the local economy may decline due to an increase in the supply of tank water. Given the widespread use of water markets and the potentially large supply shock, we expect to see non-negligible reductions in water prices due to tank rehabilitation. We are not at this stage equipped to carry out a general equilibrium analysis using purely experimental variation but we are working towards a model that will allow us to use the experimental variation along with strong assumptions on behavior to detect such effects.

[2] This prediction is largely based on farmer responses during qualitative fieldwork.

2 Research Strategy

The Government of Telangana (GOT) planned to roll out the MK rehabilitation project to approximately all of 46,500 tanks in the state in 5 phases over 5-7 years. The largest tanks in the state received higher priority and tended to be rehabilitated in the earlier phases. The first 4 phases of works have all been approved as of April 2018 and are currently in various stages towards completion. It is unclear whether and when phase 5 will commence. In this context, we conduct two impact evaluations.

2.1 Observational evaluation

Using an observational design, we will first assess the impact of tank rehabilitation in the phases that were already completed before our involvement (phases 1-2). Specifically, we will conduct a difference-in-difference analysis that compares the change in outcomes at treatment tanks that were approved to be rehabilitated prior to Summer 2017 (when we became involved with MK) to the change at control tanks that were not yet approved. To increase precision, we constructed an observational counterfactual for each treatment tank by matching earlier-approved tanks to those approved later and those yet to be approved based on observable characteristics – primarily the narrow geographic location of the administrative and revenue mandal (sub-district) that also roughly corresponds to the underlying hydrological sub-basin.

2.1.1 Sample

The GOT announced about 17,000 tanks to be rehabilitated as of summer 2016 (under phases 1 and 2)[3]. Not all of these were actually rehabilitated nor were all phase 1 tanks completely rehabilitated before phase 2 tanks. However, being approved in an earlier phase increases the probability of actually being rehabilitated earlier. Thus, the set of phase 1 and 2 tanks that were approved for rehabilitation serve as the sampling frame for the "treatment" tanks. Tanks that were yet to be approved as of Summer 2017, whether they were assigned to Phase 3 or to a later phase serve as the comparison group. The sample for our study was selected as follows:

1. As recommended by the Government of Telangana, we focus on the administrative districts of Mahbubnagar and Warangal because they represent two different agro-climatic zones. We start with the list of all tanks in these districts.

2. Typically, villages have more than one tank and therefore, we need to worry about SUTVA violation as the tanks may share an aquifer. To minimize this, we drop all tanks in villages that have repairs under both phases 1 and 2. That is, we are left with sample tanks that do not have any neighboring rehabilitated tank.

3. We follow the same process to ensure that the comparison tanks also do not have any neighboring rehabilitated tanks either under phases 1 or 2.

[3] 9000 tanks were approved for rehabilitation under Phase 1 in summer 2015 and about 8000 under Phase 2 before summer 2016

4. This leaves us with 262 tanks from Phase 1, 318 under Phase 2 and 119 non-rehabilitated tanks in 32 mandals (sub-districts) across the two districts.

2.1.2 Treatment assignment (selection)

We conduct 2 types of analysis. First, we compare a group of rehabilitated tanks (treatment group) to a group of non-rehabilitated tanks (control group). Because we include mandal fixed effects, is functionally done within blocks defined by mandal.

Since rehabilitation may be non-random, we also estimate the effect of rehabilitation in two other ways. One is by instrumenting for rehabilitation with whether a tank was assigned to phase 1 or to 2 (as opposed to not being assigned to either phase). Because assignment to a phase begins a long process of making engineering plans, selecting a vendor, and vendor performance, not all phase 1 or phase 2 tanks were rehabilitated prior to Summer 2017. Our identifying assumption is that, conditional on controlling for, e.g., tank size, assignment to phases is exogenous, and that phase assignment only affects outcomes via rehabilitation. (For completeness, we also provide a reduced form estimate of the effect of phase assignment on outcomes.) The other way is to control for assignment to phase 1 or to phase 2. Even if assignment to phases is not conditionally random, perhaps the progress of construction is random conditional on phase assignment.

While this evaluation is not experimental, we offer alternative assumptions under which our analysis is causal. Even though none of the assumptions are perfect, this exercise is still worthwhile as the observational analysis is necessary to estimate the impacts of rehabilitation on the larger tanks, which tended to be rehabilitated in earlier phases.

2.1.3 Outcomes

To gather data on farm-level outcomes, we surveyed farmers who cultivate plots in the head-end and in the tail-end of irrigated areas within the command area of the study tank.[4] Detecting changes at both intensive margin (head-end) and extensive margins (tail-end) are important as one might reasonably expect possible spillover effects on the entire village economy including on farmers with no land in the tank command area both because of hydrological reasons (water tank restoration will recharge groundwater in the surrounding areas) and behavioral ones (through markets).

2.2 Experimental evaluation

Our second evaluation of MK assesses the impact of rehabilitation via an experiment wherein a sub-sample of yet to be rehabilitated tanks are randomly assigned to either be rehabilitated in phase 4 (the treatment group) or to be rehabilitated in phase 5 (the control group).[5]. Our analysis will provide both an intent-to-treat estimate that will examine the impact of being

[4] Head-end is the area closest to the sluice gates that control the outflow of water from the tank to the surrounding area. Tail-end is the area in the ayacut that is the farthest away from sluice gates. In many cases, there may be sub-channels that carry water from the sluice gates to tail-end farmers' plots.

[5] There is a chance that the control group will never be treated if the MK project is terminated before phase 5 is undertaken. See `https://www.thehansindia.com/posts/index/Telangana/2019-02-05/New-plan-puts-brakes-on-Mission-Kakatiya/488358`

assigned to phase 4 and a treatment-on-treat estimate of the impact of rehabilitation by using randomization to phase 4 as an instrument for rehabilitation.

