Agricultural Productivity and Local Economic Development: Evidence from Private Investment in Irrigation

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Motivation

- Industrial growth is often preceded by unprecedented increases in agricultural output.
- Theory:
  1. Closed economies: a boost to agricultural productivity generates demand for manufacturing goods which leads to a re-allocation of labour away from agriculture (Gollin et al. 2002; Kongsamut et al. 2001; Ngai and Pissarides 2007).
  2. Open economies: improved agricultural productivity can retard industrial growth as the economy specialises in the comparative advantage sector (Matsuyama 1992; Field, 1978).

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  2. Open economies: improved agricultural productivity can retard industrial growth as the economy specialises in the comparative advantage sector (Matsuyama 1992; Field, 1978).
- Limited accompanying empirical evidence identifying the process by which shifts in agricultural productivity can alter the shape of the wider economy (Bustos et al. 2016; Carillo 2021).

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- **Question**: Does access to groundwater irrigation lead to increases in productivity? Does this increase in output lead to structural shifts in the rural economy?

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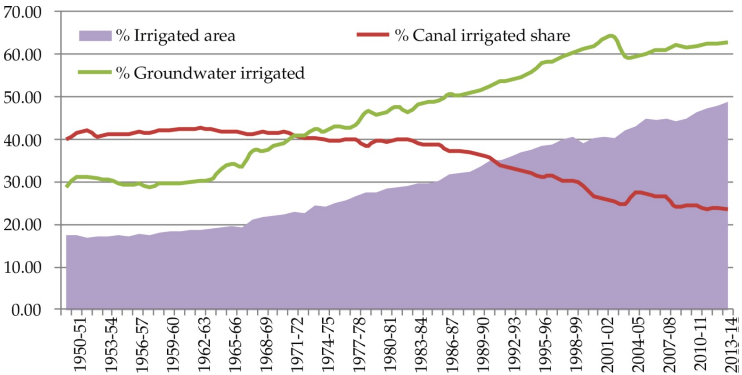
- To answer this, we exploit quasi-random between-village variation in access to groundwater driven by an exogenous constraint in irrigation technology.
  - We leverage a kink in the relationship between groundwater depth and water extraction for irrigation.



- Canal Irrigation: Asher et al. (2022) Long-run Development effects, and Blakeslee et al. (2022) Spatial Patterns.
- Ground Water Irrigation: Significant private investment & policy relevant.

Irrigation Pump Technology

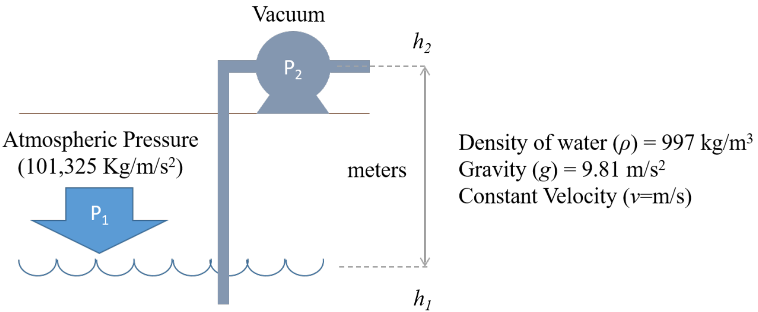
Figure: Centrifugal Pumps

INR 16,000
Max Lift 10.33m

Figure: Submersible Pumps

INR 25,000
No Max Lift

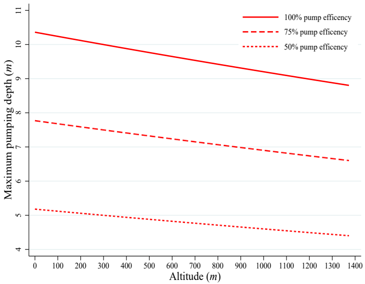
Bernoulli's Principle of Fluid Dynamics



$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2 \quad (1)$$

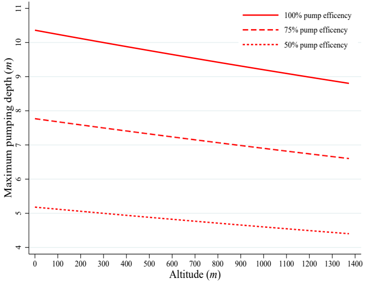
$$h_2 - h_1 = \frac{P_1 - P_2}{\rho g} \quad (2)$$

