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**Impact of access to irrigation on crop productivity: Evidence from
community-led lift irrigation schemes in India**

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Introduction

Access to irrigation can increase agricultural productivity and raise incomes of smallholder farmers. Despite these benefits, globally more than a billion people have insufficient access to water due to a lack of necessary infrastructure or human and financial capital (Molden 2007). Inadequate access to irrigation can persist even in contexts with significant amounts of water resources. In India, large-scale, historical investments in irrigation canals generated sustained agricultural productivity growth (Asher et al. 2023; Blakeslee et al. 2023). However, even with abundant amounts of available water, productivity growth in eastern India fell behind western India during the Green Revolution, primarily due to the slow development of groundwater resources (Shah 2001).

The current study estimates the causal impact of access to community-led lift irrigation schemes on crop productivity focusing on a state in India. More specifically, we will use high-resolution satellite data on vegetation to assess the medium-term impacts of access to irrigation on crop yields and crop choice. We empirically model this using two-way fixed effects regression with the treatment being defined as whether an area has a pump installed.

Our primary contribution is to the literature concerning the impacts of irrigation access on agricultural productivity. Much of the existing productivity literature has focused on the impacts of large-scale irrigation schemes (Asher et al. 2023; Blakeslee et al. 2023; Boudot-Reddy and Butler 2023; Dillon 2011a; Duflo and Pande 2007; Jones et al. 2022) while only a few studies have evaluated the impacts of small-scale projects (Bravo-Ureta, Higgins, and Arslan 2020; Dillon 2011b; 2011a; Kishore et al. 2023). We contribute to the literature by providing causal estimates of a small-scale irrigation scheme on crop productivity using high-resolution satellite data over a multi-year period. We provide important insights on the possible benefits of

the investment in small-scale, community-led irrigation schemes and the potential sustainable impacts of local productivity.

Data

We use the administrative data on the GPS coordinates of 667 pumps, their corresponding irrigation outlets, and their dates of installation completion. As a part of community-led development scheme, irrigation pumps were installed between May 2020 and September 2022 and can have up to four outlets.

We used the GPS coordinates to extract Enhanced Vegetation Index (EVI) data using the Moderate Resolution Imaging Spectroradiometer (MODIS) Terra Vegetation Indices 16-Day Global 500m dataset on Google Earth Engine.¹ Vegetation Indices are increasingly being used as a proxy for crop production in economic studies (Asher et al. 2023; Benami et al. 2021; Blakeslee et al. 2023; Boudot-Reddy and Butler 2023). EVI has been identified as the preferred proxy for crop production since it corrects for atmospheric and background conditions, compared to other vegetation indices such as the Normalized Difference Vegetation Index (Gao 2000; Kouadio et al. 2014; Wardlow and Egbert 2010).

The vegetation indices are measured on a 500-square meter pixel grid. To construct our counterfactual, we extracted EVI estimates for the 8-pixel grids that surround either a pump source or outlet plot of land and took the average of these 8 grids. We also extracted rainfall values for the GPS coordinates from the Climate Hazards Group InfraRed Precipitation Daily (Version 2.0 Final) dataset on Google Earth Engine.² This dataset included gridded daily rainfall estimates at a 0.05° resolution. Additionally, temperature values were extracted using the

¹ https://developers.google.com/earth-engine/datasets/catalog/MODIS_061_MOD13A1

² https://developers.google.com/earth-engine/datasets/catalog/UCSB-CHG_CHIRPS_DAILY

MOD21C2.061 Terra Land Surface Temperature and 3-Band Emissivity 8-Day L3 Global 0.05 Deg CMG dataset.³ These data are occurred over 8-day periods at a 0.05° resolution. To account for temporal variation in EVI, rainfall, and maximum daytime temperatures, we calculated monthly averages for each variable.