2.2.1 Sample

Our sample is a list of 92 tanks provided by the GOT.[6] Tanks in this list were not rehabilitated in phases 1 to 3 of MK and GOT was indifferent with regard to their allocation to phases 4 or 5. The tanks also met engineering and financial criteria and thus were feasible for rehabilitation.

2.2.2 Statistical power

We carried out standard power calculations assuming an ITT estimator that is normally distributed, but with correlation across farmers within a command area. We calculated effect sizes and intra-cluster correlations (ICCs) using farmer level data from Cole, Giné and Vickery (2014). This data set is from undivided Andhra Pradesh (and thus covers parts of Telangana).

For our calculations, we used the village (rather than tank) as the unit of randomization[7] and calculated ICC's for the following outcome measures corresponding to our expected impact measures: a) crop yield for paddy and maize (averaged over 2 years) by crop season (Kharif and Rabi); b) area under paddy and maize as a proportion of total cultivated area by crop season; and c) fraction of land left fallow during Kharif. For example, the average Kharif yield in the data set is 968 kgs/acre with a standard deviation of 2737 kgs/acre and an ICC of 0.2.

For our sample size calculations, we assumed that the treatment and control have the same standard deviation and that we would sample 5 farmers per village, and we targeted a significance level of at 5% and power level of 80%. We then calculated the relationship between sample size and effect sizes as shown in Figure 1 below. With a sample size of 150 clusters per arm we would be powered to detect effect sizes slightly upwards of 0.2.

Unfortunately, after multiple meetings with GoT, we were only able to obtain a list of 92 tanks that we could include in the RCT. To address concerns about inadequate power, we increased the number of farmers we planned to sample in each village to 30. As a result of the change in our farmer sample, our sample size of farmers remains roughly the same as before (∼2500 farmers) even though the sample of tanks were reduced to 92. Further, we used data from our observational study (rather than Cole, Giné and Vikery (2010)) to estimate correlation between plots within a tank ayacut so that our power calculation reflected variation in a same context more closely connected to our experimental study. Our sample size calculations suggest that, with 46 tanks per arm, we are now powered to detect effects larger than 0.25 SD (see Figure 2). We also enhance power in two ways, the value of which are positive but harder to quantify. First, we stratified across plot location within the tank ayacut to capture the heterogeneity in access to surface irrigation. Second, we plan

[6] Although we had requested for a list of 300 tanks, 150 in each group based on our power calculation, we were only able to get a smaller sample due to political reasons.

[7] A tank typically service the village level. Plus the Cole, Giné and Vickery (2014) data have village level – but now tank-level – indicators.

to conduct multiple rounds of data collection at different stages of rehabilitation as well as during different crop seasons.

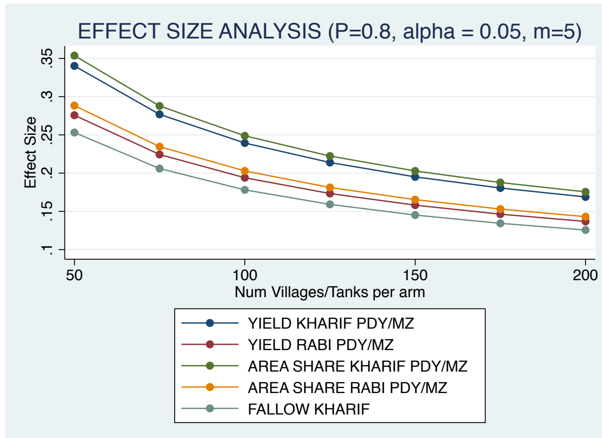

Figure 1: Study Effect Size: Using data from Cole, Giné, and Vickery 2014

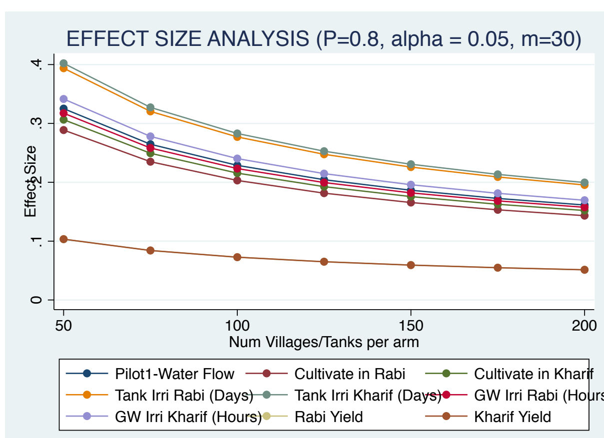

Figure 2: Revised Study Effect Size Calculation: Using Baseline Data

2.2.3 Treatment assignment

We define strata by the administrative district[8], which roughly overlap with underlying hydrological sub-basins. Within strata, we assigned half the tanks (46 in total) to rehabilitation in summer 2018 as part of MK phase 4, while the rest were assigned to be rehabilitated later as part of MK phase 5. Rehabilitation in Summer 2018 means in the months before the 2018 monsoon season begins. Phase 5, if it takes place, will occur in Summer 2019.

2.2.4 Attrition from the sample

We do not expect attrition to be a problem in this study. For ITT and TOT estimates, we need not worry about whether tanks are rehabilitated. For ITT, non-rehabilitation only impact estimated effects sizes. For TOT estimates, non-rehabilitation only affects the strength of our randomization instrument. In any case, we monitored adherence to randomization and implementation of rehabilitation orders and found few discrepancies. As for attrition of farmers, we think the risk is minimal. Farmers own the plots in the ayacut and have been cultivating for years. Based on the data collection by Cole, Giné and Vickery (2014), the survey refusal rate and the overall attrition rate should be minimal.

