Run On The Reservoir: Evidence on Administrative Competition for Groundwater in India

UCSD-World Bank Workshop on Climate Adaptation

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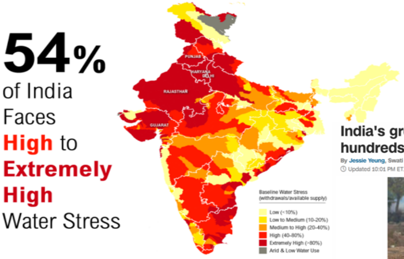
Introduction

Groundwater aquifers are predicted to run dry by the 2050s in parts of the United States, southern Europe, and India (de Graaf et al., 2019)

Depletion Levels



Research Question

Administrative borders impose spillovers on common-pool resources

(Mobarak and Lipscomb (2016), Sigman (2002, 2005); Hatfield and Kosec (2013), Helland and Whitford (2003); Balboni, et al. (2020), Naylor et al. (2019), Burgess et al. (2012); Leonard and Parker (2021); Sears et al (2021), Ayres, Meng, and Plantiga (2019))

Long-standing work has differed on the role of government in managing common resources

(Importance of government regulation (Hardin, 1968), Support community-regulation (Ostrom, 1990), Adapt to scarcity (Demsetz, 1967))

How do governments respond to the Tragedy of the Commons?

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- do decentralized local administrations ameliorate the problem?
  (Oates and Schwab 1988)

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  (Oates 1999)

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- do decentralized local administrations ameliorate the problem?
  (Oates and Schwab 1988)
  - $\times$
- do decentralized local administrations exacerbate the problem?
  (Oates 1999)
  - $\checkmark$: when externalities and competition are high

Empirical Roadmap

When districts in India compete for groundwater:

1. **... How does it affect the groundwater resource?**
   - **Agricultural decisions**: Reliance on irrigation sources, Investments in water extraction, Agricultural decisions like cropping areas
   - **Long-term Resource Health**: Well water levels

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   - **District's Budgetary Allocations**: Rural credit, Farm mechanization
   - **Adaptation at the Village-level**: Collective action in a public-infrastructure program

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→ **Empirical Methodology:** Difference-in-differences using variation in the competition for groundwater and physical characteristics of aquifers.

- Geological features that facilitate externalities

Role of Districts in Agriculture

1. Green Revolution-era: Agricultural cropping and irrigation largely planned; **subsidies implemented through districts**
2. **Agricultural credit channelled through districts** by India's central bank Details
   - Including: crop-specific credit, credit for tubewells/borewells
3. **Districts** undertake distribution of seed varieties, agricultural extension services, investments in infrastructure to support cropping and irrigation Plan

Districts influence farmer's decisions on water-use through policy levers

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Natural Resource Boundary

Sub-basins: A network of streams and aquifers that are separated by continuous ridgelines which restrict the flow of water.

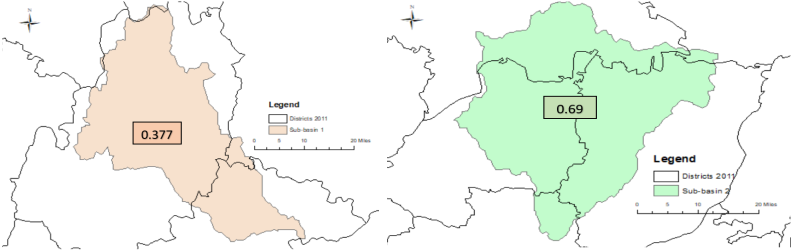
Figure: Sub-basin Illustration

Aquifers within a sub-basin are more connected than across by virtue of the geography.

Measuring Competition

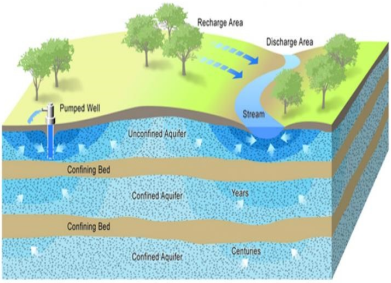
Districts share a *sub-basin* equitably $\implies \uparrow$ competition for groundwater

- **Inverse Herfindahl-Hirschman or Fractionalization index** $(\text{I-HHI})_s$: $1 - \sum_{i \in s} s_i^2$, where s_i is the share of overlap of *districts i* on the *sub-basin s*