In Table 1, the pre-treatment period covers September 2017 to April 2020, using this long time period allows us to discern if there was balance in Log EVI between the treatment and control plots at baseline. The post-treatment period includes May 2020 to September 2023. However, it is important to note that in our main analysis (Tables 2 through 7) we restrict our time period to September 2019 to September 2023 to discern the impact of the treatment on log EVI using a starting date relatively closer to the start of pump installation in May 2020.

Method

To assess the impact of access to irrigation on crop productivity, we estimate the following equation using two-way fixed effects:

$$Y_{it} = \beta T_{it} + \delta X_{it} + \alpha_i + \gamma_t + \epsilon_{it} \quad (1)$$

where Y_{it} denotes our outcome variable, log of EVI, for grid i at time t . The main parameter of interest is β , as it represents the marginal treatment effect. T_{it} is our binary treatment variable equal to one if a plot has access to an installed pump, i.e. the grid has either a pump source or an outlet. α_i represents the grid fixed effect while γ_t denotes the time fixed effect. The vector of control variables, X_{it} , which include temperature and rainfall variables.

³ https://developers.google.com/earth-engine/datasets/catalog/MODIS_061_MOD21C2#description

We further assess the heterogeneous impacts of the treatment across rainfall level by estimating the following equation:

$$Y_{it} = \beta T_{it} + \delta X_{it} + \lambda_1 T_{it} Prec_{it} + \lambda_2 T_{it} Prec_{it}^2 + \alpha_i + \gamma_t + \epsilon_{it} \quad (2)$$

where $T_{it} Prec_{it}$ and $T_{it} Prec_{it}^2$ are the interaction terms between the treatment and the quadratic rainfall variables.

Results

Tables 2 – 4 report the estimated results of the main specification represented by equation (1). Table 2 reports the estimated results using the full sample from September 2019 to September 2023. Column (1) is using all observations, pump sources and outlets (treated) and neighboring grids (control). Each of the next 5 columns are disaggregated based on the treatment specifications, i.e., the pump source versus neighboring grids and each outlet versus neighboring grids. Overall, we find positive and significant effects of the access to irrigation on crop productivity except for the fourth outlet.

Table 3 and 4 separate the sample into Kharif (wet) and Rabi (dry) seasons. We observe that the analyses with only Kharif season do not find any significant effects of the treatment. For Rabi season, we find the consistent effects to the findings of table 2. This tentatively implies that the most of the overall effects were driven by improved productivities in Rabi season.

To further unpack the mechanism, we estimate equation (2) to capture the heterogeneity across the rainfall level (tables 5 – 7). Converting the coefficient estimates to marginal effects provides a better interpretation of the results. We observe that the effects are more positive when the rainfall is low.

Implications and next steps

With limited empirical evidence surrounding small-scale irrigation projects, our study provides insights into the potential of community-led lift irrigation schemes to increase agricultural productivity. We find that the irrigation access increase agricultural productivity, particularly for the dry season and when rainfall is low.

For the next step, as a robustness check, we plan to estimate a difference-in-differences model following Callaway and Sant'Anna (2021) and an interactive fixed-effects counterfactual model following Liu et al. (2022).

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Table 1: Overall EVI Descriptive Statistics

Panel A	Mean		
<i>Overall</i>			
Log EVI	7.929 (N = 202,979)		
VARIABLE	Log Enhanced Vegetation Index (EVI)		
	Mean		
Panel B	Treatment	Control	Difference
<i>Pump Source</i>			
Before May 2020	7.909 (N = 19,258)	7.921 (N = 18,313)	-0.011***
After May 2020	7.942 (N = 19,794)	7.955 (N = 18,841)	-0.013***
<i>Outlet 1</i>			
Before May 2020	7.897 (N = 9,144)	7.904 (N = 8,600)	-0.006
After May 2020	7.931 (N = 9,398)	7.940 (N = 8,823)	-0.008*
<i>Outlet 2</i>			
Before May 2020	7.905 (N = 10,008)	7.909 (N = 9,416)	-0.003
After May 2020	7.940 (N = 10,286)	7.946 (N = 9,684)	-.005
<i>Outlet 3</i>			
Before May 2020	7.907 (N = 10,152)	7.910 (N = 9,815)	-0.002
After May 2020	7.940 (N = 10,434)	7.945 (N = 10,084)	-0.005
<i>Outlet 4</i>			
Before May 2020	7.884 (N = 2,088)	7.896 (N = 1,952)	-0.012
After May 2020	7.927 (N = 2,146)	7.939 (N = 2,000)	-0.011
*** p<0.01, ** p<0.05, * p<0.1			

