Irrigation Makes It Rain?
Climate Spillovers and Adaptation in India

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Motivations

Economic development both depends on and changes the environment (Jack and Ryan, 2026).

- Irrigation exemplifies this dual relationship:
  - Leads to higher productivity, lower poverty, human development (Dillon and Fishman, 2019).
  - But drives groundwater depletion, constraining future growth (Sekhri, 2014).
  - Beyond depletion, natural sciences evidence that irrigation reshapes the climate.

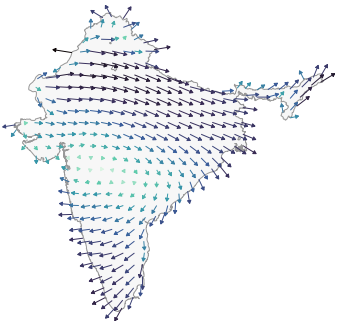
- India:
  - The world's most irrigated country, with >100 billion invested in surface irrigation.
  - Dependent on the monsoon system.
  - Puzzling delayed structural transformation, with >50% of people relying on agriculture.

⇒ Does the expansion of irrigation affect the climate and, in turn, India's development?

This Paper

Methodology

- Combine five decades of spatial data on irrigation, climate, and development outcomes in India.
- Exploit exogenous wind exposure to distant locations to identify causality.



Dry Season (Rabi)

This Paper

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Results

I Irrigation increases precipitation:
  - +20% in volume and +10% in intensity during the dry season.
  - This positive externality persists 5 and 10 years later.

II Impact on development and adaptation decisions:
  - ↑ wheat production by 5%, with no productivity improvements.
  - How? ↑ **private irrigation**. No yield-enhancing technologies investments.
  - Smallholders survive and do not exit agriculture.

Contributions

1. Irrigation and Development (Duflo and Pande, 2007; Dillon and Fishman, 2019; Blakeslee et al., 2023).
   - → **New positive externality** of development infrastructures, i.e. climatic spillovers.
   - → Trace effects on output, investment, and farm structure over five decades.

2. Climate Change, Adaptation, and Development (Dell et al., 2014; Kala, 2017; Taraz, 2018; Emerick, 2018; Liu et al., 2023).
   - → **Feedback loop**: irrigation is both adaptation to and driver of climate change.
   - → Quasi-experiment: persistent climate variation orthogonal to local adaptation.
   - → **Seasonality** matters: precipitation and irrigation are **complements** in the dry season.

3. Climate Endogenous to Human Activity in natural sciences (Puma and Cook, 2010; Alter et al., 2015; Greve et al., 2025) and in economics (Li, 2021; Araujo, 2023; Grosset-Touba et al., 2024; Degois et al., 2025; Braun and Schlenker, 2023).
   - → **Monsoon systems respond differently**: irrigation shifts their **seasonal** distribution.
   - → Predicted by climate models → **first empirical evidence**.
   - → Document feedbacks on development.

What is Canal Irrigation?

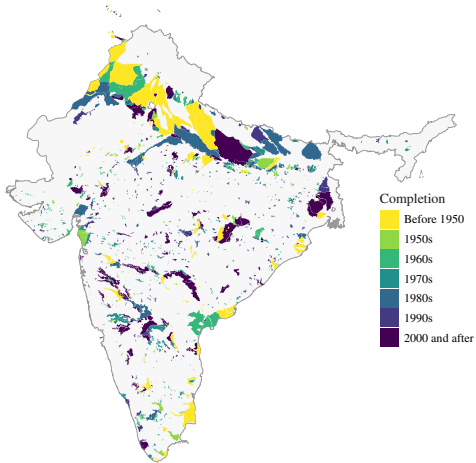
Context

Follows the Green Revolution (1960's).

