CLIMATE ADAPTATION
RESEARCH SYMPOSIUM

MEASURING & REDUCING SOCIETAL IMPACTS

Wading into the Economic Impacts of Climate Change on Water

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The session will begin shortly.

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Valerie Muller
Arizona State University

Will Rafey
UCLA

Katrina Jessoe
UC Davis

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UCLA Luskin Center for Innovation

Valerie Mueller

Associate Professor, Arizona State University

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Sea Level Rise and the Economic Repercussions of Salinity Front Expansion

Sea Level Rise and the Economic Repercussions of Salinity Front Expansion

J. Chen[1] V. Mueller[2] F. Durand[3] E. Lisco[1] Q. Zhong[4] V. R. Sherin[5] AKM S. Islam[6]

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September 9, 2021
UCLA's Climate Adaptation Research Symposium

- Very difficult to measure effects of environmental risks that occur at the tails (if at all)
- Uncertainty around how (and when) SLR does (or will) affect humans
- Exposure is multi-faceted (e.g. inundation, king tides, storm surges, erosion, soil/groundwater salinization
- Chen and Mueller (2018) show migration and livelihoods strongly related to changes in soil salinity in Bangladesh

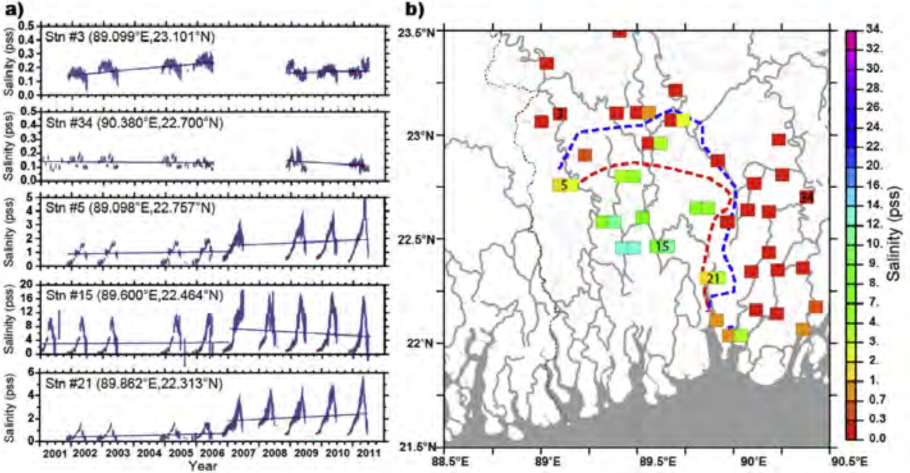

Fig. 4. (a) Timeseries of salinity observed at selected stations (red points). The blue vertical bars in all panels feature the year-to-year standard deviation, computed month-wise, separately over the 2001–2006 period and over the 2007–2011 period. For each of these two periods, we superimpose the linear fit in thin solid line. (b) Salinity climatology in April, with the positions of the pre-2006 (red) and post-2007 (blue) 2 units isohaline. The right-shifted squares in certain stations show the April climatological salinity computed over the post-2007 period only. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Research Question

1. Are there short-term economic losses from the salinity front expansion?
2. What practices might have led to these short-term losses?

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Contributions

- Policy contribution is that the salinity front expansion of 20km is equivalent to what is projected to occur over the coming century
- We identify the economic impacts of newly-exposed areas rather than coastal areas (Kocornik-Mina et al., 2020; Desmet, 2021)
- Most studies focus on flooding, without differentiating effects of inundation from salinization (Chen and Mueller, 2018)
- Few studies measure the effects of increased salinization focus on the agricultural sector (Dasgupta et al., 2015; Dasgupta et al., 2018)

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What levels of water salinity are dangerous?

- 0.6 unit on Practical Salinity Scale (PSS) cannot be used for drinking purposes
- >2 PSS cannot be used for rice irrigation purposes
- HYV rice output is 15.6 percent lower in locations with soil salinity greater than 2 PSS (Dasgupta et al., 2018)

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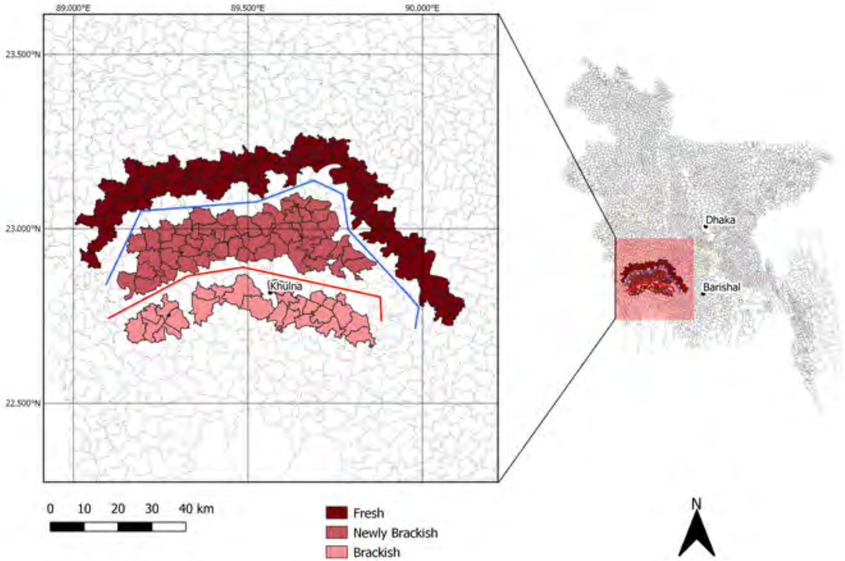
- Increase in sea level
- Lower river discharges
- Decrease in groundwater levels