2.2.5 Outcomes

We will examine changes in irrigation and agricultural practices for farmers that were receiving tank irrigation before (intensive margin) and for those that were not (extensive margin). The latter is particularly central to the sustainability of the rehabilitation exercise since increases along the extensive margin should make it easier for farmers to co-ordinate on tank maintenance going forward.

3 Data collection

3.1 Observational evaluation

To gather data on farm-level outcomes, we surveyed 5 farmers who cultivate within the command area of the study tank: 2 farmers with plots in the head-end and 3 with plots in the tail-end of the irrigated areas.

We collected data in summer 2017 [9], which involved a combination of a farmer-level survey, a survey of key village officials including the revenue officer, and the elected representative (Sarpanch) of the village. We obtained pre-period (pre-rehabilitation) data based on recall during the surveys, which we plan to validate using secondary data sources, where possible.

Although we conduct our surveys in Summer 2017, our surveys gather data on outcomes over eight points in time: 4 seasons before the start of MK and 4 seasons since. A year comprises of 2 seasons that starts with Kharif (wet) following monsoon from Jul-Dec and

[8]In the observational study, we have mandal fixed or random effects. Here, in contrast, we have district-level strata.

[9]Note that rehabilitation was not completed for all tanks in phases 1 and 2 by this time.

ends with Rabi (dry) that falls between Jan-April. Our survey, therefore, includes pre-years 2013-14 and 2014-15 (Kharif 2013, Kharif 2014, Rabi 2014, and Rabi 2015) and post years 2015-16 and 2016-17 (Kharif 2015, Kharif 2016, Rabi 2016, and Rabi 2017). Since our surveys for the observational study were conducted between Feb-Aug 2017, data from earlier seasons were obtained via recall.

3.2 Experimental evaluation

Although treatment is randomly assigned at the level of the tank, outcomes are measured both at the tank level as well as the level of individual fields (plots) within the tank ayacut.

To measure farm-level outcomes, we sample all farmers who cultivate within the command area of each study tank with a ceiling of 30 farmers per tank. The tanks in our sample vary in the number of farmers cultivating in its ayacut - some tanks only have a few (2-4) farmers while others have over 50 farmers. Therefore, we construct our farmer sample in the following manner:

- If the tank has less than 30 farmers in the ayacut, we survey all the farmers;
- If the tank has more than 30 farmers in the ayacut, we randomly sample 30 farmers stratifying by plot location. Specifically:
  - Randomly sample 10 farmers each in head, middle, and tail-end.
  - When there are fewer than 10 farmers in a given strata, we sample all the farmers in that strata and increase sampling from the other strata to reach a random sample of 30 farmers in total.

We will collect survey data from our sample at baseline before treatment, at midline in the season after treatment, and (hopefully) at endline 2 seasons after treatment. The data collection timeline is presented in table 3.4.

3.3 Survey Modules

Our primary survey contain the following specific modules, which is used across both observational and experimental study components:

1. **Tank Structure Details:** Administrative data on the tank structure details and the details of rehabilitation works commissioned from the corresponding Engineer's office (Assistant Engineer/Assistant Executive Engineer).
2. **Process monitoring data:** A phone-based survey to gather data on the details of actual works executed under the rehabilitation program. It was administered on bi-weekly schedule, alternating between the concerned Engineer and the VRO.
3. **Random Audits:** Random in-person inspection of tank sites and recording of the observation based on visual inspection.

4. **Tank Module:** Village tank operations and water markets survey module surveying officials at the village revenue office, including any of the following: village revenue officer (VRO), bill collector, or the village water police.

5. **Farmer Listing:** A listing survey administered at the tank level to enumerate all farmers cultivating in the ayacut of the sample tank. This information is obtained from the VRO, and includes farmer name, contact number, area cultivated within the ayacut, plot location (head/middle/tail), whether or not the farmer has a functioning bore-well on the plot. This listing data is then use to draw the farmer sample as described in the "Statistical Power" section above.

6. **Farmer Module:** A farmer survey module administered to the farmers in our sample covers farmer household and demographic characteristics, overall land ownership, history of farming practices and agriculture investment behavior, in addition to detailed plot-level characteristics and cropping decisions for the plot within the ayacut of the tank. During follow-up rounds we will also collect farmer consumption and income data to facilitate welfare calculations.

7. **Village Socio-Economic Module:** Village socio-economic survey module to capture village-level covariates to help with sub-group/heterogeneous treatment effects analysis. This will be administered to the village elected official (Sarpanch).

8. **Administrative data:** Administrative data from the GOT covers monthly groundwater table levels at the level of measuring stations across our sample districts and other outcomes likely to be impacted such as aquaculture output (e.g. fish yield) in the event tanks are used for aquaculture.

Tank data collection will include measurement of both outcome indicators during modules described below, as well as process indicators through in-person random (unannounced) site inspection. The latter set of variables will capture the extent to which actual restoration work meets the goals set out under the project as specified in the work estimation reports. Additional process monitoring data will be obtained from inspection reports at the corresponding local office of the Department of Irrigation and Command Area Development, GOT.

3.4 Variables and balancing tests

Details on the variables we capture during the data collection process are mentioned in the tables below. Balancing tests will be performed on the baseline levels of variables in the groups below.