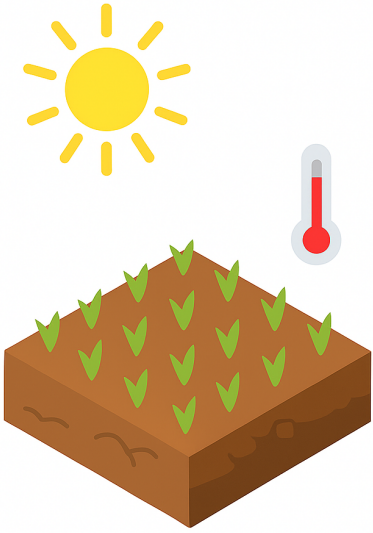
29% irrigation source in India in 2000.

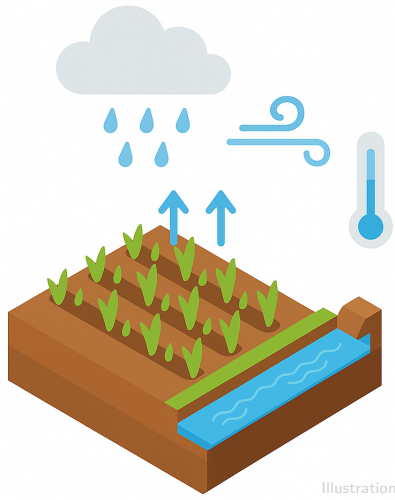
1,500 projects (median size 4,000 ha).



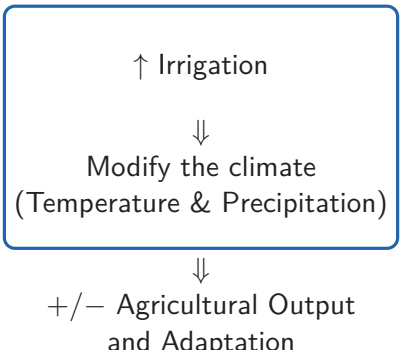


Mechanism



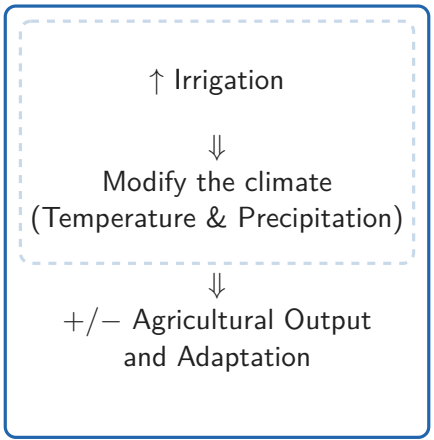


Illustrations generated by AI.


↑ Irrigation
⇓
Modify the climate
(Temperature & Precipitation)
⇓
+/− Agricultural Output
and Adaptation

Part I

Course



Part I

Part II

Data

Satellite climate at $0.25°$ cell (monthly):

- Wind direction and atmospheric pressure from *ERA5*, temperature from *ERA5-Land*.
- Total precipitation from India Meteorological Department (IMD) (Pai et al., 2014).

Irrigation from WRIS:

- Surface irrigated by canals.
- Canal construction date from Wiki WRIS, Asher et al. (2022) and hand cleaning.
- Yearly proportion of pixel irrigated.

Agricultural from DLD ICRISAT (yearly):

- Cropped area, production and yields.
- Agricultural practices: irrigation, fertilizer use, mechanization.
- Farm size distribution: *marginal* (< 1 ha), *small* (1–2 ha), *semi-medium* (2–4 ha), *medium* (4–10 ha), and *large* (> 10 ha).

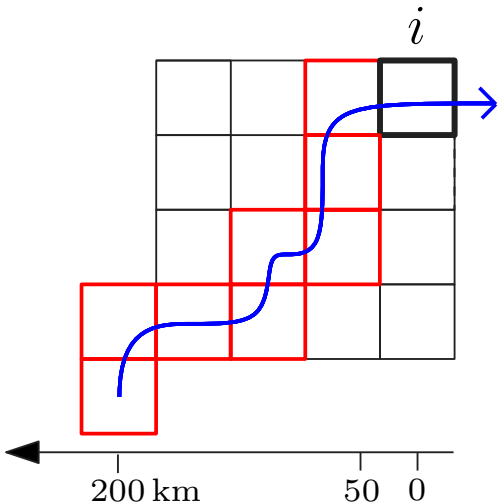
Identification Strategy

Endogeneity:

- Reverse causality, i.e. irrigation decisions are endogenous to the local climate.
- Confounding factors can impact both irrigation and development outcomes.