Natural Resource Type

Permeability of the water bearing layer determines the ease with which water flows underground



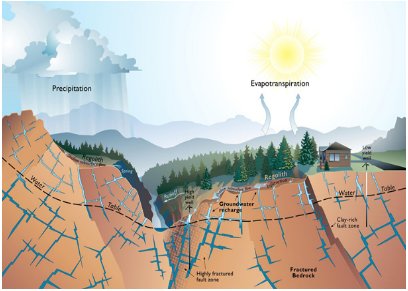


Figure: Permeable Aquifer system versus Non-Permeable Aquifer System

When districts share a sub-basin, **permeability intensifies externalities** $\implies \uparrow$ competition for groundwater

Empirics: Framework

Setting: Cross-sectional variation in how districts share a resource

$\rightarrow$ **variation in permeability is key for identification.**

- Less competition, no permeability $\sim$ Social Planner

- More competition, permeability $\Longrightarrow$ Competitive Administrations

Comparative Stats

Empirics: Framework

Setting: Cross-sectional variation in how districts share a resource

$\rightarrow$ **variation in permeability is key for identification.**

- Less competition, no permeability $\sim$ Social Planner
- More competition, no permeability $\implies$ Not competitive
- Less competition, permeability $\implies$ Not competitive
- More competition, permeability $\implies$ Competitive Administrations

Comparative Stats

$\Rightarrow$ Difference-in-Differences: Competition X Permeability

Maps

Empirics: Difference-in-Difference

$$y_{dbst} = \alpha + \beta_1 Comp_b + \beta_2 Perm_{db} + \underbrace{\beta_3 Comp_b * Perm_{db}}_{\text{Administrative Competition}} + \mu_1 \mathbb{X}_d + \mu_2 \mathbb{X}_{dt} + \delta_{db} + \delta_{db} * Perm_{db} + \gamma_{st} + \epsilon_{dbst} \quad (1)$$

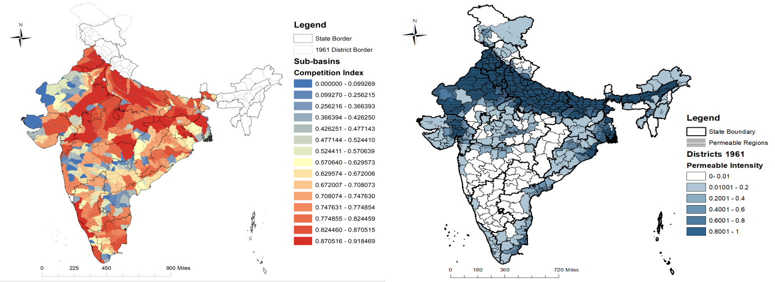
where, d = district, b = sub-basin, s = state, t = year

- $Comp_s$: Inverse Herfindahl-Hirschman index (I-HHI) or Fractionalization
- $Perm_{db}$: dummy variable if district $\cap$ sub-basin is permeable
- $Comp_b * Perm_{db}$: Coefficient (β_3) of interest
- $\mathbb{X}_d$: 1961 log population, fraction rural, fraction literate, caste composition, fraction agricultural, log mean elevation, log distance to coast, predicted dam upstream, dummies for predominant soil type
- $\mathbb{X}_{dt}$: monthly rainfall, monthly temperature
- δ_{db}: Sub-basin area quintile $\times$ district area quintile FE; γ_{st}: State $\times$ Year FE

Weights: share of overlap between district and sub-basin, Clustering: Two-way, by district and sub-basin

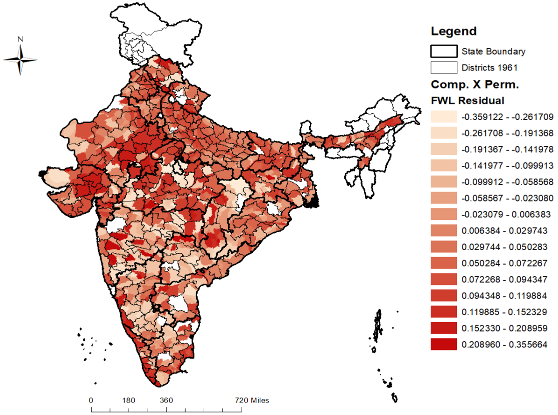
Competition for Groundwater

Figure: Heat map of Competition and Distribution of Permeability in Districts



Competition for Groundwater

Figure: Spatial Variation in Competition × Permeability



Note: This is a heat map of the Frisch-Waugh-Lovell Residuals.