Process Monitoring/First Stage (FS) Variables			
Variable Label	**Nature of the Variable**	**Specification**	**Variable Construction Method**
Completion of works (Binary)	Outcome (FS)	First Stage	Site visual inspection, survey (interview with Village Revenue Assistant)
Fraction of works completed	Outcome (FS)	First Stage	survey (interview with field engineer), works record (admin data)
Tank capacity (full capacity, dead storage, sill level, bund length, wier capacity)	Outcome (FS)	First Stage	survey (interview with field engineer), works record (admin data)
Area irrigated by tank (surface irrigation); area irrigated by tank as a fraction of its "design" ayacut	Outcome (FS)	First Stage	Site visual inspection, survey (interview with Village Revenue Assistant)
Area indirectly irrigated by tank (percolation)	Outcome (FS)	First Stage	Site visual inspection, survey (interview with Village Revenue Assistant)
Water table level - Public Wells	Outcome (FS)	First Stage	Site visual inspection, survey (interview with Village Revenue Assistant)
Whether tank used for aquaculture	Outcome (FS)	First Stage	Site visual inspection, survey (interview with Village Revenue Assistant)

Table 1: First Stage Variables Table

Note: All time variant outcomes are measured by season, with two seasons in a calendar year. We collect data from 4 seasons prior to baseline survey and 2 seasons intervening between baseline and midline, and 2 seasons between midline and endline.

Impact on Farm Production within Tank Ayacut			
Variable Label	**Nature of the Variable**	**Specification**	**Variable Construction Method**
Source of irrigation (surface irrigation binary) by season	Intermediate Irrigation Outcome	ITT, TOT	Survey (interview with sample farmer)
Intensive margin irrigation effects (days of surface irrigation) by season	Intermediate Irrigation Outcome	ITT, TOT	Survey (interview with sample farmer)
Source of irrigation (ground water irrigation binary) by season	Intermediate Irrigation Outcome	ITT, TOT	Survey (interview with sample farmer)
Plot level water table by season	Intermediate Irrigation Outcome	ITT, TOT	Survey (interview with sample farmer)
Intensive margin irrigation effects (hours of groundwater irrigation) by season	Intermediate Irrigation Outcome	ITT, TOT	Survey (interview with sample farmer)
Conflict over water use	Intermediate Irrigation Outcome	ITT, TOT	Survey (interview with sample farmer)
Agricultural inputs used (fertilizer, pesticide, hired labor, family labor, high yielding variety seed) by season	Intermediate Outcome on Input Use	ITT, TOT	Survey (interview with sample farmer)
Crop choice by season and intensity (what crop, number of crops grown in a year)	Intermediate Outcome on Input Use	ITT, TOT	Survey (interview with sample farmer)
Crop area sown by season	Final Production Outcome	ITT, TOT	Survey (interview with sample farmer)
Crop output by season (quantity harvested), yield (output/area), net revenue from sale	Final Production Outcome	ITT, TOT	Survey (interview with sample farmer), GIS estimation (alternate measurement)
Satisfaction with rehabilitation and surface irrigation	Farmer Welfare	ITT, TOT	Survey (interview with sample farmer) on a Likert scale (1 to 5)

Table 2: Farm Production Within Tank Ayacut

Note: All the questions here pertain to the reference plot within the tank ayacut. Also, crop production is typically zoned, with the ayacut exclusively zoned for paddy. All farmer level outcomes are measured by season, with two seasons in a calendar year. We collect data from 4 seasons prior to baseline survey and 2 seasons intervening between baseline and midline, and 2 seasons between midline and endline.

Control Variables/Heterogeneous Treatment Effects			
Variable Label	**Nature of the Variable**	**Specification**	**Variable Construction Method**
Geographic identifiers (agro-climatic zone > district > mandal)	Sub-group analysis, Fixed Effect	Tank Specs	Administrative data
Rainfall shock	Heterogeneous Treatment Effect	Tank Specs	Administrative data, Survey (village module)
Baseline village population	Control	Tank Specs	Survey (village module)
Baseline caste fractionalization of tank ayacut	Control	Tank Spec (Robustness check)	Survey (village module)
Nature of tank irrigation (channels, flood, percolation)	Heterogeneous Treatment Effect	Tank Spec (Robustness check)	Survey (village module)
Nature of tank management (state department, gram panchayat)	Heterogeneous Treatment Effect	Tank Spec (Robustness check)	Survey (village module)
Presence of baseline encroachment on tank bed ("patta land")	Control	Robustness Spec	Survey (village module)
Plot area	Control	Farmer-plot Specs	Survey (farmer module)
Plot characteristics (soil type, depth, porosity)	Control	Farmer-plot Specs	Survey (farmer module)
Plot location (head-end/middle/tailend, next to or far away from main channel/sub-channel)	Heterogeneous Treatment Effect	Farmer-plot specs	Survey (farmer module)
Presence of a functioning bore-well on the plot at baseline	Heterogeneous Treatment Effect	Farmer-plot specs	Survey (farmer module)
Farmer demographics (total land owned, total irrigated, household size, jati/sub-caste, gender)	Control	Farmer-plot specs	Survey (farmer module)
Farmer behavioral variables (risk aversion, time inconsistency, trust)	Control (potentially outcome as well – especially trust)	Farmer-plot Specs (Robustness check)	Survey (farmer module)
Government support received (subsidies, DBT)	Control (orthogonal to MK and is predetermined)	Farmer-plot Specs (Robustness check)	Survey (farmer module)

Table 3: Control Variables

Note: All the variables in this table pertain to baseline levels. Column 3 mentions which specifications the variables will be used in either as control or heterogeneous treatment interaction variable. Note that the specifications include both ITT and TOT analyses.