Pump Efficiency



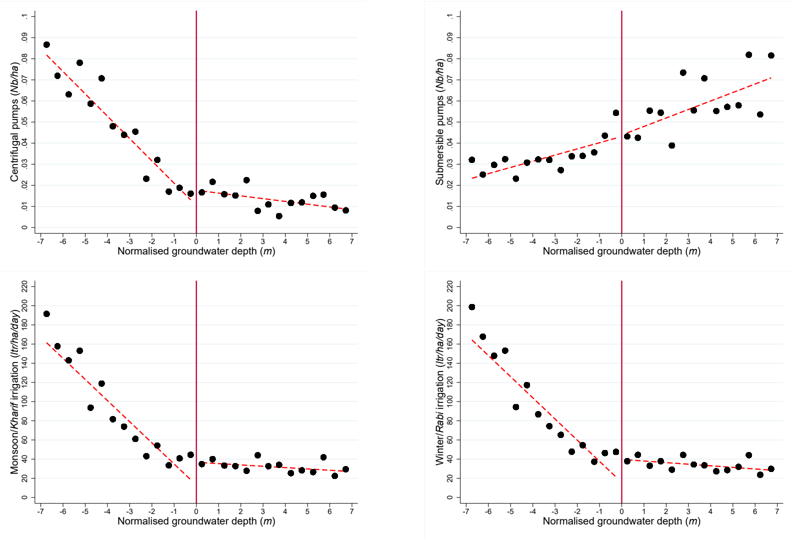
- The pump efficiency is random with known PDF $G(.)$.
- At a given groundwater depth there exists a minimum pump efficiency that will still be operational, $e(\lambda)$.

Pump Efficiency

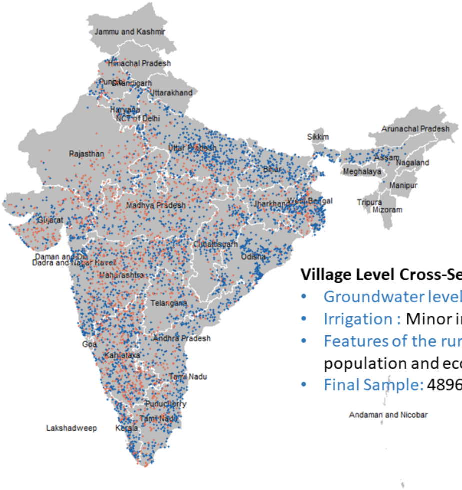


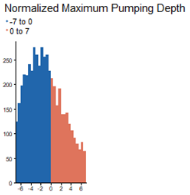
- The pump efficiency is random with known PDF $G(.)$.
- At a given groundwater depth there exists a minimum pump efficiency that will still be operational, $e(\lambda)$.

- There is a probability $g(e(\lambda_v))$ that a pump will not work, when drawn at random.



water calculation
estimation table





Village Level Cross-Section

- Groundwater level : Central Ground Water Board
- Irrigation : Minor irrigation Census
- Features of the rural economy: Remote sensing, population and economic census.
- Final Sample: 4896 villages

Fuzzy Regression Kink Design

- The *fuzzy* RK design exploits a discontinuity in the first-derivative of the assignment function with respect to the treatment variable at a kink point.

$$E[I|W=w]=\alpha_0+\left[\sum_{p=1}^{\bar{p}}\omega_p(w-k)^p+\pi_p(w-k)^p\cdot D\right] \tag{3}$$

where $D=\mathbb{1}[W\geq k]$, W is the groundwater depth (assignment variable), and k is the operational threshold of centrifugal pumps.

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where $D = \mathbb{1}[W \geq k]$, W is the groundwater depth (assignment variable), and k is the operational threshold of centrifugal pumps.