Causality:

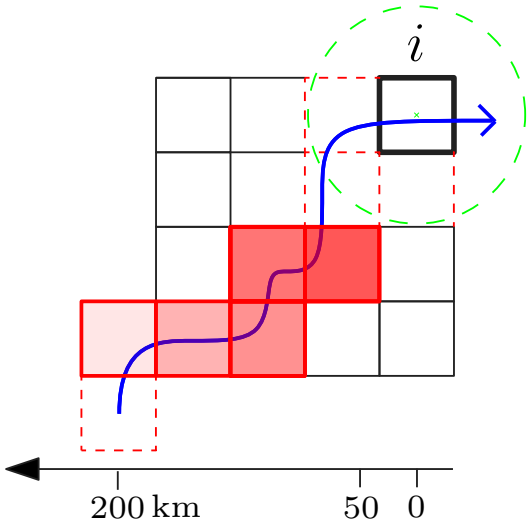
- Exploit exogenous wind direction. Backward Wind Path
- Look at a distant spatial scale.
- Control for time-varying and geographic characteristics.



Pixel of Interest i

Backward Wind Path

Upwind Pixels



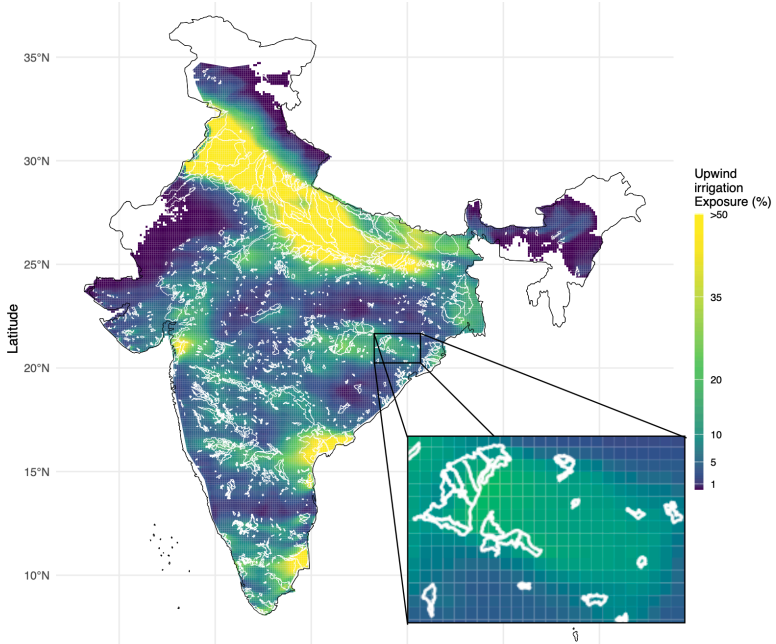
Pixel of Interest i