General Equilibrium (GE) Effects			
Variable Label	**Nature of the Variable**	**Specification**	**Variable Construction Method**
Crop Output Price	GE Outcome	ITT, TOT	Survey (village module)
Wages (hired labor)	GE Outcome	ITT, TOT	Survey (village module)
Migration (in/out)	GE Outcome	ITT, TOT	Survey (village module)
Household consumption	GE Outcome	ITT, TOT	Survey (farmer module)
Water markets (contract types, prices)	GE Outcome	ITT, TOT	Survey (farmer module)
Political Economy (incumbency)	GE Outcome	ITT, TOT	Secondary data (state election commission)
Aquaculture and other alternate forms of tank use	GE Outcome	ITT, TOT	Secondary data (department of agriculture and fisheries), and survey (Village module)
Continuing encroachment in tank area	GE Outcome	ITT, TOT	Site visual inspection, survey (interview with Village Revenue Assistant)

Table 4: General Equilibrium Outcome Variables

Note: All variables are measured once per survey round except household consumption that will be measured during endline only.

Intervention and Data Collection Timelines	
Intervention/ Data Module Name	**Data Collection Period**
MK Phase 1 announcement	May 2015
MK Phase 2 announcement	May 2016
Survey for the Observational Study	Feb - Aug 2017
MK Phase 3 announcement	May 2017
MK Phase 4 (RCT treatment intervention) announcement	May 2018
RCT Baseline	May - June 2018
RCT Phone Surveys (Process Monitoring)	Fortnightly since July 2018
RCT Midline (Endline 1)	Feb-April 2019
RCT Data cleaning, analysis, writing	May-Aug 2019
RCT Endline 2	Feb-April 2020
RCT Data cleaning, analysis, writing	May-Aug 2020

Table 5: Timeline of Data Collection

4 Empirical analysis

4.1 Observational evaluation: difference in difference

Recall that we study the effects of a large-scale government rehabilitation of water tanks using the staggered roll-out of the repair works under MK, where phase 1 started in 2015 and phase 2 in 2016. We will compare tanks treated prior to Summer 2017 with those treated later using a difference-in-differences design. In the base (preferred) specification, we identify the effect of rehabilitation post completion of the works by including fixed effect for the tank and clustering the standard errors at the lowest conservative administrative and hydrological level (mandal). While this would be conservative and may risk loss of precision[10], we will also run an alternate specification in which we include mandal fixed effects and cluster the standard errors at the tank level.

Because MK phases 1 and 2 commenced before the involvement by the researchers, the identification methodology is observational. However, an evaluation of these earlier phase provides an important complement to our experimental design because GoT selected larger tanks for repairs in the initial phases. Assuming GOT picked tanks for phase 1 on the basis of larger treatment effects, our observation study would provide something like an upper bound for the treatment effects of such rehabilitation works.

4.1.1 Tank-level analyses

Base DiD model. We use the following basic DiD empirical model for our tank-level analyses:

$$\begin{aligned} Y_{jmt} = {} & \beta_1(\text{Rehab}_{jm} \cdot \text{Post}_{yr1}) + \beta_2(\text{Rehab}_{jm} \cdot \text{Post}_{yr2}) \\ & + \delta_t + \delta_j + \mathbf{X}_{jm}\Psi + \epsilon_{jmt} \end{aligned} \tag{1}$$

where j indexes tanks, m indexes mandals, and t indexes season-year. We identify treatment effects within tanks by using tank fixed effects (δ_t). Rehab$_{jm}$ indicates whether a tank was rehabilitated prior to Summer 2017 and subscripts on Post indicate whether Summer 2017 was 1 year or 2 years after rehabilitation. The coefficients on the product of these (β_1 and β_2) estimate treatment effects 1 year and 2 years post rehabilitation, respectively. The main effect of Post is absorbed by time fixed effects (δ_t) and that of Rehab is absorbed by tank fixed effects (δ_j). Standard errors are clustered at the mandal level to allow for correlations across tanks within a mandal (though we will also experiment with tank level clustering).

4.1.2 Farmer plot-level analyses

Base DiD model. We use the following empirical model for our basic DiD analysis of farmer-level outcomes:

$$\begin{aligned} Y_{ijmt} = {} & \beta_1(\text{Rehab}_{jm} \cdot \text{Post}_{yr1}) + \beta_2(\text{Rehab}_{jm} \cdot \text{Post}_{yr2}) \\ & + \delta_t + \delta_j + \mathbf{X}_{ijm}\Psi + \epsilon_{ijmt} \end{aligned} \tag{2}$$

[10] At the tank level, we have N (farmers)=5, T (season-year)=8, whereas at the mandal level, we have ≈ 20 tanks per mandal with 5 farmers each measured across 8 seasons.

where i is a reference plot in tank j ayacut in mandal m at season-year t. Standard errors are clustered by tank in all analyses using plot level data. Y is a plot-level outcome variable such as whether cultivated or not, crop cultivated and the amounts of inputs used, etc. (see table 2 above). The rest of the treatment and time variables in the specification are as defined above. The set of controls now, however, refer to plot- and farmer-level controls and are represented as vector $\mathbf{X}_{ijm}$, defined in the same manner as the control vector above.

4.1.3 Time-invariant treatment effects

In the DiD model above, we separately estimate the effect of rehabilitation 1 year and 2 years past rehabilitation. [11] However, this exhausts some of our power. If we assume that treatment effects are constant year to year, we can estimate a simpler form of (1):

$$Y_{jmt} = \beta(\text{Rehab}_{jm} \cdot \text{Post}) + \delta_t + \delta_j + \mathbf{X}_{jm}\Psi + \epsilon_{jmt} \tag{3}$$

We will label this a time-invariant treatment effect version of our basic DiD model.