Research Design



Data Sources

- Nightlight intensity (2000-2013) (NOAA, 2020)
- Enhanced Vegetation Index (2000-2015) (Didan, 2020)
- Agricultural Census 2008: Land Devoted to HYV (local) Boro and Aman Rice and Land Fallowed
- CHIRTSmax and CHIRPS v2.0 to include annual monthly average maximum temperature and monthly average precipitation as control variables (Funk et al., 2015; Funk et al., 2019)

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$$Y_{ut} = \alpha_u + \alpha_t + \beta NB_u \times Post_t + \delta X_{ut} + \epsilon_{ut} \quad (1)$$

Adopt EB Matching for Pre-Processing the Data

- Run the EB matching procedure to weight the control observations in each of the three designs (Ho et al., 2017; Hainmueller 2012; Zhao and Percival, 2017)
- All runs use time-invariant pre-treatment (2000-2006) average of the EVI and nightlight intensity outcomes (Ferraro and Miranda, 2017)
- Impose constraints that the first two moments be balanced

Table 1. Covariate Balance, All Experimental Designs

	Newly Brackish	Always Fresh		Always Brackish		Always Fresh & Brackish	Always
	Unweighted	Unweighted	Weighted	Unweighted	Weighted	Unweighted	Weighted
EVI							
Mean	2,879.29	3,181.65	2,879.29	2,800.09	2,879.22	3,064.94	2,879.42
SD	347.91	303.95	332.85	471.94	336.96	404.40	340.65
Mean difference		-302.37	-0.01	79.19	0.06	-185.65	-0.13
Standardized mean difference		-94.99	-0.00	19.10	0.02	-58.32	-0.04
Variance ratio (treat/untreat)		1.31	1.09	0.54	1.07	0.74	1.04
Nightlight intensity							
Mean	1.27	1.36	1.27	1.82	1.27	1.50	1.27
SD	0.68	1.02	0.87	0.90	0.86	1.00	0.88
Mean difference		-0.09	-0.00	-0.55	0.00	-0.23	-0.00
Standardized mean difference		-10.30	-0.00	-62.47	0.00	-26.78	-0.02
Variance ratio (treat/untreat)		0.74	1.02	0.95	1.03	0.76	0.99
N	322.00	413.00		182.00		595.00	

Notes: N=Union-years. Summary statistics computed from data collected in years 2000 through 2006. The mean difference row displays the difference between the covariate mean in the newly brackish group and the covariate mean in the assigned comparison group. The standardized difference in percent is calculated using the formula in [25]. The variance ratio is the ratio of the variances in the newly brackish and comparison groups.

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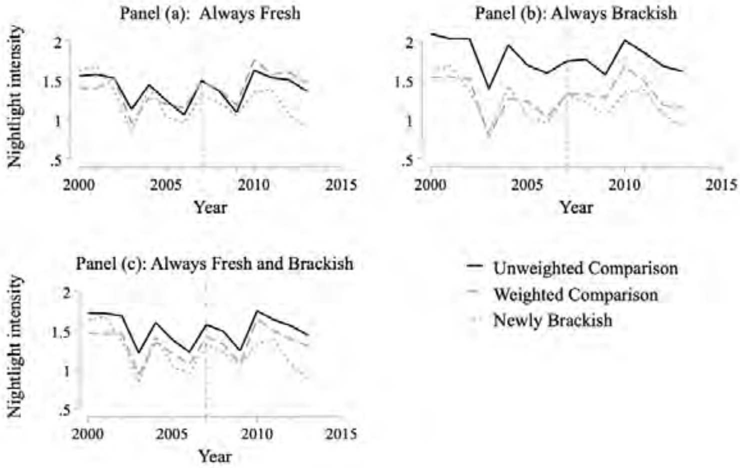
Nightlight Intensity



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Nightlight Impacts

Table 2. Difference-in-Difference Nightlight Intensity Regression

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Always Fresh						
Post	0.063	0.061	-0.223	0.220	0.225	0.009
	(0.049)	(0.049)	(0.114)*	(0.041)***	(0.041)***	(0.173)
NB × Post	-0.157	-0.162	-0.107	-0.313	-0.322	-0.218
	(0.064)**	(0.065)**	(0.061)*	(0.058)***	(0.059)***	(0.053)***
Elasticity	-0.283	-0.291	-0.214	-0.485	-0.496	-0.365
R^2	0.01	0.04	0.28	0.05	0.06	0.33
N	1,470	1,470	1,470	1,470	1,470	1,470
Panel B: Always Brackish						
Post	-0.078	-0.077	-1.130	0.069	0.067	-0.986
	(0.055)	(0.054)	(0.169)***	(0.079)	(0.078)	(0.171)***
NB × Post	-0.015	-0.018	-0.046	-0.162	-0.159	-0.191
	(0.069)	(0.069)	(0.069)	(0.089)*	(0.089)*	(0.087)**
Elasticity	-0.096	-0.099	-0.365	-0.292	-0.288	-0.327
R^2	0.01	0.04	0.37	0.01	0.03	0.37
N	1,008	1,008	1,008	1,008	1,008	1,008
Panel C: Always Fresh and Always Brackish						
Post	0.020	0.019	-0.370	0.102	0.105	-0.311
	(0.039)	(0.038)	(0.113)***	(0.050)**	(0.050)**	(0.144)**
NB × Post	-0.113	-0.119	-0.088	-0.196	-0.203	-0.154
	(0.057)**	(0.057)**	(0.055)	(0.065)***	(0.066)***	(0.062)**
Elasticity	-0.211	-0.219	-0.175	-0.324	-0.334	-0.268
R^2	0.01	0.03	0.28	0.01	0.03	0.29
N	1,834	1,834	1,834	1,834	1,834	1,834
EB weights?	No	No	No	Yes	Yes	Yes
Year FEs?	No	No	Yes	No	No	Yes
Covariates?	No	Yes	Yes	No	Yes	Yes
Union FEs?	Yes	Yes	Yes	Yes	Yes	Yes