- The outcome of interest also exhibits a kink in slope in its relation to the assignment variable at the same point.

$$E[Y|W = w] = \mu_0 + \left[\sum_{p=1}^{\bar{p}} \gamma_p (w - k)^p + \nu_p (w - k)^p \cdot D\right] \quad (4)$$

▸ Estimation Notes

Graphical Evidence: Covariates and Outcomes

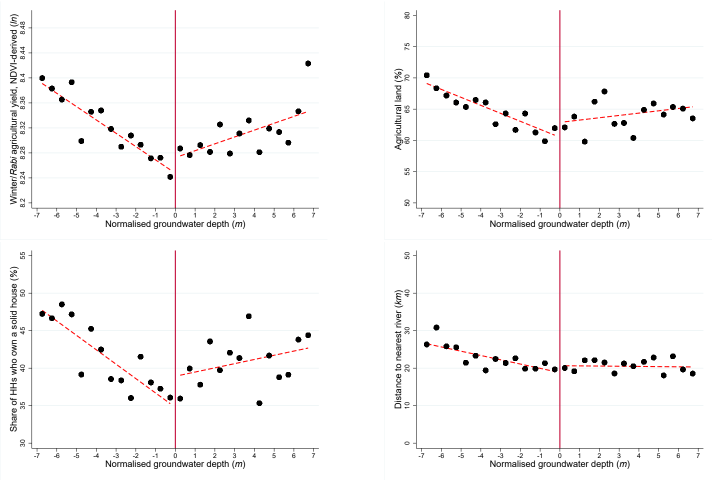

Table: Impact of tube-well irrigation on agricultural yield and production choices

	Agricultural yield ‣ NDVI derived		Inputs	Crop choice		
	Winter/*Rabi* Differenced (*ln*) (1)	Monsoon/*Kharif* Differenced (*ln*) (2)	Cultivated land (%) (3)	Winter/ *Rabi* (*binary*) (4)	Drought tolerant (*binary*) (5)	Cash (*binary*) (6)
Irrigation (*standardised*)	0.098*** (0.035)	0.036 (0.062)	15.972*** (4.580)	0.071 (0.062)	-0.254*** (0.084)	0.050 (0.072)
Mean	253.350	3411.471	64.364	0.242	0.315	0.198
SD	1575.954	1229.687	25.330	0.429	0.465	0.398
N	4896	4896	4896	3848	3848	3848

Land We test the impact of access to irrigation on landholdings and find no evidence of land agglomeration. ‣ Results - Landholdings

Table: Impact of tube-well irrigation on consumption

	Consumption per capita (*ln*) (1)	Poverty rate (*share*) (2)	Asset index (*SD unit*) (3)	Mean night light (*ln*) (4)
Irrigation	0.060	-0.054*	0.178**	0.451*
(*standardised*)	(0.039)	(0.028)	(0.081)	(0.230)
Mean	18.215	0.316	6.715	0.317
SD	4.900	0.190	4.665	0.994
N	4896	4896	4896	3600

Housing We test for the impact of access to irrigation on the different components of the asset index. Groundwater irrigation increases the share of households in the village that own a solid house by 17%. Results - Assets

Table: Impact of tube-well irrigation on agricultural sector employment

	Total (%) (1)	Cultivators (%) (2)	Manual labourers (%) (3)
Panel A: Share of population			
Irrigation	-2.481*	0.506	-1.701
(*standardised*)	(1.464)	(1.605)	(1.850)
Mean	44.582	13.319	18.394
SD	10.354	10.239	11.951
Panel B: Share of workforce			
Irrigation	-	2.521	-1.849
(*standardised*)	(-)	(3.099)	(3.393)
Mean	-	29.224	39.853
SD	-	19.585	21.502
Panel C: Share of full-time workers			
Irrigation	10.289***	6.648**	10.224**
(*standardised*)	(3.583)	(3.239)	(4.971)
Mean	73.651	84.616	61.758
SD	21.592	20.191	30.915
N	4896	4896	4896

Table: Impact of tube-well irrigation on village industrial sector employment

	Total (1)	Agro-processing (2)	Livestock (3)	Construction (4)	Manufacturing (5)	Services (6)
Panel A: Share of workforce (%)						
Irrigation	0.983	-0.235	1.167	0.150	0.026	0.313
(*standardised*)	(3.043)	(0.180)	(1.617)	(0.120)	(1.009)	(1.479)
Mean	21.247	0.262	4.924	0.263	3.606	8.824
SD	19.165	1.090	9.572	0.724	5.904	9.262
Panel B: Establishments (*nb*)						
Irrigation	83.095	-0.644	19.087	1.565	2.570	41.841
(*standardised*)	53.002	1.247	22.069	1.177	10.703	28.921
Mean	249.779	2.076	68.078	2.612	38.548	122.033
SD	457.944	7.389	171.334	7.444	79.370	226.965
N	4896	4896	4896	4896	4896	4896