Table 2: EVI TWFE Analysis

	(1)	(2)	(3)	(4)	(5)	(6)
	Log Enhanced Vegetation Index (EVI)					
VARIABLES	Overall	Pump Source	Outlet 1	Outlet 2	Outlet 3	Outlet 4
Treatment	0.010*** (0.001)	0.013*** (0.002)	0.007*** (0.003)	0.008*** (0.003)	0.009*** (0.003)	0.002 (0.007)
Rainfall	0.022*** (0.002)	0.022*** (0.003)	0.022*** (0.004)	0.023*** (0.004)	0.018*** (0.004)	0.027*** (0.009)
Rainfall Squared	-0.001*** (0.000)	-0.001*** (0.000)	-0.001*** (0.000)	-0.001*** (0.000)	-0.001*** (0.000)	-0.001 (0.001)
Daytime Temperature	-0.009*** (0.001)	-0.009*** (0.001)	-0.008*** (0.001)	-0.007*** (0.001)	-0.008*** (0.001)	-0.010*** (0.002)
Constant	10.522*** (0.213)	10.709*** (0.444)	10.403*** (0.381)	10.123*** (0.366)	10.314*** (0.356)	10.880*** (0.681)
Observations	125,268	47,685	22,504	24,651	25,311	5,117
R-squared	0.829	0.826	0.835	0.830	0.831	0.832
Plot FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 3: Kharif EVI TWFE Analysis

	(1)	(2)	(3)	(4)	(5)	(6)
	Log Enhanced Vegetation Index (EVI)					
VARIABLES	Overall	Pump Source	Outlet 1	Outlet 2	Outlet 3	Outlet 4
Treatment	-0.002 (0.003)	0.002 (0.005)	0.001 (0.006)	-0.002 (0.006)	-0.004 (0.006)	-0.036** (0.014)
Rainfall	0.006** (0.003)	0.007* (0.004)	0.005 (0.007)	0.005 (0.007)	0.001 (0.007)	0.021 (0.018)
Rainfall Squared	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	0.000 (0.000)	-0.000 (0.001)
Daytime Temperature	-0.004*** (0.001)	-0.005*** (0.001)	-0.003* (0.002)	-0.002 (0.002)	-0.006*** (0.001)	-0.006* (0.004)
Constant	9.513*** (0.235)	9.676*** (0.429)	9.092*** (0.510)	8.789*** (0.491)	9.984*** (0.456)	9.883*** (1.105)
Observations	51,208	19,489	9,199	10,079	10,346	2,095
R-squared	0.663	0.662	0.673	0.661	0.664	0.674
Plot FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 4: Rabi EVI TWFE Analysis