Notes: NB=Newly Brackish; EB= Entropy Balancing. Nightlight intensity is transformed using the inverse hyperbolic. The title of each panel reflects the comparison group being used in the estimation procedure. The elasticity of NB X Post is calculated using the formula derived in [11]. The covariates included in the model are contemporaneous precipitation and temperature levels. Unit of analysis is union-year. Union-clustered standard errors reported. * p<0.1 ** p<0.05 *** p<0.01.

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EVI Impacts

Table S2. Difference-in-Difference EVI Regression

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Always Fresh						
Post	132.668	127.298	458.859	141.897	134.933	506.588
	(10.643)***	(10.406)***	(31.447)***	(13.050)***	(13.277)***	(78.609)***
NB × Post	-29.708	-25.600	-26.183	-38.936	-32.206	-28.595
	(20.034)	(19.952)	(19.949)	(21.410)*	(21.171)	(17.765)
R^2	0.11	0.14	0.40	0.10	0.14	0.43
N	1,680	1,680	1,680	1,680	1,680	1,680
Panel B: Always Brackish						
Post	31.921	31.103	216.350	52.919	53.618	179.755
	(28.175)	(28.246)	(55.951)***	(41.785)	(42.100)	(55.569)***
NB × Post	71.040	70.938	65.952	50.042	48.551	40.393
	(32.915)**	(32.943)**	(33.919)*	(45.117)	(45.117)	(44.754)
R^2	0.05	0.07	0.25	0.05	0.07	0.24
N	1,152	1,152	1,152	1,152	1,152	1,152
Panel C: Always Fresh and Brackish						
Post	101.852	98.894	426.638	103.600	99.430	408.246
	(12.401)***	(12.216)***	(31.438)***	(16.770)***	(16.514)***	(39.921)***
NB × Post	1.109	3.402	3.222	-0.640	2.657	2.527
	(21.006)	(20.909)	(21.181)	(23.847)	(23.710)	(24.090)
R^2	0.08	0.10	0.34	0.08	0.10	0.32
N	2,096	2,096	2,096	2,096	2,096	2,096
EB weights?	No	No	No	Yes	Yes	Yes
Year FEs?	No	No	Yes	No	No	Yes
Covariates?	No	Yes	Yes	No	Yes	Yes
Union FEs?	Yes	Yes	Yes	Yes	Yes	Yes

Discussion

- Increased salinization in newly brackish areas led to declines on the order of 33% in nightlight intensity
- We also show that effects on EVI and nightlights intensity coincide with reductions in land designated to HYV rice and increases in land taken out of production
- Analyzing additional data to confirm whether the effects on economic activity may be driven by population displacement from shifts in orientation towards shrimp rather than rice production

Arizona State University

Will Rafey

Assistant Professor, UCLA

Droughts, Deluges, and (River) Diversions:
Valuing Market-Based Water Reallocation

Droughts, deluges, and (river) diversions: Valuing market-based water reallocation

Will Rafey

UCLA Economics

September 2021

Climate change, water scarcity, and trade

Water resources: increasingly scarce and variable in a changing climate

- historically not traded; allocated in non-market ways

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This paper measures the value of a water market, given that

- evolving hydrological conditions may constrain water market access differentially across locations and over time
- trading may not be competitive, efficient, or valuable

1. Measuring the value of water reallocation

Challenges:

- evolving, unobserved river flow constraints
  - cannot assume trading behavior reveals true valuations
  - set of feasible trades depends on river flows, tributaries, third parties

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- irrigated agriculture: $\approx$ 70% of all freshwater diversions globally

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Regulated river system:

- environmental regulation $\times$ distribution of permanent water rights $\implies$ initial allocation of water in each year,
- then continuous water trading throughout the growing season.

