The Scope for Climate Adaptation:
Evidence from Water Scarcity in Irrigated Agriculture

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Indian villages lie empty as drought forces thousands to flee

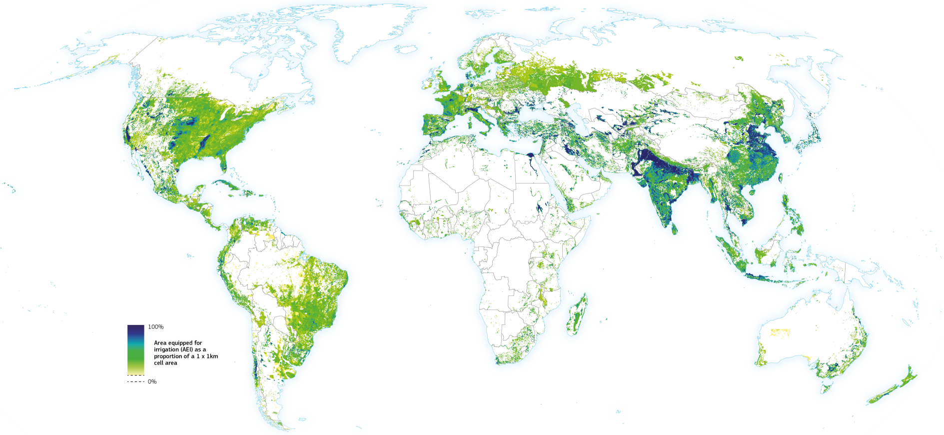
Sick and elderly left to fend for themselves with no end in sight to water crisis

▲ Homes are inundated with flood waters from the Arkansas river in Sand Springs, Oklahoma. Photograph: Tom Gilbert/AP

'So much land under so much water': extreme flooding is drowning parts of the midwest

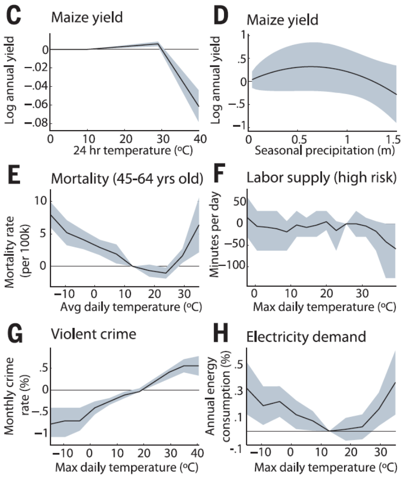
Economic costs of surface water scarcity are uncertain

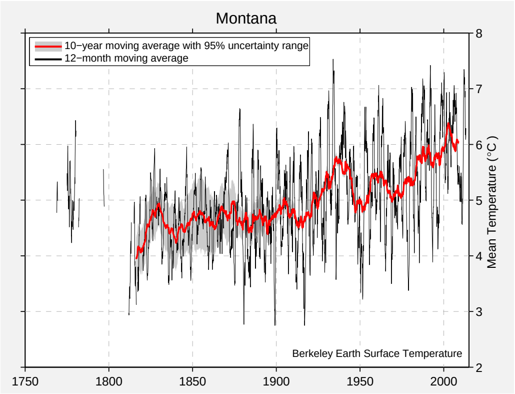
42% of global crop output relies on irrigation – not just rainfall...



...but so far we don't have much empirical evidence.

Long-run impacts of environmental change are hard to quantify





Will short-run impacts persist in the long run?

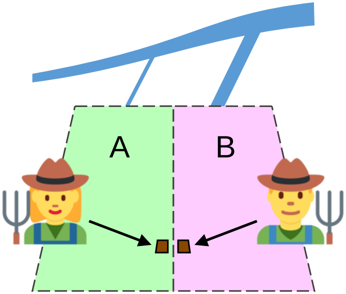
Or will we reduce the costs through adaptation?

Research Question #1

How does surface water affect long-run agricultural production?

Estimate long-run effects using spatial variation from institutional history in California.

- Farm water supplies vary by water district.
- Compare farms across district boundaries using a spatial regression discontinuity.



Key idea: Measure effects of relative differences in water supplies today to predict effects of changes in water supplies in the future.