Backward Wind Path

Upwind Irrigation

Excluded Pixels

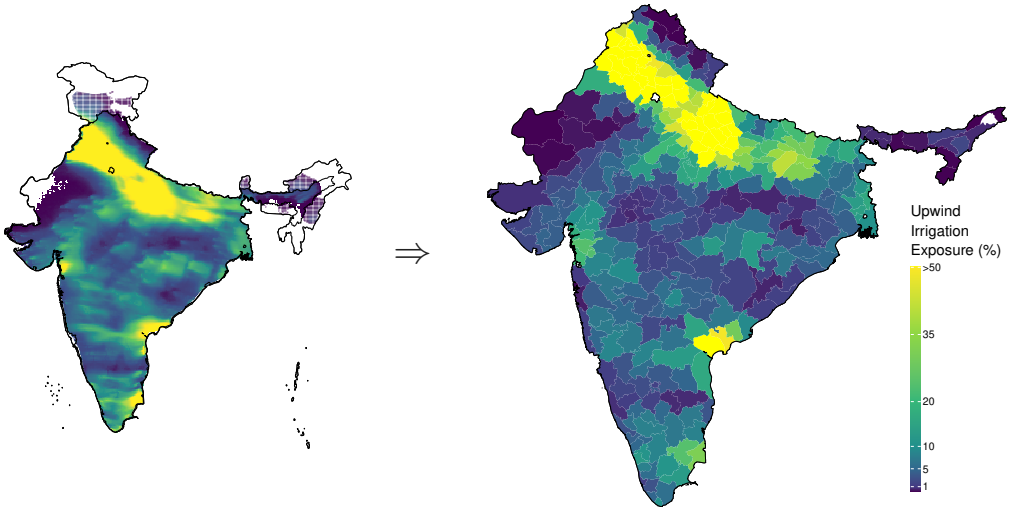
50km Excluded Area



Distance

Direction

District Aggregation



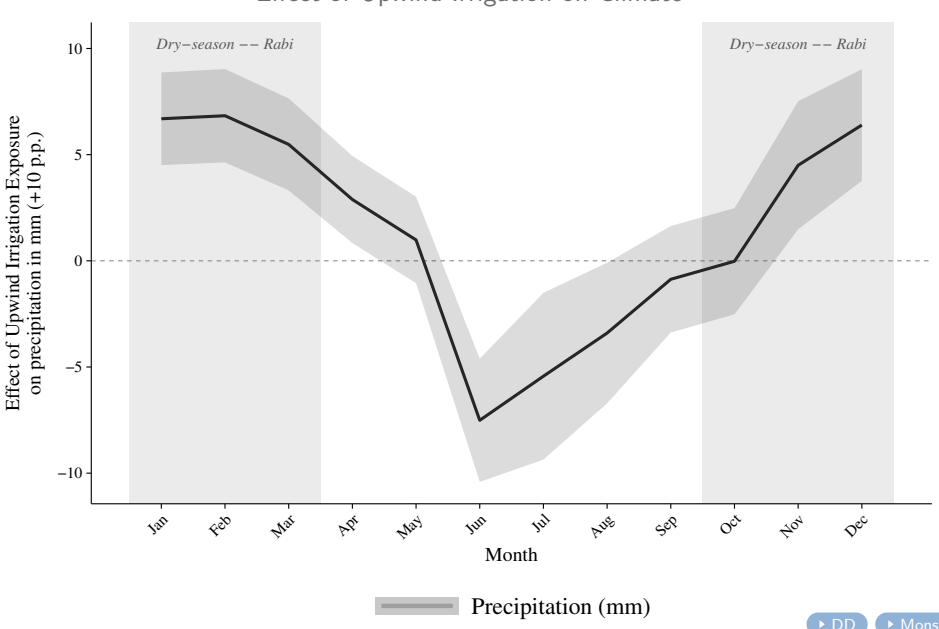
Upwind Irrigation exposure is defined as a continuous district-level variable $\in [0, 1]$. ▸ Details