3. Key findings

With the estimated production functions and observed trade flows, I then ask:

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   - extension: dynamic model of forward-looking land use
     - land-use channel: $\approx 1/5$ of long-run value of the market

Related literature: Two main contributions

1. Measure the value of a **water market** to adapt to climate shocks
   - water rights and trade: Dales (1968), Burness and Quirk (1979), Chong and Sunding (2006), Libecap (2011), Gupta et al. (2018), Regnacq et al. (2016), Hagerty (2019), Donna and Espín-Sanchez (2019), Edwards et al. (2018)
   - agricultural markets and environmental shocks: Schlenker et al. (2005), Hornbeck and Keskin (2014), Costinot et al. (2016), Dingel et al. (2018)

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2. Market institutions to solve factor **misallocation**
   - dispersion in shadow values across firms/countries
     - capital (Hsieh and Klenow 2009, Asker et al. 2014), land (Adamopoulos and Restuccia 2014), credit (Midrigan and Xu 2014), SO_2 (Carlson et al. 2000)
   - market structure, regulation, and misallocation
     - electricity (Cicala 2019); labor (Garicano et al. 2016); oil cartels (Asker et al. 2019)

Plan

1. Irrigated agriculture and river water trading
2. A model of irrigated agricultural production
3. Empirical strategy and parameter estimates
4. Valuing market-based water reallocation
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The sMDB water market

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The sMDB water market

Focus on irrigated farms in Australia's **southern Murray-Darling Basin**:

- connected river network: spans three state governments, several regions
- large dams: water engineers predict, monitor, manage flows

The sMDB water market

Regulated river system with tradable water rights.

The sMDB water market

Regulated river system with tradable water rights.

1. annual diversion caps determined by formulas that differ
    - across regions, based on interstate water-sharing agreements.
    - across years, due to river inflows into upstream dams,

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Annual water allocations traded bilaterally

- most transactions brokered through intermediaries (fees: 1–4%);
- regulator maintains online ledger for water rights; coordinates diversions with farms
- any two farms can trade, provided that they are **connected** at a given moment in time

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   - from regulatory MDBA, state gov't records

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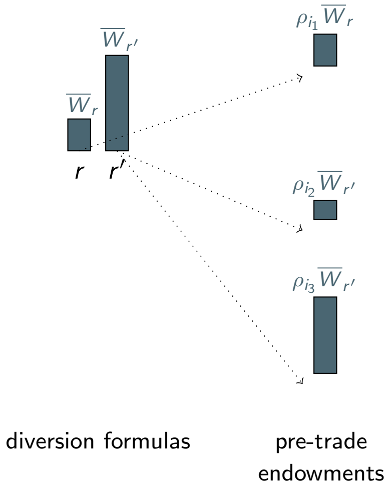
Production, river regulation, and trade: Example



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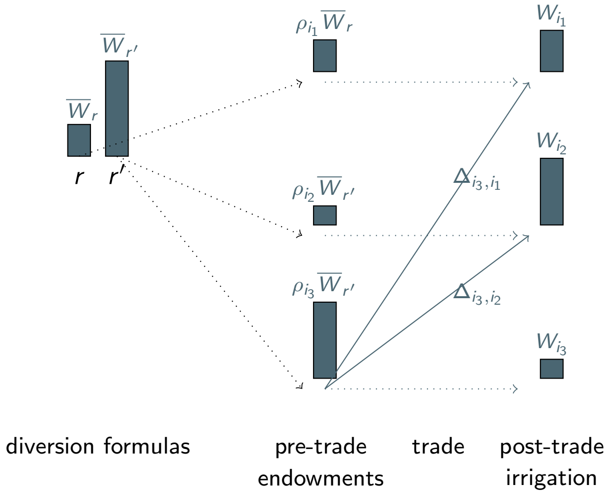

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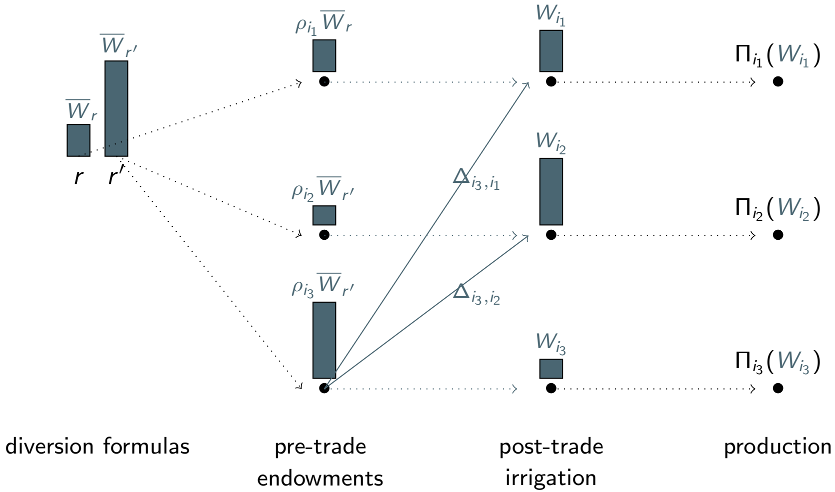

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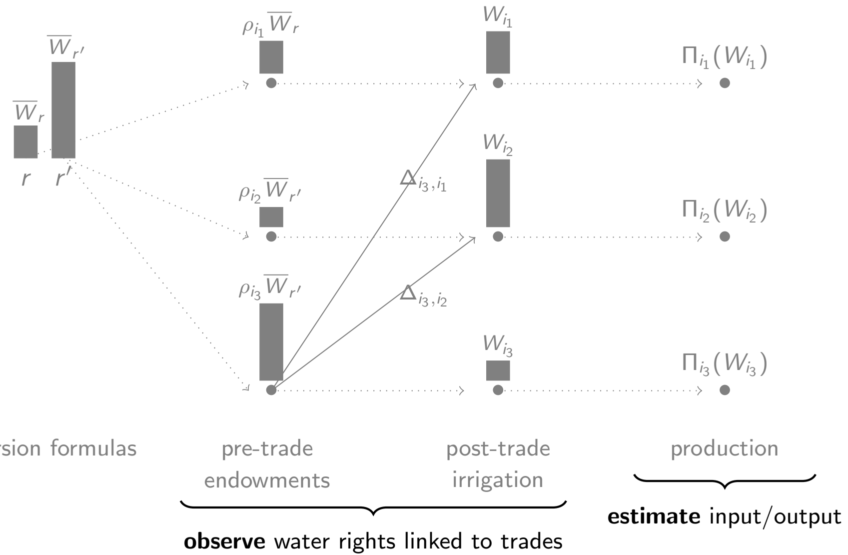