Research Question #2

How much do farmers adapt to surface water supplies?

- Estimate short-run effects using year-to-year fluctuations in water supplies.
- Compare short-run effects to long-run effects in the same setting.

Adaptation: Difference between short-run and long-run effects.

- Short run? Limited range of ability to respond.
- Long run? Invest in knowledge & equipment to grow new crops.

Outcomes $Y(w, A)$ depend on water w and adaptations A.

$$\underbrace{\frac{dY}{dw}}_{\text{long run effect}} = \underbrace{\frac{\partial Y}{\partial w}}_{\text{short run effect}} + \underbrace{\frac{\partial Y}{\partial A}\frac{dA}{dw}}_{\text{adaptation effect}}$$

Outcomes: Land use and crop choice via remote sensing

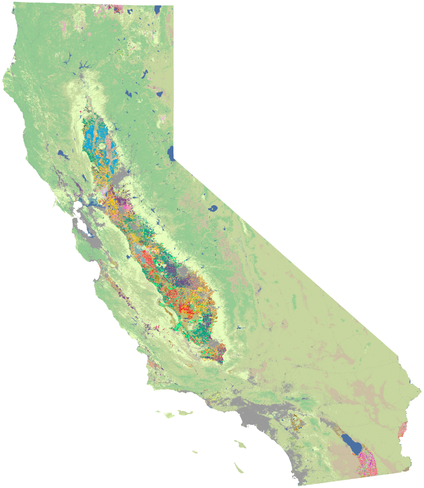
Cropland Data Layer (U.S. Department of Agriculture)

- All farmland in California, 2007-2018.
- Crop planted at every pixel in a 30m grid.

Outcome variables: Binary indicators for crop choice and land use categories.

Predicted crop revenue: A revenue-weighted index.

- >100 land use options on a 1-dimensional scale.
- Weights: Mean revenue by crop$\times$county$\times$year.



Surface water availability determined by water district

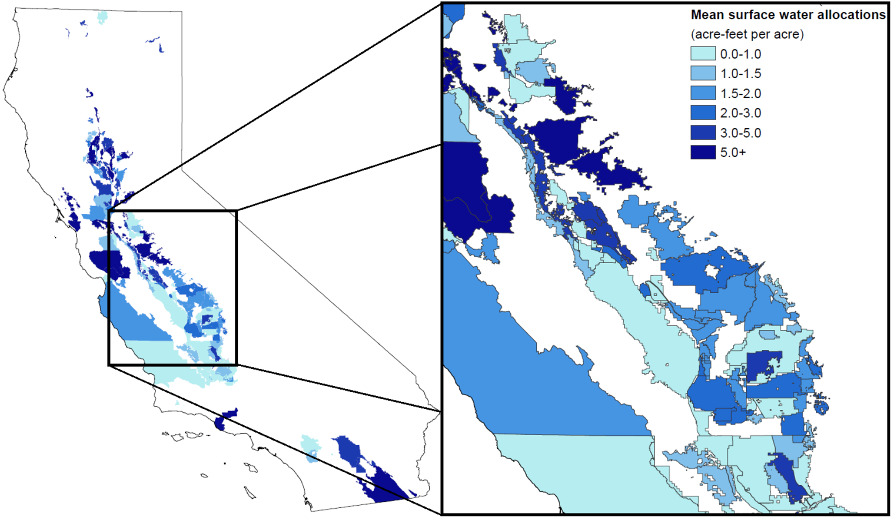
Water districts:

- Local organizations established by groups of farmers, 1860s-1950s.
- Hold long-term entitlements to surface water from:
  - Rivers & streams (permanent rights).
  - Canals run by federal & state governments (long-term contracts).
- Distribute to farmers within their service area, dividing evenly by land area.

$\Rightarrow$ **Spatial distribution of water to farmland has changed little in over 40 years.**

Large differences in average water supplies across districts

Per-acre surface water entitlements by water district



Long run: Regression discontinuity

Exploit boundaries between neighboring water districts.