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How does administrative competition affect resource use?

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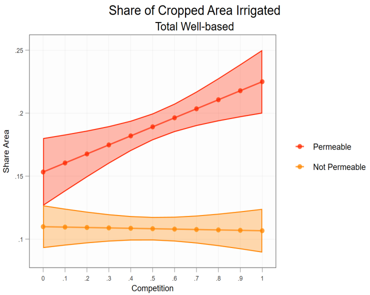

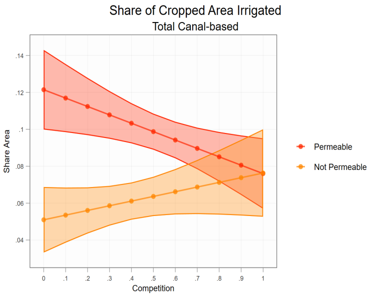

Outcomes Data Source: ICRISAT-TCI Panel

Results I

Competition for groundwater leads to the Tragedy of the Commons.

1. $\uparrow$ extractive agricultural practices
   $\rightarrow$ irrigation and cropping patterns

   Irri Source | Areas | District Splits | Tech

2. $\downarrow$ long term health of the resource
   $\rightarrow$ well water-levels, defunct wells

   Wells

What role does the administration play in influencing farmer's decisions as well as community decisions?

Results II

Administrations largely exacerbate negative externalities

1. $\uparrow$ budgetary allocations escalate extractive practices Credit
   $\rightarrow$ rural credit, farm infrastructure expenditures

2. $\downarrow$ in adaptation investments towards restoring groundwater NREGA
   $\rightarrow$ take-up of groundwater rehabilitation projects under NREGA

Robustness

1. Pre-green Revolution Outcomes and Demographics Balance Demog Agri
2. Environmental Descriptives Balance Rain and Temp Suit
3. Interaction coefficient is significant 7-11% of the times under the zero null where permeability is spuriously allocated Graph
   - Randomization inference adjusted t-stats Table
4. Results hold after dropping original Green Revolution Districts
5. Alternate specifications: District splits specification

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Discussion

Government's fail to price out externalities through Pigouvian taxation or Coasian bargaining $\implies$ worsening scarcity, inhibiting adaptation

1. **Spillovers from surface water**: Effects persist even in areas without historic/contemporary canal access Table
2. **High transaction costs**: No inter-district communication or negotiation based on qualitative survey of 20 officers across the country
3. **Lack of monitoring from States, Politics**: State governments cannot effectively monitor in the presence of contradictory policies that empower decentralized actors to extract water; Misaligned political incentives such that close elections $\implies$ more extraction (Mahadevan and Shenoy, 2022; Sekhri and Nagavarapu, 2022; Tarquininio, 2022)
4. **Bureaucratic Turnover**: Average term of "District Collector" is 1.5-2 years $\implies$ Short time horizons

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Conclusion

1. Human X Natural factors affect the depletion and movement of groundwater $\rightarrow$ our variation combines both to find...
    - Administrations enable the competition for groundwater which adversely affects the efficiency of resource-use

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2. Resource conservation investments affected
   - Substantial funds channelled towards groundwater conservation: World Bank alone spends 12 Billion USD in India

Conclusion

1. Human X Natural factors affect the depletion and movement of groundwater $\rightarrow$ our variation combines both to find...
    - Administrations enable the competition for groundwater which adversely affects the efficiency of resource-use

2. Resource conservation investments affected
    - Substantial funds channelled towards groundwater conservation: World Bank alone spends 12 Billion USD in India

3. The failure to adapt to scarcity could be for a number of reasons
    - Importance of policy interventions

Example

Thank you!