	(1)	(2)	(3)	(4)	(5)	(6)
	Log Enhanced Vegetation Index (EVI)					
VARIABLES	Overall	Pump Source	Outlet 1	Outlet 2	Outlet 3	Outlet 4
Treatment	0.014*** (0.001)	0.011*** (0.001)	0.010*** (0.001)	0.010*** (0.001)	0.011*** (0.001)	0.010*** (0.001)
Rainfall	0.052*** (0.006)	0.026*** (0.006)	0.008 (0.007)	0.009 (0.007)	0.010 (0.007)	-0.003 (0.007)
Rainfall Squared	-0.010*** (0.001)	-0.006*** (0.001)	-0.002* (0.001)	-0.003* (0.001)	-0.003* (0.001)	-0.000 (0.001)
Daytime Temperature	-0.021*** (0.001)	-0.023*** (0.001)	-0.024*** (0.001)	-0.024*** (0.001)	-0.024*** (0.001)	-0.024*** (0.001)
Constant	14.022*** (0.258)	14.571*** (0.281)	14.964*** (0.281)	14.852*** (0.281)	14.844*** (0.283)	15.080*** (0.288)
Observations	68,573	56,682	52,821	53,148	53,252	50,158
R-squared	0.871	0.864	0.856	0.859	0.857	0.847
Plot FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 5: EVI TWFE with Interaction Terms (Rainfall Variables x Treatment)

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	Log Enhanced Vegetation Index (EVI)					
	Overall	Pump Source	Outlet 1	Outlet 2	Outlet 3	Outlet 4
Treatment	0.014*** (0.001)	0.014*** (0.003)	0.012*** (0.003)	0.014*** (0.003)	0.016*** (0.003)	0.006 (0.008)
Rainfall	0.022*** (0.002)	0.022*** (0.003)	0.023*** (0.005)	0.024*** (0.004)	0.019*** (0.004)	0.027*** (0.009)
Rainfall Squared	-0.001*** (0.000)	-0.001*** (0.000)	-0.001*** (0.000)	-0.001*** (0.000)	-0.001*** (0.000)	-0.001 (0.001)
Temperature	-0.009*** (0.001)	-0.009*** (0.001)	-0.008*** (0.001)	-0.007*** (0.001)	-0.008*** (0.001)	-0.010*** (0.002)
Rainfall x Treatment	-0.002*** (0.001)	-0.001 (0.001)	-0.003** (0.002)	-0.004** (0.001)	-0.003** (0.001)	0.000 (0.004)
Rainfall Squared x Treatment	0.000** (0.000)	0.000 (0.000)	0.000* (0.000)	0.000* (0.000)	0.000 (0.000)	-0.000 (0.000)
Constant	10.526*** (0.213)	10.711*** (0.444)	10.407*** (0.381)	10.127*** (0.366)	10.325*** (0.355)	10.885*** (0.680)
Observations	125,268	47,685	22,504	24,651	25,311	5,117
R-squared	0.829	0.826	0.835	0.830	0.831	0.832
Plot FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
ME of Treatment at 10 th Percentile of Rainfall	0.013*** (0.001)	0.014*** (0.002)	0.011*** (0.003)	0.013*** (0.003)	0.015*** (0.003)	0.006 (0.008)
ME of Treatment at 50 th Percentile of Rainfall	0.011*** (0.001)	0.013*** (0.002)	0.008*** (0.003)	0.008*** (0.003)	0.011*** (0.003)	0.006 (0.007)
ME of Treatment at 90 th Percentile of Rainfall	0.005** (0.002)	0.011*** (0.004)	0.004*** (0.005)	0.002 (0.005)	0.002 (0.005)	-0.007 (0.012)

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 6: Kharif EVI TWFE with Interaction Terms (Rainfall Variables x Treatment)