- Find all 532 pairs of neighboring districts & stack into one regression.
- Regress mean outcomes on mean water supply (field *i*, district *d*, pair *b*):

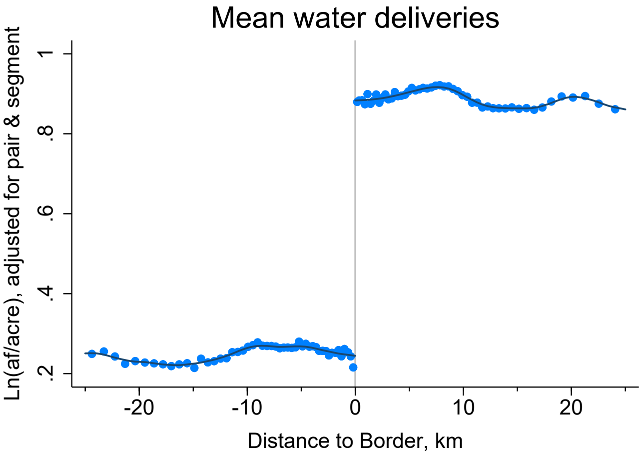
$$\bar{Y}_{idbs} = \alpha_{bs} + \beta \overline{\ln(WaterSupply)}_{d} + f_{bs}(DistanceBorder_{idbs}) + \varepsilon_{idbs}$$

  - Separate intercepts α_{bs} and running variables f_{bs} for each border pair *b*.
  - Border segments *s* further split each border into 5-km pieces.

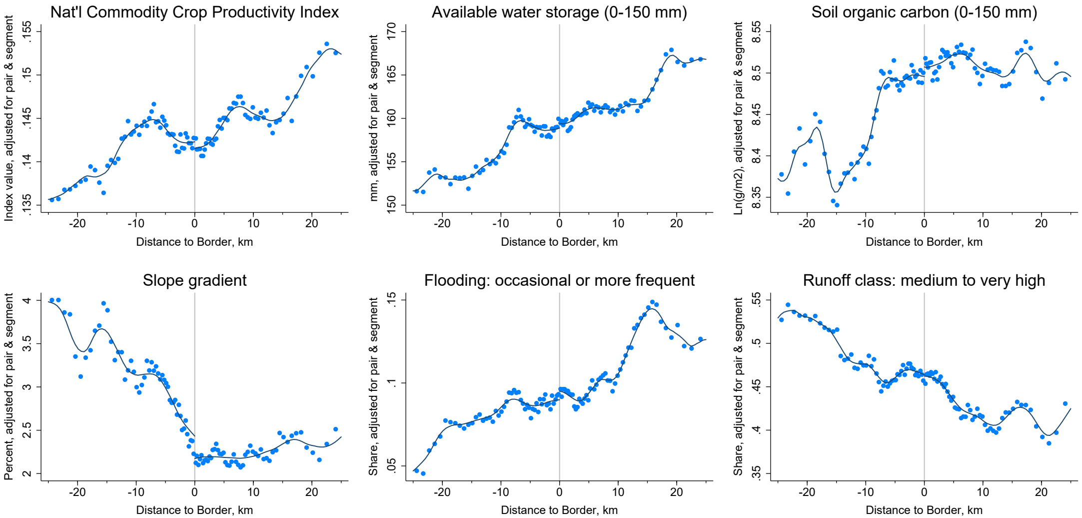
- Instrument mean water supply with indicator for water-rich district of each pair.
  - Scales effect into units of water supply.

Long run: First stage

Mean difference between neighboring districts is nearly double.



Soil characteristics are continuous at borders



Short run: Panel specification

Exploit year-to-year fluctuations in water supplies driven by weather.

- Regress outcomes (field *i*, district *d*, year *t*) on yearly water supply:

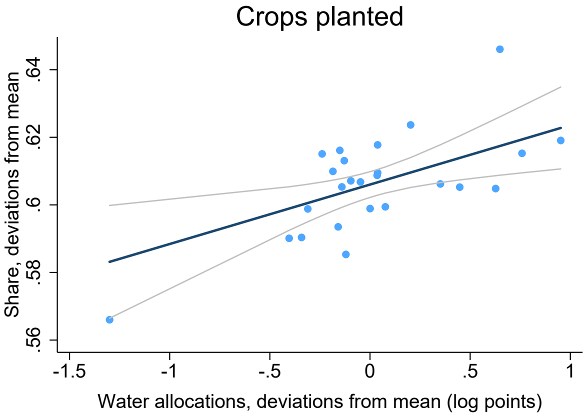
$$Y_{idt} = \alpha_{id} + \gamma \ln(WaterSupply)_{dt} + \lambda_t + \varepsilon_{idt}$$

  - Fixed effects for field (α_{id}) and year (λ_t).