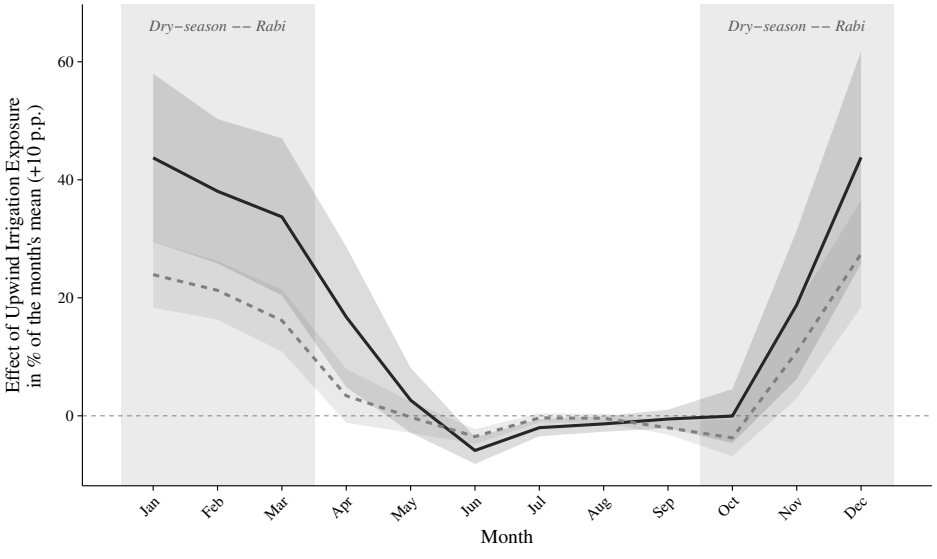
Specification – Climate Seasonal

Panel. District-month :

$$y_{d,t,m} = \beta_{Jul}\, E^{\uparrow}_{d,t,m} + \sum_{m \neq \text{Jul}} \beta_m\, \mathbf{1}\{M_{d,t,m} = m\} \cdot E^{\uparrow}_{d,t,m} + \mu_d + \delta_m + \lambda_{s,t} + \varepsilon_{d,t,m} \quad (1)$$

- $y_{i,d,t,m}$ climate variable in pixel i, district d, year t, month m
- $E^{\uparrow}$: **upwind** irrigation exposure (10pp.)
- $\beta_{Jul} + \beta_m$ measures the total effect of upwind irrigation in month m
- district μ_d, month δ_m and state×year $\lambda_{s,t}$ fixed effects
- $\varepsilon_{d,t,m}$ clustered at the district level


Effect of Upwind Irrigation on Climate
Dry−season −− Rabi
Dry−season −− Rabi
Effect of Upwind Irrigation Exposure on precipitation in mm (+10 p.p.)
10
5
0
−5
−10
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Precipitation (mm)


Effect of Upwind Irrigation on Climate
Dry−season −− Rabi
Dry−season −− Rabi
Effect of Upwind Irrigation Exposure in % of the month's mean (+10 p.p.)
60
40
20
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Precipitation
Number of rainy days (>1mm)

Part II

What are the consequences for development?

1. On agricultural outcomes.
2. In terms of adaptation strategies.
3. And the consequences for medium-term farm structure.

Specification – Development

Panel. District-year :

$$y_{d,t} = \beta_1 E^{\uparrow}_{d,t} + \underbrace{\beta_2 E^{\downarrow}_{d,t}}_{\text{placebo}\approx 0} + \gamma \mathbf{X}_{d,t} + \boldsymbol{\alpha} + \varepsilon_{d,t}$$

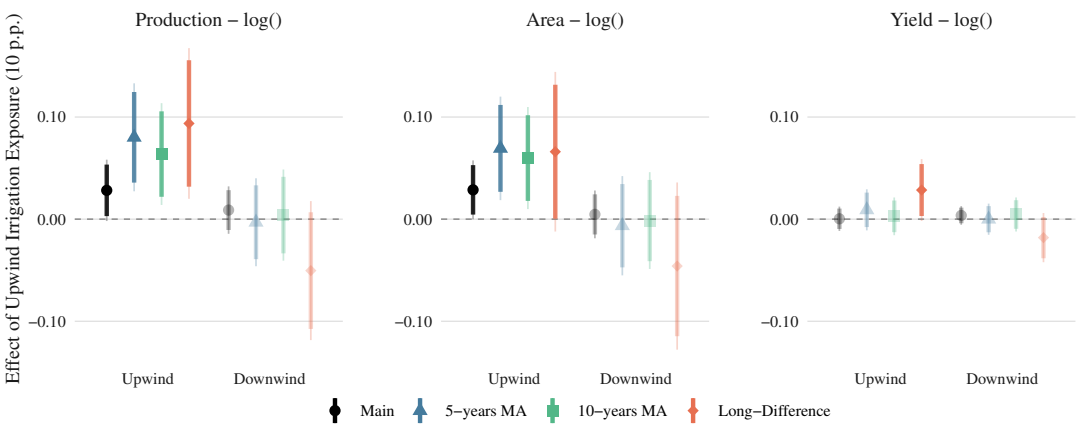
- $E^{\uparrow}$: **upwind** irrigation exposure
- $E^{\downarrow}$: **downwind** irrigation exposure (placebo)