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more details

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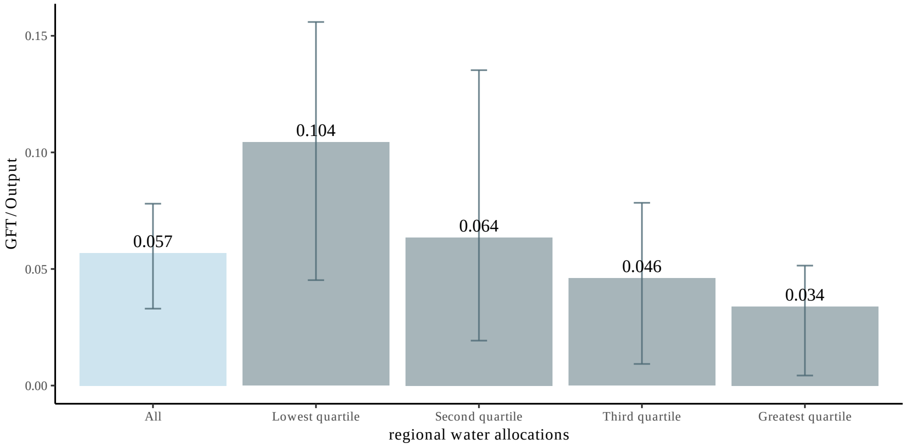
- cf. climate models: sMDB surface water $\downarrow$ 11% for 1°C warming (CSIRO, 2012)

Water scarcity and the value of annual trade



Value of **annual** allocation trading by regional water allocations

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- Value of (a well-functioning) water market: possibly on the order of medium-run climate shocks
- Nonlinear (very convex) value in water scarcity:
    - retrospective analyses, that estimate the value of water markets or trading using historical data, may understate the prospective benefits of trade
    - water markets may be a crucial part of the set of climate adaptation strategies going forward

Katrina Jessoe

Associate Professor, UC Davis

Industry Impacts of Pricing Externalities: Groundwater Pricing and Agricultural Land Use

The Long-Run Industry Impacts of Pricing Externalities: Groundwater and Agricultural Land Use

Ellen Bruno[1], Katrina Jessoe[2], Michael Hanemann[3,1]

[1]University of California, Berkeley

[2]University of California, Davis

[3]Arizona State University

September 9, 2021

Groundwater Externalities

Groundwater describes classic common-pool resource

- Gordon (1954); Hardin (1968); Ostrom (1990)
- Often unregulated and property rights poorly defined

Pumping externalities on water quantity and quality

- Pumping costs and cones of depression
- Depletes stock of resource and availability in future
- Brozoviè et al. (2010); Pfeiffer and Lin, (2012); Edwards (2016); Merrill and Guilfoos (2017)

Economists prescription: price the externality

- Pigou (1927); Baumol (1972); Brown (1974)

10,000 Foot View of Groundwater

Agricultural groundwater typically not priced

30% of largest groundwater supplies under stress

- Declining water tables increase agricultural production costs
- Degrade quality of water supplies
- Make uncertain long-run viability of groundwater irrigation

In CA, up to 40% water supply annually but 80% during drought

- In U.S. 27% of supply, globally 1/2 domestic use
- Buffer costs of drought

Climate change will alter water supplies

- Warming temperature increase rain (v.snow) and evaporation
- More frequent and extreme droughts
- Saltwater intrusion will compromise water quality

Our Paper: Agricultural Impacts of Pricing GW Externality

Estimate short and long-run effect of groundwater pricing on:

- Agricultural water use (input use)
- Irrigated acreage (output) and land fallowing
- Crop switching
- Permanent conversion out of crop production (industry exit)

Empirical Setting: irrigation district with volumetric pricing

Data:

- Quarterly groundwater extraction from 900 wells
- Annual spatial land use spanning 8 years from three sources
- Tax assessor (ownership boundary) data

Shift from a single to two geographically distinct volumetric prices

Quantifying Long-Run Margins of Response is Challenging

Agricultural land-use decisions are a longer-run decision

- Planting to harvesting 6 months to 10+ years

Evidence on short-run response to agricultural water prices

- Groundwater priced and metered: Bruno and Jessoe (2021)
- Electricity prices and aquifer depth as price proxy: Pfeiffer and Lin (2014); Burlig et al. (2020)
- Panel data approach that uses month/year variation in price
- Not designed to capture longer-run decisions

Our approach: permanent price split and annual land use

- Effect of price split on land use decisions over 5+ year horizon

And Important

In practice, little experience with groundwater prices

Correct groundwater externalities

- On the ground evaluation of pricing to address salinity

Cost-effective compliance with SGMA

- Sustainable Groundwater Management Act of 2014
- Basins achieve stable groundwater levels by 2040
- Flexibility in instruments to achieve compliance
- Little familiarity but lots of resistance to prices