- Instrument for water supply using **allocation percentages**
  - Set each year by government algorithm.
  - Based only on weather & environmental conditions.

1. Surface water availability is economically important

Short run: Crop area is lower in years with less surface water.



IV estimate:

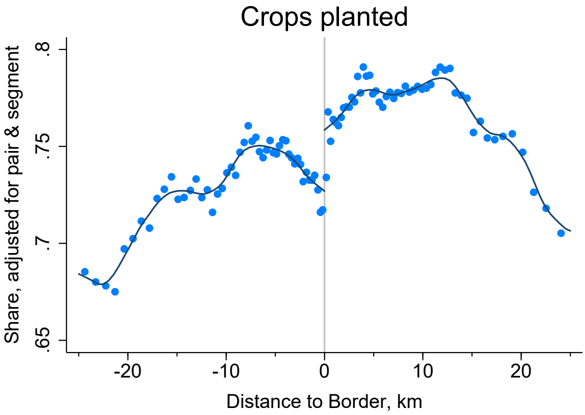
(p.p./Δ%)

0.048***

(0.019)

1. Surface water availability is economically important

Long run: Crop area is lower in places that have less water on average.



IV estimate:

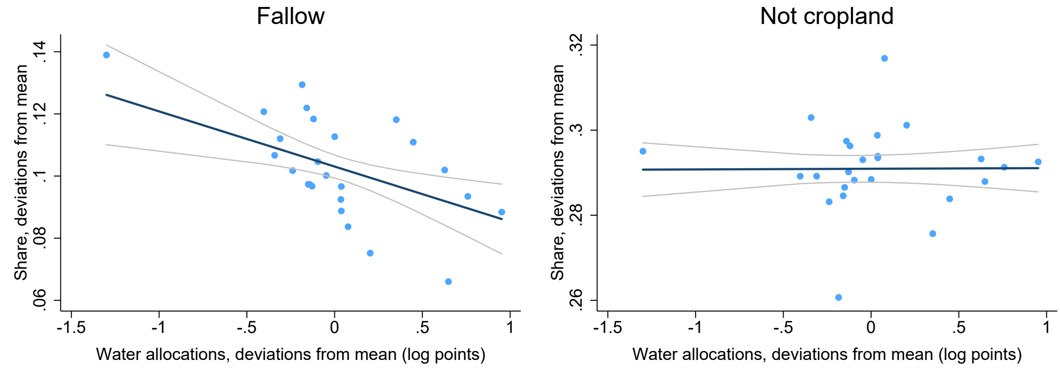
(p.p./Δ%)

0.050***

(0.017)

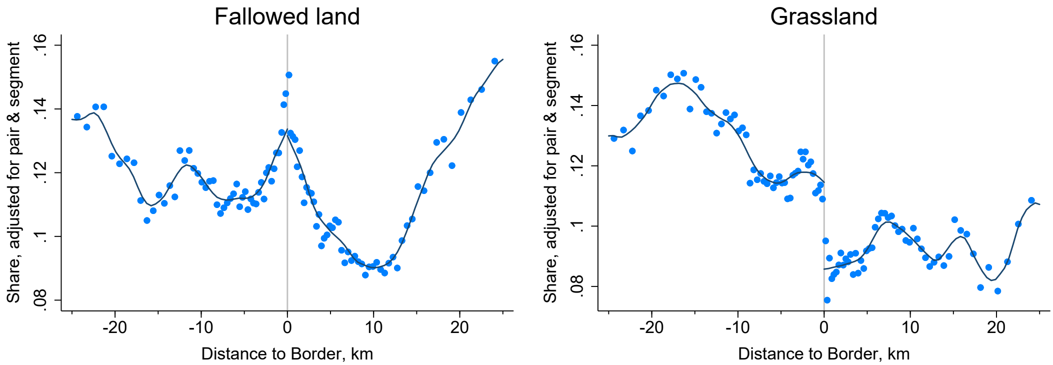
2. Farmers adapt in some ways in the long run

In the short run, land taken out of production is held fallow.