We also estimate plot-level analogues of the above equation to estimate a single post-treatment parameter. We next turn to endogeneity issues in the observational study.

4.1.4 Control variables

In both our observational study and our experimental study, we control for baseline time-variant and all time-invariant characteristics of the tank and farmer-plot via $\mathbf{X}_{jm}$ and $\mathbf{X}_{ijm}$, respectively. We choose the variables that are in this vector in two ways. One is that we specify the components of the vector of baseline or time-invariant controls from Table 3. Second, we will implement the post-double-selection method of Belloni et al. (2014) to identify the subset of the control variables from this table to include in our vector of controls. The latter provides a disciplined way of choosing control variables while allowing for credible inference without data-mining concerns.

4.1.5 Selection

Whether a tank is rehabilitated may be endogenous. We address this in two ways that exploit the process by which tanks are chosen for rehabilitation. This process begins with the Department of Irrigation, in consultation with politicians, choosing when tanks will be rehabilitated by assigning them to a particular phase of MK. It continues with the contracting (via a tendering process) of a vendor to rehabilitate a tank and the actual rehabilitation of that tank by the vendor.[12]

[11] Specifically, since we use 2017 outcomes to estimate 1 year post outcomes for tanks rehabilitated in 2016 and 2 years post outcomes for tanks rehabilitated in 2015. We use 2016 outcomes to estimate 1 year post outcomes for tanks rehabilitated in 2015.

[12] More precisely, there is a four step process for rehabilitating a tank in a given phase. First, the Department of Irrigation (DoI) of the GoT proposes a list of tanks to be rehabilitated to a phase with priority to earlier phase accorded largely based on size. Second, local politicians can recommend additions or subtractions from this list. Third, the Department of Irrigation conducts surveys of the feasibility of rehabilitating these tanks and, based on this, designates that certain tanks be rehabilitated in that phase. Fourth, the designation of a tank for rehabilitation initiates a process of developing a rehabilitation plan by the DoI,

Given this process, our first method of addressing the endogeneity of rehabilitation is to instrument for the two interactions in the base specifications above with interactions between whether a tank was assigned to phase 1 or 2 or not assigned at all and whether it is 1 or 2 years post assignment in 2017. The intuition here is that choosing to rehabilitate a tank increases the chance that a tank is rehabilitated, but it does not guarantee that the tank is rehabilitated by the time we measure outcomes. The proposed instruments are valid so long as one believes that (a) assignment to a phase is exogenous and (b) that phase assignment only affects outcomes via rehabilitation.

It is possible that assignment to a given MK phase is endogenous, but that the second step in the rehabilitation process – construction progress after assignment – is idiosyncratic. In that case, we estimate the following specification, which is simply the main DiD in (1) and (2) plus controls for phase assignment, which is controls for endogeneity:

$$\begin{aligned} Y_{jmt} = {} & \beta_1(\text{Rehab}_{jm} \cdot \text{Post}_{yr1}) + \beta_2(\text{Rehab}_{jm} \cdot \text{Post}_{yr2}) \\ & + \delta_t + \delta_j + \mathbf{X}_{jm}\Psi + \rho_1\text{Phase1} + \rho_2\text{Phase2} + \epsilon_{jmt} \end{aligned} \tag{4}$$

and analogous for the farmer-plot specifications.

In sum, we provide DiD estimates assuming either that (a) rehabilitation itself is exogenous, (b) rehabilitation is not exogenous but that assignment to an earlier MK phase is, or (c) phase assignment is not exogenous but that the progress of construction prior to measurement of outcomes is.

Finally, one might be concerned that not only is rehabilitation is endogenous, but that the process that determines when it occurs is also endogenous. To address this we do 3 things. First, we conduct a difference in difference analysis, which means that endogeneity is only a concern if there are differential trends across rehabilitation, assignment or construction progress status. Second, we can apply Joseph G. Altonji et al. (2005) method to estimate the degree of selection on unobservables required to change the sign of our estimated treatment effects. Third, we conduct an experimental evaluation, described below. A trade-off, however, is that the experimental evaluation examines smaller tanks than were included in phases 1 and 2 of MK.

4.1.6 Heterogeneous treatment effects

We will explore heterogeneity in treatment effects by interacting treatment indicators with indicators for the source of heterogeneity. For example, in our base DiD model for farmer-plot

bidding out a construction contract, and performance of that contract. This last step takes time and is subject to delays. In the main text, we group the first two steps and group the second two steps, compressing the four steps into two.

level analyses, we estimate

$$\begin{aligned} Y_{ijmt} = &\beta_1(\text{Rehab}_{jm} \cdot \text{Post}_{yr1}) + \beta_2(\text{Rehab}_{jm} \cdot \text{Post}_{yr2}) \\ &+ \omega_1(\text{Rehab}_{jm} \cdot \text{Z}_{ijmt}) + \omega_2(\text{Rehab}_{jm} \cdot \text{Z}_{ijmt}) \\ &+ \theta_1(\text{Post}_{yr1} \cdot \text{Z}_{ijmt}) + \theta_2(\text{Post}_{yr2} \cdot \text{Z}_{ijmt}) \\ &+ \gamma_1(\text{Rehab}_{jm} \cdot \text{Post}_{yr1} \cdot Z_{ijmt}) + \gamma_2(\text{Rehab}_{jm} \cdot \text{Post}_{yr2} \cdot Z_{ijmt}) \\ &+ \alpha Z_{ijmt} + \delta_t + \delta_j + \mathbf{X}_{ijm}\Psi + \epsilon_{ijmt} \end{aligned} \tag{5}$$

where Z_{ijmt} is a farmer-plot level variable along which we expect heterogeneous treatment effects. This model can be readily modified for tank level analyses, and to allow for wider-than-tank-level heterogeneous effects. We will explore heterogeneous treatment effects along the following dimensions: Farmer-Plot level heterogeneity:

- Head vs. tail plot: An increase in tank storage should either serve greater area (if the head-end farmers were already at constraint), or more to head-end (if slack).
- Plots with and without functioning bore-well: An increase in tank storage should lead to substitution away from groundwater to tank unless collective rule on water allocation takes into account access to groundwater resources.