	Specification	**Fixed effects α**
(1)	Main	$\mu_d + \lambda_{s,t}$
(2)	5-year MA (± 2 y, $\tau \in \{1970, \ldots, 2000\}$)	$\mu_d + \lambda_{s,\tau}$
(3)	10-year MA (± 5 y, $\tau \in \{1970, 1980, 1990, 2000\}$)	$\mu_d + \lambda_{s,\tau}$
(4)	Long difference 1970→2000 (± 2 y)	λ_s

- $\mathbf{X}_{d,t}$: controls, i.e. log(pop) and log(high yielding varieties)
- $\varepsilon_{d,t}$ clustered at the district level

What are the consequences for development?

Better climate conditions → Wheat: **5% ↑ production**, ↑ **area**, ∼ yield



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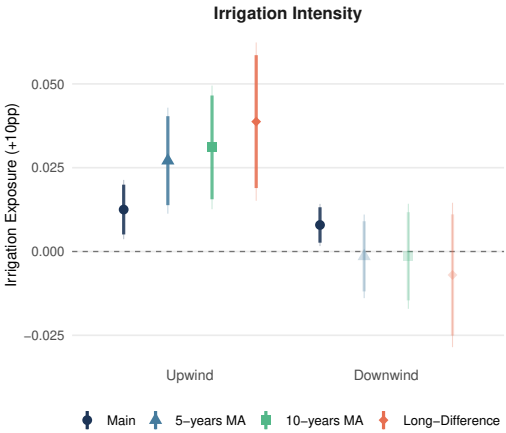
Adaptation ? → Irrigation adoption.

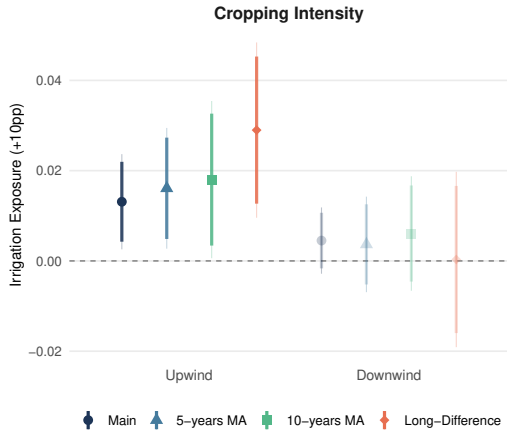
Theoretical predictions

1. A net improvement in rainfall should *reduce* irrigation adoption → Substitution.
2. Taking into account seasonality could instead *increase* irrigation adoption:

$$\underbrace{\text{Increase rainfall in } \textit{rabi}}_{\text{Complementarity}} \rightarrow \text{to cultivate the second cropping season}$$

Effect of Upwind Irrigation on Adaptation





- 5% ↑ irrigation intensity, through private irrigation, not canals.
- Leading to an 6% ↑ cropping intensity.
- No other adaptation: no fertilizer, no mechanization, no crop switching.

What is the effect on Farm Structure?

	(1) Marginal (<1 ha)	(2) Small (1–2 ha)	(3) Semi-medium (2–4 ha)	(4) Medium (4–10 ha)	(5) Large (≥10 ha)	(6) Total
	Dep. Var.: Number of Farms ('000)					
Upwind Irrigation (sd.)	4.163*	−0.394	−0.267	−0.302**	0.062	3.228
	(2.192)	(0.506)	(0.321)	(0.151)	(0.093)	(2.353)
Mean	171.926	58.045	41.375	24.562	6.296	304.031

- Sustain more marginal farms *at the expense of* medium-sized farms.