2. Farmers adapt in some ways in the long run

In the long run, land not in crop production is left in grassland.



2. Farmers adapt in some ways in the long run

Shift into a higher-value mix of crops

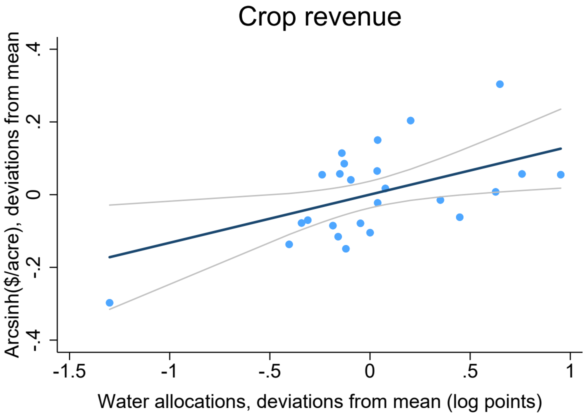
- More cotton & grapes.
- Less alfalfa, rice, corn.

Shift toward lower-water crops (weaker evidence)

- More wheat & grains.
- Fewer fruit & nut orchards.

3. Revenue value of adaptation is small

Predicted crop revenue falls in response to short-run water scarcity.



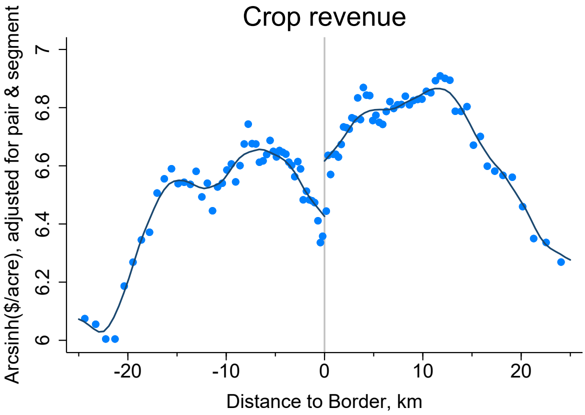
IV elasticity:

0.362***

(0.160)

3. Revenue value of adaptation is small

Predicted crop revenue still falls in response to long-run water scarcity.



IV elasticity:

0.306***

(0.137)

3. Revenue value of adaptation is small

Most of the short-run effect persists into the long run.

Adaptation $=$ Long-run effect $-$ Short-run effect

	Elasticity of revenue	Percent
Short-run	0.36 ***	100%
Long-run	0.31 ***	85%
Adaptation	**0.06**	**15%**

Scarcer water is likely to reduce future agricultural output

What do these results imply for the future of climate change in California?

- Large revenue losses from severe droughts
  - \$2.9 billion/year during major drought in 2014-15.
- Moderate revenue losses from secular rise in water scarcity
  - \$430 million/year by midcentury
    (Rough estimate applying hydrological projections of Wang et al. 2018).
- Groundwater substitution feedback likely to exacerbate future losses.

Can cross-sectional regression replicate the RD results?

Only when combining multiple alternative research designs.

Specification	**Mean squared bias** (10^{-3})
Cubic control in lat & lon	1.4
Physical covariates	6.6
County fixed effects	55.8
Matched neighbor pair fixed effects	6.6
All of the above	0.1

In summary

I estimate adaptation to surface water scarcity in irrigated agriculture in California

- By comparing short- and long-run effects credibly estimated in the same sample.

1. **Surface water is economically important.** (Water scarcity reduces crop area.)
2. **Farmers adapt in some ways.** (Land-use choices respond differently.)
3. **The value of this adaptation is limited.** (Short-run revenue losses persist.)

Absent new investments or policy changes...

projected future declines in surface water supplies

are likely to reduce the land area and output of agriculture.