Table: Impact of tube-well irrigation on population

	Population (*ln*) (1)	Population density (*ln*) (2)	Working age population (%) (3)	Male working age population (%) (4)
Irrigation (*standardised*)	0.347* (0.179)	0.445*** (0.147)	-0.455 (0.838)	0.676 (1.188)
Mean	7.783	5.888	61.295	71.144
SD	1.105	0.951	4.744	6.849
N	4896	4896	3600	3600

Concluding Remarks

1. Irrigation improves agricultural productivity primarily during the dry winter.
   - Intensity of irrigation is similar in both seasons; suggesting that monsoon season irrigation is much less efficient.
2. This study adds to the evidence that access to irrigation improves average welfare outcomes at the village level.
3. Access to irrigation does not lead to a significant reallocation of labour into or out of the agricultural sector.
4. Excess demand for labour generated by irrigation is largely absorbed by extending the hours of existing workforce.

Fuzzy Regression Kink Design

- The causal impact is found by dividing the change in slope of the outcome by the change in slope of the treatment
  $\beta = \nu_1 / \pi_1$
  **The standard errors are recovered using the Delta method.*
- All regressions are estimated:
  - Using a linear functional form (As a robustness test we compare our results under a quadratic and cubic function.)
  - Including covariates and state fixed effects as controls
  - Using a bandwidth of 7 metres (Results are robust to a range of bandwidth down to 3 metres.)

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Calculation of Water Input

We use the MIC variables to calculate water input in litres, for each villages, following a standard engineering formula for water extraction (Manring, 2013).

$$W_i(H_i D_i) = \rho \frac{P_i H_i}{D_i} \tag{5}$$

Where P_i is the average pump capacity (HP) in the village; H_i is the total pumping hours per day; and D_i is the ground water depth (m).

$$\rho = c \frac{E}{dg} \tag{6}$$

Where c is a constant to correct units and account for friction, E is the pump efficiency, d is density of water, and g is the gravitational constant.

Table: Constants used in water input calculation

Variable	Value	Units
c	3.6×10^6	
E	0.25	
d	10^3	kg/m^2
g	9.81	m/s^2

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Table: Evolution of Irrigation and Covariates at the Kink Point

	Irrigation	Covariates		
	Average (*standardised*) (1)	Distance to nearest river (*km*) (2)	Inside a canal command area (*binary*) (3)	Potential yield (*index*) (4)
π_1	0.090***	0.332	0.006	0.013
	(0.012)	(0.329)	(0.004)	(0.012)
Mean	-0.000	21.783	0.081	-0.081
SD	1.000	23.185	0.273	0.963
N	4896	4896	4896	4896

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Table: Correlates of NDVI proxy for agricultural production

	(1)	(2)	(3)	(4)
Agricultural Output	0.056	0.035	0.331	0.233
	(0.018)	(0.017)	(0.042)	(0.040)
Fixed Effects	State	State-Year	District	District-year
N	2124	2124	2124	2124
R^2	0.35	0.53	0.74	0.78

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Table: Impact of tube-well irrigation on the distribution of landholdings

	Landless (%) (1)	0-2 Acres (%) (2)	2-4 Acres (%) (3)	4+ Acres (%) (4)
Irrigation (*standardised*)	1.522 (4.699)	0.491 (3.746)	-2.543 (1.575)	0.601 (2.587)
Mean	55.696	22.641	9.271	12.081
SD	22.904	19.078	7.296	12.756
N	3600	3600	3600	3600

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Table: Impact of tube-well irrigation on ownership of assets

	Solid house (%) (1)	Refrigerator (%) (2)	Vehicle (%) (3)	Phone (%) (4)
Irrigation	19.991***	2.150	3.524	5.808
(*standardised*)	(6.217)	(2.377)	(3.125)	(4.356)
Mean	40.716	8.799	19.707	68.053
SD	28.570	12.957	15.411	24.972
N	3600	3600	3600	3600

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