▸ Effect on Wages

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	Dep. Var.: Share of Total Area					Area ('000 ha)
Upwind Irrigation (sd.)	0.003	−0.002**	−0.001	−0.003*	0.004**	2.032
	(0.002)	(0.001)	(0.002)	(0.001)	(0.002)	(1.851)
Mean	0.167	0.180	0.229	0.259	0.165	535.047
Obs.	2,014	2,014	2,014	2,014	2,014	2,043
Fixed Effects	District and State×Year					

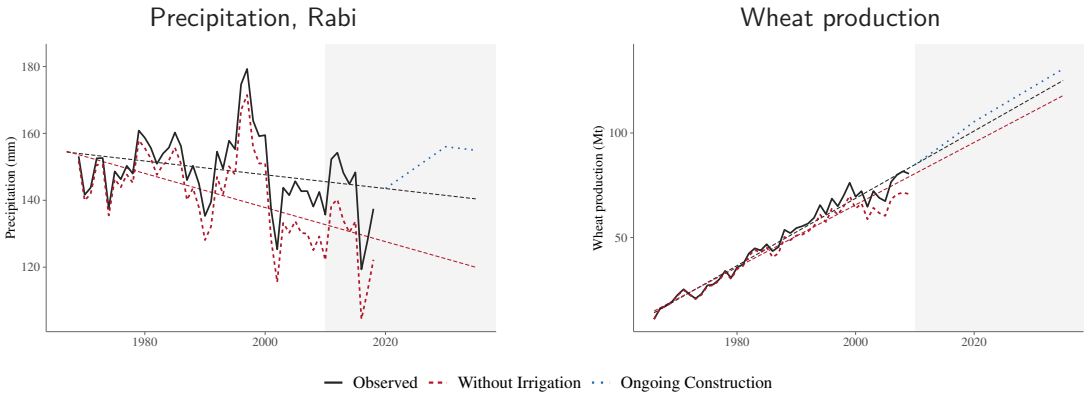
- Sustain more marginal farms *at the expense of* medium-sized farms.
- Enable consolidation at the upper tail *at the expense of* small and medium farms.

⇒ Polarization of the agricultural sector.

▸ Effect on Wages

Policy

Counterfactual exercise: climate and production trends without irrigation expansion

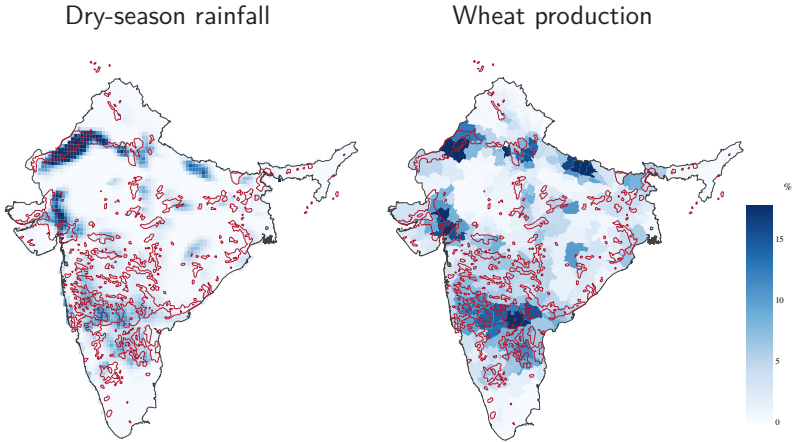


→ Rabi rainfall 1967–2020: −27.0 mm without upwind irrigation, vs. −10.9 mm.

→ Upwind irrigation accounts for 7% of wheat production growth ($1 billion a year).

Policy

Expected rain and production growth from ongoing projects: +32.3 Mha of canals (+10 pp)



→ Expected: +8.4% of dry-season rainfall and +3.6 Mt of wheat (4.6% of today's production).

→ 30% of the benefits fall outside any command area.

Robustness Checks

Specification

Climate response: district vs. pixel — A13

Alternative fixed effects — A16

Exposure definition: distance bands — A17

Functional form: log, Poisson, levels — A22

Geographic confounders

Balance of district characteristics — Tab. A14

Geographic controls — A18, A19

Leave-one-out — A20, A21

Other confounders

Green Revolution — Tab. A15, A23

Crop-residue burning — A24, A25, A26, Tab. A16

Inference

Conley s.e., 100–500 km — A27, A28

Randomisation inference — A29

Placebo

Wheat production, area, yield — A30

Cropping and irrigation intensity — A31

Summary

What did we learn?