Tank and higher level heterogeneity:

- Agro-climatic region: The districts in our student span 3 agro-climatic regions. The dryer the region, the more valuable is rainfall capture via rehabilitated tanks.
- Water-table level: The effect of a tank is greater in areas with deeper water tables.
- Rainfall: The effect of a tank is less when there is less rainfall.

Note that since these tank and higher level heterogeneity variables are captured at a higher spatial unit than a tank, we will be able to identify only the interaction terms.

4.2 Experimental evaluation

Recall that our RCT uses a sample of 92 tanks that were yet to be rehabilitated as of early 2018, of which a half (46) were randomly assigned to be rehabilitated under MK phase 4 beginning in Summer 2018 and the rest to be rehabilitated (if at all) in phase 5 in Summer 2019. We discuss the details of our empirical strategies in this section.

4.2.1 Intent to treat (ITT)

Tank-level analysis. We use the following empirical model for our tank-level ITT analyses:

$$Y_{jdt} = \beta_t \text{Treat}_{jd} + \delta_d + \delta_t + \mathbf{X}_{jd}\Psi + \nu_{jdt}$$

where j is a sample tank in district d at season-year t. Y is a tank-level outcome variable such as storage, irrigated area, groundwater level (as described in the variable tables above).

$Treat$ is dummy variable, equal to 1 when the tank j is randomly assigned to be rehabilitated under phase 4 (Summer 2018). We control for all time invariant characteristics of the district via district fixed effects (δ_d)[13]; for flexible, secular time trends with year fixed effects (δ_t); and for baseline, time varying tank- and district-level features (or outcomes) and for time-invariant tank-level features represented by $\mathbf{X}_{jd}$. These covariates are selected in the same manner as they were in the observational analysis including implementing the post-double-selection method of Belloni et al. (2014). Standard errors are clustered at the tank level.

Farmer plot-level analysis. We use the following empirical model for our ITT analysis of farmer-plot level outcomes:

$$Y_{ijdt} = \beta_t \text{Treat}_{jd} + \delta_d + \delta_t + \mathbf{X}_{ijd}\Psi + \epsilon_{ijdt}$$

where i is a reference plot in the ayacut of tank j in district d at season-year t. Y is a plot level outcome variable such as whether cultivated or not, crop cultivated and the amounts of inputs used, etc. (see table above). *Treat* is defined as above. We again include a district and time fixed effect. Finally, the set of controls ($\mathbf{X}_{ijd}$) now include plot- and farmer-level controls. We select those the same way as with the tank-level analyses. Standard errors are clustered by tank in all analyses using plot-level data.

Heterogeneous Effects: Finally we will estimate heterogeneous treatment effects along the same dimensions as we estimate them in both tank-level and plot-level analyses in the observational study.

4.2.2 Treatment on the treated (TOT)

While the ITT analyses above provide estimates for the average effects of the tank rehabilitation program irrespective of the take-up (i.e., whether or not a tank assigned to the treatment group is rehabilitated in a timely fashion), we are also interested in identifying the local average treatment effect (LATE) estimate for the sub-sample of compliers (tanks) that are actually rehabilitated. Unfortunately, completion of rehabilitation may be endogenous. To address this we use random assignment to rehabilitation as the instrument for actual rehabilitation.

We will employ the following two stage least squares estimation procedure for tank-level analysis:

$$\begin{aligned} \text{Rehab}_{jdt} &= \beta_t Treat_{jd} + \gamma_d + \gamma_t + \mathbf{X}_{jd}\Delta + e_{jdt} \\ Y_{jdt} &= \phi \widehat{Rehab}_{jdt} + \delta_d + \delta_t + \mathbf{X}_{jd}\Psi + u_{ijdt} \end{aligned} \tag{6}$$

where the subscripts refer to units as described in the specifications above, $Treat$ is whether a tank is assigned to rehabilitation in phase 4 or not, *Rehab* is whether the tanks is actually rehabilitated, and the remaining variables are as described above. This ToT specification will be adapted in a straightforward matter for the farmer plot-level analysis. Covariates are selected and heterogeneous treatment effects are estimates as they were for the ITT analysis.

[13]Due to the small number of tanks in the experimental study, we have stratified random assignment at the district level (a higher geographical aggregation similar to a county) instead of a mandal (sub-district) level. As a result we include district rather than mandal fixed effects (as we did in the observational study).

5 Inference

5.1 Multiple hypothesis testing

We worry about for multiple hypothesis testing for four families of outcomes: tank-level outcome parameters (tank capacity, water level, repair metrics including bund length, leakage, etc. mentioned in table 1), intermediate irrigation outcomes at the level of the reference plot, inputs used into production, and finally the family of production measures (crop area, crop yield, net revenue, etc., mentioned in table 2). We will test each family of measures jointly using family-wise error rate (FWER) corrections. The concern for multiple hypotheses concerning GE outcomes listed in table 4 will be addressed through both FWER corrections and by structural estimation of specific predictions from theoretical model taking into account the interactions and frictions present in the local markets.