Introduction

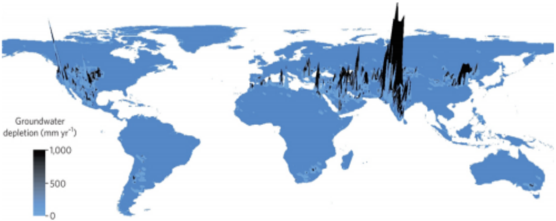

Figure: Global groundwater depletion (Aeshbach-Hertig 2012)

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Data: Maps

1. **District Boundary Maps**: Census data, 1961 onwards Map
2. **Water-resource Boundary maps**: Sub-Basins (World Resource Institute) Map
    - Competition for a resource = equitable overlap by multiple districts
3. **Aquifer System Hydrogeology**: Central Groundwater Board Map
    - Determines externalities from extraction across district boundaries

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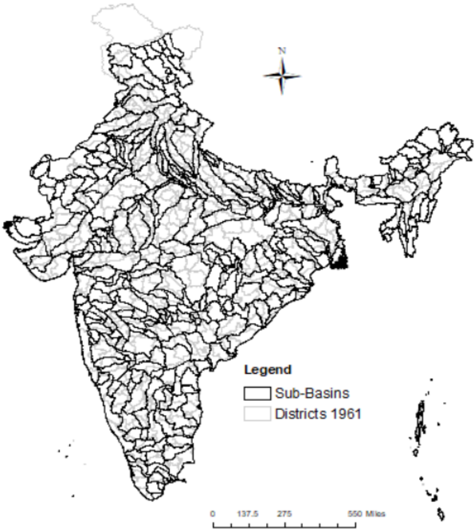
Sub-basins and Districts



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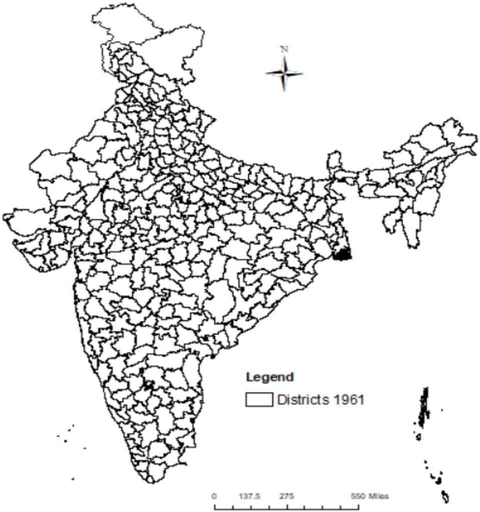
Districts 1961



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Empirics

$$y = \beta_1 Comp + \beta_2 Perm + \beta_3 Comp * Perm + \epsilon$$

$$E[\epsilon | Comp] = 0, \quad E[Comp, Perm] \neq 0$$

$$\frac{\tilde{E}[Comp * Perm * y]}{\tilde{E}[Comp^2 * Perm]} = \beta_3$$

Now, let:

$$Perm = \pi Comp + \nu \implies y = \beta_1 Comp + \beta_2 \pi Comp + \beta_2 \nu$$

$$+\beta_3 \pi Comp^2 + \beta_3 Comp * \nu + \epsilon$$

Empirics

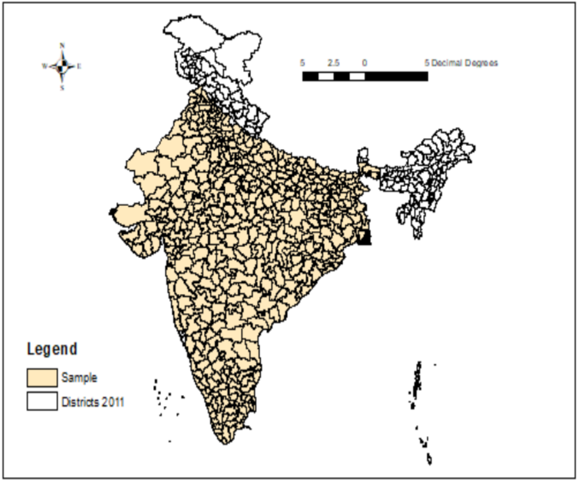
Conditional on $Perm = 1, \quad \nu = 1 - \pi Comp,$

$$E[y|Perm = 1] = \beta_1 Comp + \cancel{\beta_2 \pi Comp} + \beta_2 - \cancel{\beta_2 \pi Comp}$$

$$+\cancel{\beta_3 \pi Comp^2} + \beta_3 Comp - \cancel{\beta_3 \pi Comp^2} + \epsilon$$

$$\beta_3 = \frac{\tilde{E}[Comp * y|Perm = 1] * P(Perm = 1)}{\tilde{E}[Comp * Comp|Perm = 1] * P(Perm = 1)}$$

Sample



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Randomization Inference: T-stats