1. Development infrastructure reshapes the climate.
2. Seasonality matters for adaptation decisions.
3. Feedback loop: irrigation is both a driver of and an adaptation to climate change.

Policy implications

- New externality in the evaluation of large-scale development infrastructure.
  $\rightarrow$ 7% of crop production growth ($1 billion a year).
- Endogeneity of climate to adaptation decisions.

Further research

$\rightarrow$ Other development outcomes: health, education, structural transformation...

Thank you!

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References I

Alter, R. E., Im, E.-S., and Eltahir, E. A. B. (2015). Rainfall consistently enhanced around the Gezira Scheme in East Africa due to irrigation. *Nature Geoscience*, 8(10):763–767.

Araujo, R. (2023). When clouds go dry: An integrated model of deforestation, rainfall, and agriculture. *Working Paper*.

Asher, S., Campion, A., Gollin, D., and Novosad, P. (2022). The long-run development impacts of agricultural productivity gains: Evidence from irrigation canals in india. CEPR Discussion Paper No. 17414.

Blakeslee, D., Dar, A., Fishman, R., Malik, S., Pellegrina, H. S., and Bagavathinathan, K. S. (2023). Irrigation and the spatial pattern of local economic development in India. *Journal of Development Economics*, 161:102997.

Braun, T. and Schlenker, W. (2023). Cooling externality of large-scale irrigation. NBER Working Paper No. 30966.

Degois, M., Vendryes, T., and Wolfersberger, J. (2025). Clearing the way to conflict: Deforestation and downwind rainfall. *Working Paper*.

Dell, M., Jones, B. F., and Olken, B. A. (2014). What do we learn from the weather? the new climate-economy literature. *Journal of Economic Literature*, 52(3):740–98.

Dillon, A. and Fishman, R. (2019). Dams: Effects of Hydrological Infrastructure on Development. *Annual Review of Resource Economics*, 11(1):125–148.

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

Emerick, K. (2018). Agricultural productivity and the sectoral reallocation of labor in rural India. *Journal of Development Economics*, 135:488–503.

Greve, P., Schmitt, A. U., Miralles, D. G., McDermid, S., Findell, K. L., García-García, A., and Peng, J. (2025). Observational evidence of increased afternoon rainfall downwind of irrigated areas. *Nature Communications*, 16(1):3415.

Grosset-Touba, F., Papp, A., and Taylor, C. (2024). Rain follows the forest: Land use policy, climate change, and adaptation. Available at SSRN: https://ssrn.com/abstract=4333147.

Jack, B. K. and Ryan, N. (2026). Economic development and the environment. NBER Working Paper number 34735.

Kala, N. (2017). Learning, adaptation, and climate uncertainty: Evidence from indian agriculture. MIT CEEPR Working Paper Series 2017-023.

Li, T. (2021). Protecting the breadbasket with trees? the effect of the great plains shelterbelt project on agriculture. *Land Economics*, 97(2):321–344.

Liu, M., Shamdasani, Y., and Taraz, V. (2023). Climate Change and Labor Reallocation: Evidence from Six Decades of the Indian Census. *American Economic Journal: Economic Policy*, 15(2):395–423.

References II

Pai, D. S., Sridhar, L., Rajeevan, M., Sreejith, O. P., Satbhai, N. S., and Mukhopadhyay, B. (2014). Development of a new high spatial resolution (0.25° × 0.25°) long period (1901–2010) daily gridded rainfall data set over india and its comparison with existing data sets over the region. *MAUSAM*, 65(1):1–18. India Meteorological Department, Pune.

Puma, M. J. and Cook, B. I. (2010). Effects of irrigation on global climate during the 20th century. *Journal of Geophysical Research*, 115:D16120.

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.

Taraz, V. (2018). Can farmers adapt to higher temperatures? Evidence from India. *World Development*, 112:205–219.