5.2 Robustness/Falsification Test

We will implement additional robustness checks to ensure that the estimated treatment effects are truly the effects of tank rehabilitation and not any other underlying macro-economic changes to the context. To test this, we exploit the fact that the tank is mainly used in the absence of good rainfall throughout the Kharif season. On the other hand, scarce rainfall, or rainfall concentrated in specific months would lead to extensive use of tank irrigation during Kharif itself, with little left for the dry (Rabi) season. Therefore, we use local variation in rainfall - length and frequency of rain spells and whether close to long term average, i.e., normal rainfall - interacted with tank rehabilitation to test its effects during the Kharif season.

$$
\begin{aligned}
Y_{jmt} = {} & \beta_1(\text{Rehab}_{jm} \cdot \text{Post}_{yr1}) + \beta_2(\text{Rehab}_{jm} \cdot \text{Post}_{yr2}) \\
& + \omega_1(\text{Rehab}_{jm} \cdot \text{Negative Rain Shock}_{jmt}) + \omega_2(\text{Rehab}_{jm} \cdot \text{Negative Rain Shock}_{jmt}) \\
& + \theta_1(\text{Post}_{yr1} \cdot \text{Negative Rain Shock}_{jmt}) + \theta_2(\text{Post}_{yr2} \cdot \text{Negative Rain Shock}_{jmt}) \\
& + \gamma_1(\text{Rehab}_{jm} \cdot \text{Post}_{yr1} \cdot \text{Negative Rain Shock}_{jmt}) \\
& + \gamma_2(\text{Rehab}_{jm} \cdot \text{Post}_{yr2} \cdot \text{Negative Rain Shock}_{jmt}) \\
& + \alpha \text{Negative Rain Shock}_{jmt} + \delta_t + \delta_j + \mathbf{X}_{jm}\Psi + \epsilon_{jmt} \qquad (7)
\end{aligned}
$$

and analogous plot-level specification. The falsification test would test $\beta_1 \neq 0, \beta_2 \neq 0, \gamma_1 = \gamma_2 = 0$ for Kharif and $\beta_1 = \beta_2 = 0, \gamma_1 \neq 0, \gamma_2 \neq 0$ for Rabi season specific outcomes.

5.3 External validity

As we just explained, rainfall affects the value of water tanks and their impact on farmer behavior. Rosenzweig and Udry (2019) argue that the external validity of estimates about the return to agricultural investments depends on the difference between the distribution of rainfall shocks in study context and the distribution in the context to which one wants to extrapolate those estimates. We will assess the external validity of our estimates by comparing the distribution of rainfall shocks in our sample and comparing those to the distribution in Telangana over time and to India more generally. We will do this by agro-climatic region. Assuming we have enough power and that the domain of rainfall observed in our sample spans the domain of rainfall observed in a longer time period or in a broader area, we will use methods such as those in Hartman et al. (2015) to generate externally more valid estimates of the impact and value of water tank rehabilitation.

References

Bardhan, P., Mookherjee, D., and Kumar, N. (2012). State-led or market-led green revolution? Role of private irrigation investment vis-a-vis local government programs in West Bengal's farm productivity growth. *Journal of Development Economics*, 99(2):222–235.

Belloni, A., Chernozhukov, V., and Hansen, C. (2014). Inference on Treatment Effects after Selection among High-Dimensional Controls. *The Review of Economic Studies*, 81(2):608–650.

Dayal, P. and Iyengar, K. (2006). Rehabilitation and Management of Tanks in India. Technical Report 122605, Asian Development Bank.

Duflo, E. and Pande, R. (2007). Dams. *The Quarterly Journal of Economics*, 122(2):601–646.

Food and Agriculture Organization. The future of food and agriculture - Trends and Challenges. Technical report, Rome, Italy.

Hartman, E., Grieve, R., Ramsahai, R., and Sekhon, J. S. (2015). From sample average treatment effect to population average treatment effect on the treated: combining experimental with observational studies to estimate population treatment effects. *Journal of the Royal Statistical Society: Series A (Statistics in Society)*, 178(3):757–778.

Joseph G. Altonji, Todd E. Elder, and Christopher R. Taber (2005). Selection on observed and unobserved variables: Assessing the effectiveness of catholic schools. *Journal of Political Economy*, 113(1):151–184.

McKinsey, J. W. and Evenson, R. (1999). Technology-Climate Interactions in the Green Revolution in India. Working Paper, Yale - Economic Growth Center.

Palanisami, K., Meinzen-Dick, R., and Giordano, M. (2010). Climate Change and Water Supplies: Options for Sustaining Tank Irrigation Potential in India. *Economic and Political Weekly*, 45(26/27):183–190.

Rodell, M., Velicogna, I., and Famiglietti, J. S. (2009). Satellite-based estimates of groundwater depletion in India. *Nature*, 460(7258):999–1002.

Rosenzweig, M. and Udry, C. (2019). External validity in a stochastic world: Evidence from low-income countries. *Review of Economic Studies*.

Sekhri, S. (2011). Public Provision and Protection of Natural Resources: Groundwater Irrigation in Rural India. *American Economic Journal: Applied Economics*, 3(4):29–55.

Sekhri, S. (2014). Wells, Water, and Welfare: The Impact of Access to Groundwater on Rural Poverty and Conflict. *American Economic Journal: Applied Economics*, 6(3):76–102.

Sharma, A. and International Water Management Institute (2003). *Rethinking tanks: opportunities for revitalizing irrigation tanks: empirical findings from Ananthapur District, Andhra Pradesh, India.* International Water Management Institute, Colombo, Sri Lanka. OCLC: 646190841.

The World Bank (2012). Turn down the heat : why a 4ÂC warmer world must be avoided. Technical Report 74455, The World Bank.