	P-Values
Share of Area Cropped Irrigated by	
Tubewells	.004
Total Wells	0
Dugwells	.003
Canals	.012
Crop Choice	
Wheat	0
Sugarcane	.016
Cropping Area	
Wheat	.014
Sugarcane	0

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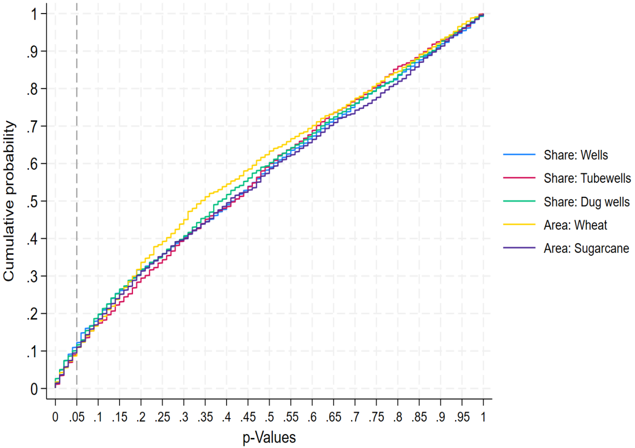
Randomization Inference Distribution of Effects



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District Crop Planning Example

Sr. No.	Department	Name of Scheme	Provision (Rs. Lakhs)					
			2012-13	2013-14	2014-15	2015-16	2016-17	Total
1	Agriculture	Dry land Farming Mission	29.86	477	127	260	315	**1208.86**
		Rainfed Agriculture Development Programme	22.71	95.4	359	600	720	**1797.11**
		Organic Farming	0	0	0	10	10	**20**
		Accelerated Fodder Development Programme	589	100	216	282	330	**1517**
		NFSM Cotton Development Programme	17.77	6.84	51	70	140	**285.61**
		NFSM Coarse Cereal Development Programme	40.6	17.28	274	72	108	**511.88**
		NFSM Oilseed Development Programme	0	227.8	0	40.5	63	**331.3**
		NFSM Pulse Development Programme	0	228	657.41	542	675	**2102.41**
		NFSM Sugarcane Development Programme	0	40	32	0	0	**72**
		NFSM APPP	0	354.09	0	0	0	**354.09**
		RKVY Sugarcane Development Programme	21.36	0	0	51	87	**159.36**
		RKVY Accelerated Fodder Development Programme	58.98	0	0	160	256	**474.98**
		RKVY Cotton Development Programme	68.82	22	50.52	27	40.5	**208.84**
		National Oilseed development Programme	0	0	0	20	36	**56**
		PPP (Cotton, Maize, Soybean)	48.26	275.1	323	367.5	551.25	**1565.11**
		Agri Polyclinic	0	0	0	18	18	**36**
		Strengthening of Nursery	0	0	0	30	30	**60**
		CROPSAP	41.73	24.26	27.6	35	45	**173.59**
		Agriculture Exhibition	0	0	0	6	6	**12**
		Soil Health Card	0	0	0	22.5	45	**67.5**
		HRD Training	0	17.51	0	3	15	**35.51**
		Exposure Visit	0	0	0	14	14	**28**
		Farm Mechanization Sub Mission	0	0	0	90	90	**180**
		SCP and OTSP	0	0	0	400	500	**900**
		Total	**939.09**	**1885.3**	**2117.5**	**3120.5**	**4094.8**	**12157.15**

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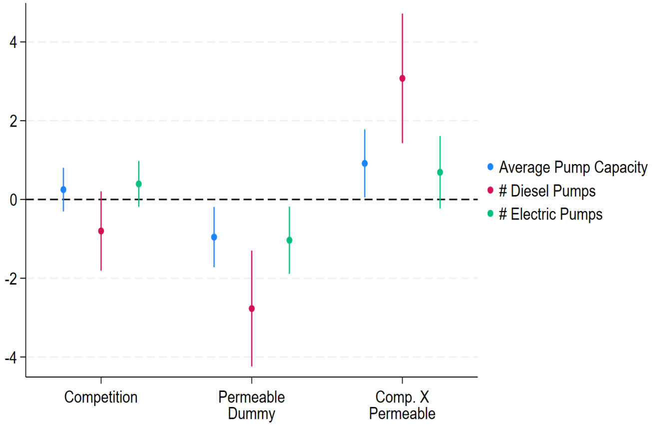
Irrigation Capacity and Technology



Data: Minor Irrigation Census Rounds 5 (2014). Outcomes are adjusted as per Chen and Roth (2023).