Climate change adaptation strategy

- Prices to manage demand and buffer cost of surface shocks

Research Setting: Pajaro Valley, California

Productive agricultural region on CA's central coast

- 30,000 irrigated acres and annual revenues of $814 million
- Portfolio of high-valued crops: berries, apples, grapes, artichokes, lettuces, and other vegetable row crops
- 97% of water supply from groundwater

Saltwater Intrusion and Groundwater Pricing

PVWMA charges volumetric prices for agricultural groundwater

- Typically unpriced, with price= energy extraction costs

To address increased salinity from saltwater intrusion

- Abuts Pacific coast
- Extraction led to declining water table
- Implication: parts of water district below sea level

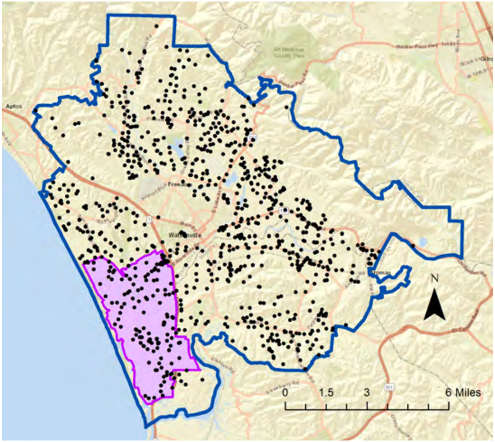
Revenues raised partly fund recycled water supplies

Assignment Mechanism: The Delivered Water Zone

Limited quantity of recycled water available

Allocation through establishment of two water zones

Only farms inside Delivered Water Zone get access



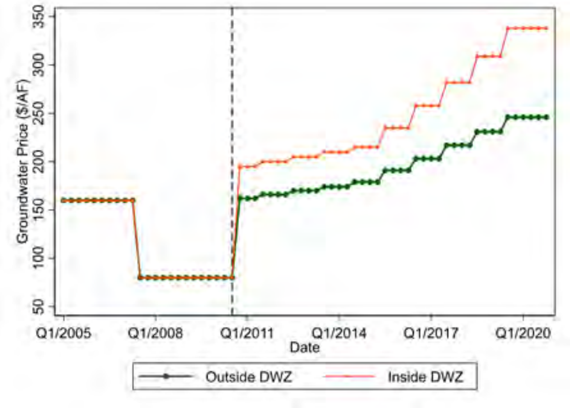
Water Prices and Price Split

1994: volumetric price per acre-foot groundwater introduced

- All agricultural users pay same rate

October 2010: price split and price increase

- 21% price increase inside zone relative to outside



Prices and Proposition 218

CA Prop 218: local gov't must get tax payer approval for

- property-related fees and
- taxes charged reflect proportionate service received

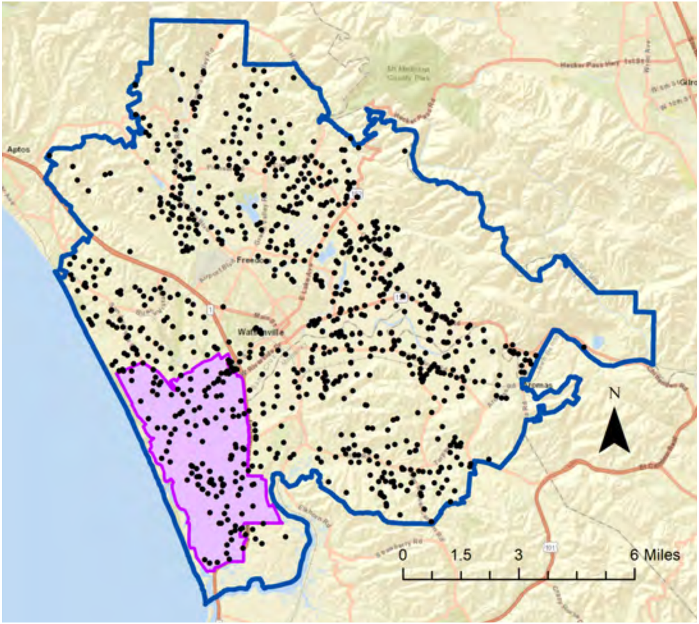
Griffith v. PVWMA: charging single price violates Prop 218

- Only those inside zone benefit from recycled deliveries

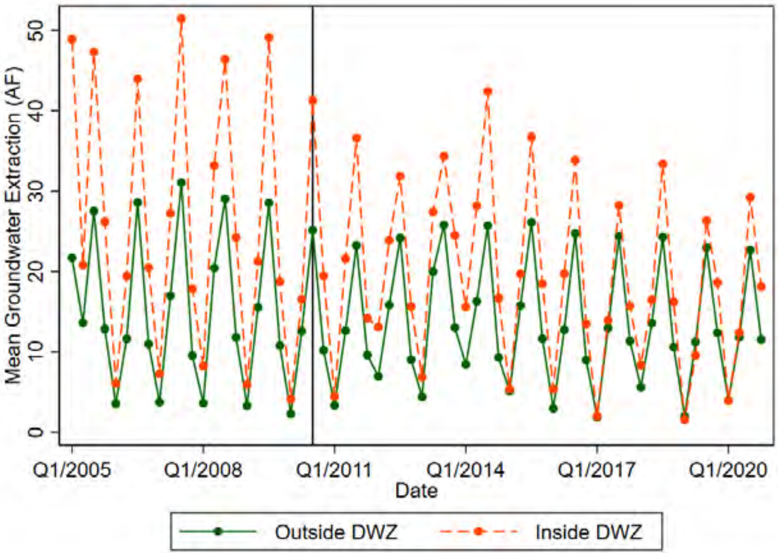
Griffith wins, and two prices based on delivered zone boundaries