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	Log Enhanced Vegetation Index (EVI)					
	Overall	Pump Source	Outlet 1	Outlet 2	Outlet 3	Outlet 4
Treatment	0.013** (0.005)	0.010 (0.009)	0.015 (0.012)	0.017 (0.012)	0.013 (0.012)	0.008 (0.033)
Rainfall	0.008** (0.003)	0.008* (0.004)	0.007 (0.008)	0.007 (0.008)	0.002 (0.007)	0.025 (0.019)
Rainfall Squared	-0.000* (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.001 (0.001)
Temperature	-0.004*** (0.001)	-0.005*** (0.001)	-0.003* (0.002)	-0.002 (0.002)	-0.006*** (0.001)	-0.006* (0.004)
Rainfall x Treatment	-0.005*** (0.001)	-0.003 (0.002)	-0.006 (0.003)	-0.007** (0.003)	-0.005 (0.003)	-0.010 (0.010)
Rainfall Squared x Treatment	0.000*** (0.000)	0.000 (0.000)	0.000* (0.000)	0.000** (0.000)	0.000 (0.000)	0.000 (0.001)
Constant	9.510*** (0.235)	9.674*** (0.430)	9.093*** (0.511)	8.786*** (0.493)	9.980*** (0.458)	9.862*** (1.107)
Observations	51,208	19,489	9,199	10,079	10,346	2,095
R-squared	0.663	0.662	0.673	0.661	0.664	0.675
Plot FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
ME of Treatment at 10 th Percentile of Rainfall	0.012** (0.005)	0.010 (0.008)	0.014 (0.011)	0.016 (0.011)	0.012 (0.012)	0.007 (0.031)
ME of Treatment at 50 th Percentile of Rainfall	0.006 (0.004)	0.006 (0.006)	0.007 (0.008)	0.007 (0.008)	0.005 (0.008)	-0.007 (0.021)
ME of Treatment at 90 th Percentile of Rainfall	-0.003 (0.003)	0.001 (0.005)	0.000 (0.007)	-0.003 (0.007)	-0.006 (0.007)	-0.045 (0.015)

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 7: Rabi EVI TWFE with Interaction Terms (Rainfall Variables x Treatment)

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
	Log Enhanced Vegetation Index (EVI)					
	Overall	Pump Source	Outlet 1	Outlet 2	Outlet 3	Outlet 4
Treatment	0.010*** (0.001)	0.011*** (0.002)	0.012*** (0.002)	0.013*** (0.002)	0.015*** (0.002)	0.019*** (0.002)
Rainfall	0.053*** (0.006)	0.030*** (0.006)	0.012* (0.007)	0.013** (0.007)	0.014** (0.007)	0.001 (0.007)
Rainfall Squared	-0.010*** (0.001)	-0.006*** (0.001)	-0.003** (0.001)	-0.003** (0.001)	-0.003** (0.001)	-0.001 (0.002)
Temperature	-0.021*** (0.001)	-0.023*** (0.001)	-0.024*** (0.001)	-0.024*** (0.001)	-0.024*** (0.001)	-0.024*** (0.001)
Rainfall x Treatment	0.029*** (0.004)	0.012** (0.005)	0.003 (0.005)	0.002 (0.005)	-0.000 (0.005)	-0.015*** (0.005)
Rainfall Squared x Treatment	-0.021*** (0.003)	-0.012*** (0.003)	-0.008*** (0.003)	-0.007*** (0.003)	-0.006** (0.003)	0.001 (0.003)
Constant	14.004*** (0.258)	14.538*** (0.281)	14.927*** (0.281)	14.816*** (0.281)	14.808*** (0.283)	15.051*** (0.289)
Observations	68,573	56,682	52,821	53,148	53,252	50,158
R-squared	0.871	0.864	0.856	0.859	0.858	0.847
Plot FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
ME of Treatment at 10 th Percentile of Rainfall	0.014*** (0.001)	0.013*** (0.001)	0.013*** (0.001)	0.013*** (0.001)	0.014*** (0.001)	0.016*** (0.001)
ME of Treatment at 50 th Percentile of Rainfall	0.000 (0.002)	-0.002 (0.002)	-0.003 (0.002)	-0.003 (0.002)	-0.003 (0.002)	-0.003* (0.002)
ME of Treatment at 90 th Percentile of Rainfall	-2.035*** (0.238)	-1.220*** (0.268)	-0.818*** (0.265)	-0.765*** (0.257)	-0.683*** (0.258)	-0.037 (0.266)

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1