- Established via rate-setting process compliant with 218
- Outside zone also benefits from recycled deliveries

Data: Geocoded Agricultural Production Wells

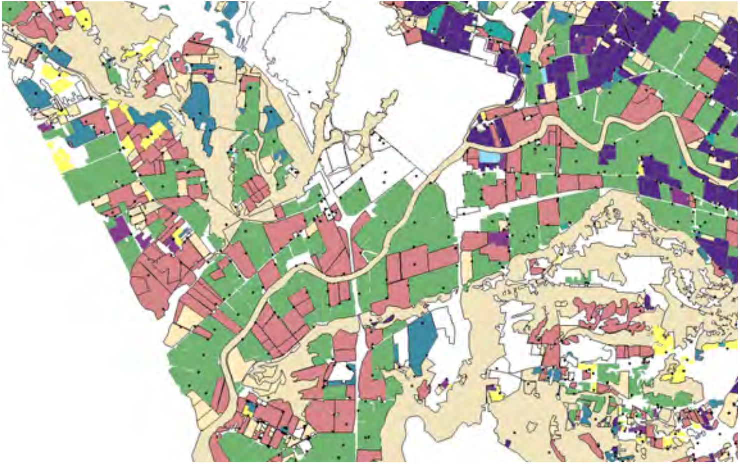


Data: Quarterly Well-level Extraction



Data: Annual Land Use Data 2009, 2011-2017

- Crop composition Crop by Zone
- Irrigated acreage
- Agricultural land (including fallowed acres)



Difference in Differences Framework

Two farm types: $r \in O, I$

- Farms located inside (I) or outside zone (O)
- Highway 1 is one boundary but other factors

Two time periods: $p \in 0, 1$

- $p = 0$: pre-October 2010, all farms same price
- $p = 1$: October 2010 onwards, post price split
- 21% price increase inside relative to outside the zone

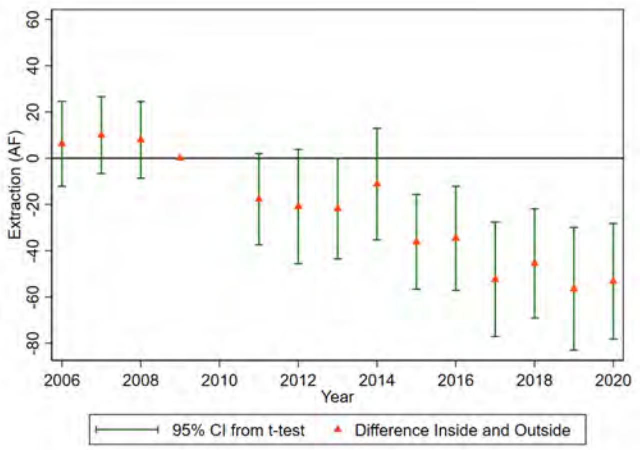
$$Y_{it} = \alpha_r + \gamma_p + \beta T_{rp} + \epsilon_{it}$$

$$\beta = [E(Y_{it}|r = I, p = 1) - E(Y_{it}|r = I, p = 0)] - \\ [E(Y_{it}|r = O, p = 1) - E(Y_{it}|r = O, p = 0)]$$

Identification

Assumption: absent split, differences in land and water use fixed across regions

Indirect evidence: event study framework (annual use)



Estimation

$$y_{irt} = \alpha_i + \gamma_t + \delta Inside * Post_{it} + \omega' X_{rt} + \epsilon_{irt}$$

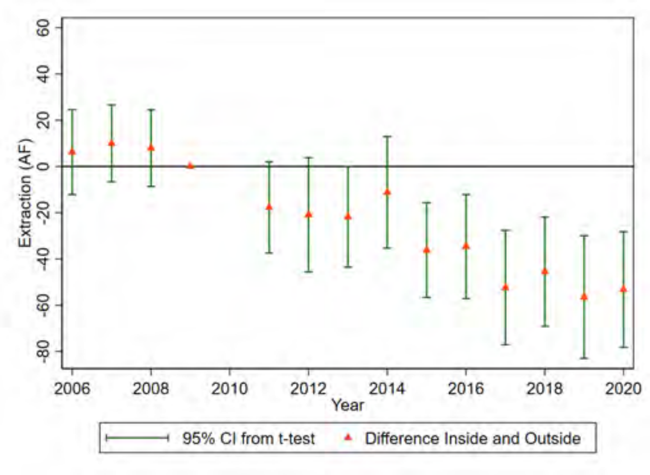
- y_{irt}: extraction or acreage for farm i of zone r in time t
- *Inside*: set equal to 1 if farm i located inside DWZ
- *Post*: set equal to 1 after October 2010 (Q4)
- α_i, γ_t: farm and year fixed effects

  X_{rt}: recycled deliveries, salinity, water table depth, ag land values

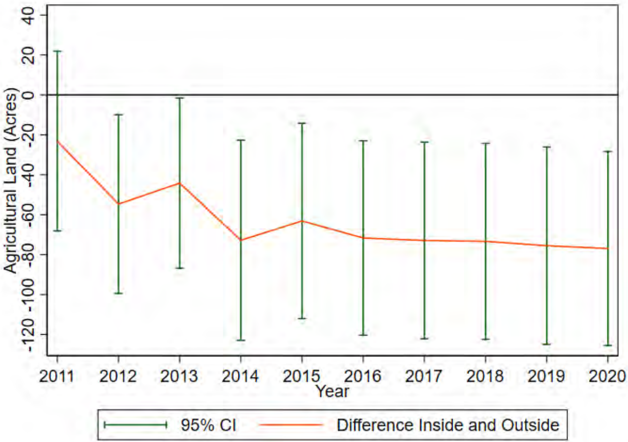
Effect of Price Split on Average Water Use

	Groundwater Extraction (AF)					
	(1)	(2)	(3)	(4)	(5)	(6)
Inside×Post	-40.70***	-42.71***	-42.69***	-41.63***	-37.70***	-36.76***
	(11.60)	(11.60)	(11.61)	(11.33)	(10.20)	(9.92)
Post-2010	-5.68***	-5.49***				
	(1.37)	(1.39)				
Inside	24.44					
	(37.88)					
Constant	67.57***	70.35***	64.73***	61.16***	69.25***	62.96***
	(5.38)	(1.28)	(1.58)	(1.87)	(1.67)	(1.93)
Mean	129.3	129.3	129.3	129.3	122.8	122.8
Observations	8,736	8,736	8,736	8,736	6,864	6,864
Parcel FE		✓	✓	✓	✓	✓
Year FE			✓		✓	
Cty-Yr FE				✓		✓

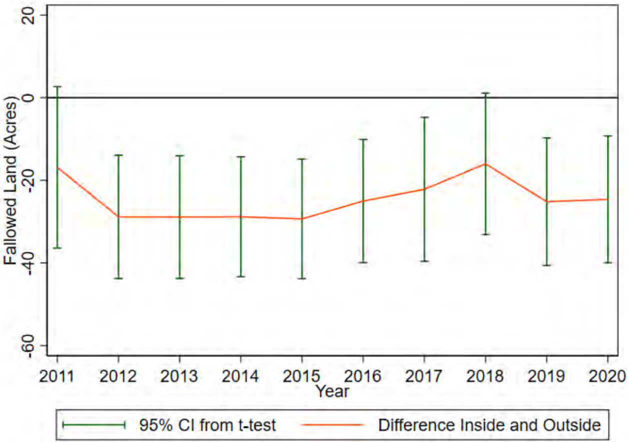
Effect of Price Split on Water Use over Time



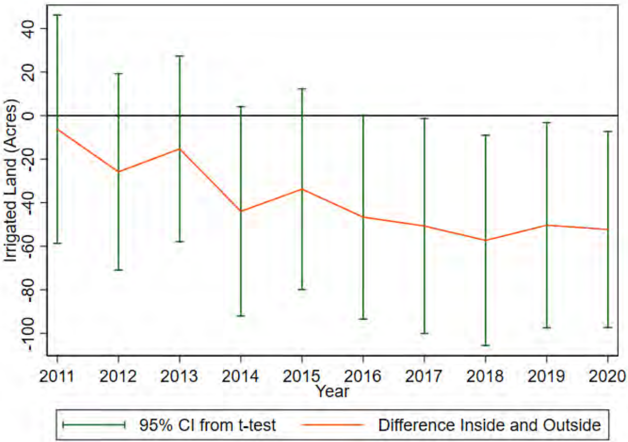
It Takes Time to Retire Agricultural Land



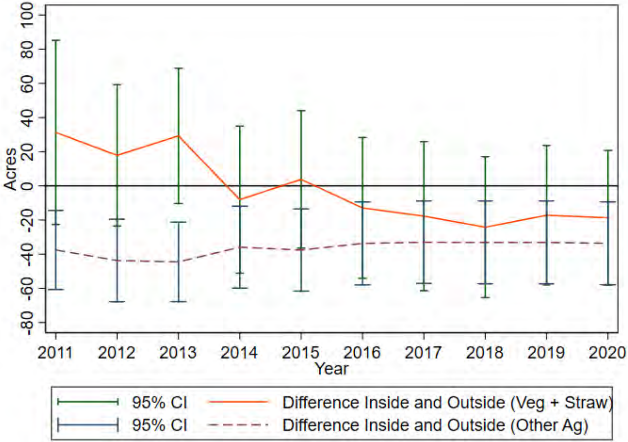
Fallowed Land Moved Out of Agriculture



Growing Reduction in Irrigated Acreage



Reduction in Acreage of Lower Value Crops



What Have We Learned

Permanent and large price increase impacts agriculture

- Reduction in water use
- Conversion of temporarily fallowed land out of agriculture
- Reduction in irrigated acreage of lower value crops

Margins of adjustment occur in longer run

- Doubling reduction in input use
- No reduction in agricultural acreage in year 1

Price change only occurred in one district

- leakage, price effects, location

Thank You!

Questions/comments: kkjessoe@ucdavis.edu

CLIMATE ADAPTATION
RESEARCH SYMPOSIUM

MEASURING & REDUCING SOCIETAL IMPACTS

Thanks for tuning in!

UCLA Luskin Center for Innovation