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Areas Irrigated by Source

	Share of Area Cropped					
	Surface Water		Groundwater		Tubewells	
	(1)	(2)	(3)	(4)	(5)	(6)
Comp. X Perm.	-0.10**	-0.09**	0.12***	0.10***	0.05**	0.06**
	(0.04)	(0.04)	(0.03)	(0.03)	(0.03)	(0.02)
Permeable	0.10***	0.09***	-0.06**	-0.07**	-0.02	-0.01
	(0.02)	(0.03)	(0.03)	(0.03)	(0.02)	(0.02)
Competition	0.07*	0.05	-0.01	-0.02	-0.00	-0.01
	(0.04)	(0.03)	(0.03)	(0.02)	(0.02)	(0.02)
Sample Mean	.08	.08	.21	.21	.16	.16
Permeability at 25^{th}%ile Comp.	.07***	.06**	-.03	-.04*	0	.01
	(.02)	(.03)	(.02)	(.02)	(.01)	(.01)
Δ Comp over the IQR	-.04**	-.03**	.05***	.04***	.02**	.02**
	(.01)	(.01)	(.01)	(.01)	(.01)	(.01)
Controls		Y		Y		Y
Obs	28889	28889	28893	28893	28897	28897

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Areas Irrigated by Source, District Splits

	Share of Area Cropped					
	Surface Water		Groundwater		Tubewells	
	(1)	(2)	(3)	(4)	(5)	(6)
Comp. X Perm.	-0.10***	-0.16***	0.09***	0.15***	0.11***	0.18***
	(0.04)	(0.06)	(0.03)	(0.05)	(0.04)	(0.06)
Permeable	0.01**		-0.01**		-0.02**	
	(0.01)		(0.01)		(0.01)	
Competition	0.02	0.03	0.01	0.00	0.01	-0.00
	(0.03)	(0.03)	(0.03)	(0.03)	(0.04)	(0.03)
Sample Mean	.07	.07	.13	.13	.08	.08
Permeability at 25^{th}%ile Comp.	.03**	.03***	-.03***	-.02***	-.04***	-.03***
	(.01)	(.01)	(.01)	(.01)	(.01)	(.01)
Δ Comp over the IQR	-.03***	-.06***	.03***	.05***	.04***	.07***
	(.01)	(.02)	(.01)	(.02)	(.01)	(.02)
Basin X District FE		Y		Y		Y
Obs	57401	57401	57401	57401	57401	57401

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Areas Irrigated by Source, by Canal Access

	Share of Area Cropped			
	Surface Water		Groundwater	
	1966 Access	Command Area Access	1966 Access	Command Area Access
	(1)	(2)	(3)	(4)
Comp. X Perm. (β_3)	-0.12***	-0.11**	0.11***	0.10**
	(0.04)	(0.05)	(0.04)	(0.04)
Permeable (β_2)	0.10***	0.12***	-0.09***	-0.11***
	(0.03)	(0.04)	(0.03)	(0.04)
Competition (β_1)	0.05*	0.06	-0.03	-0.00
	(0.03)	(0.04)	(0.02)	(0.03)
Canal Access	0.10***	0.04*	-0.04*	-0.01
	(0.03)	(0.02)	(0.03)	(0.02)
Canal Access X Comp.	-0.02	-0.01	0.02	-0.02
	(0.03)	(0.03)	(0.03)	(0.03)
Canal Access X Perm.	-0.02	-0.04	0.03	0.03
	(0.03)	(0.03)	(0.03)	(0.03)
Canal Access X Comp. X Perm.	0.06	0.03	-0.02	0.01
	(0.04)	(0.04)	(0.05)	(0.04)
Sample Mean	.08	.08	.21	.21
Controls	Y	Y	Y	Y
Obs	28889	28889	28893	28893

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Crop Suitability (FAO)

	Log(Suitability Index)					
	Wheat (1)	Sugarcane (2)	Rice (3)	Millets (4)	Maize (5)	Pulses (6)
Comp. X Perm. (β_3)	0.01	0.01	-0.01	0.02*	0.04**	0.01
	(0.02)	(0.03)	(0.01)	(0.01)	(0.02)	(0.01)
Permeable (β_2)	-0.01	0.02	0.00	-0.01	-0.01	0.00
	(0.01)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)
Competition (β_1)	0.01	0.03	0.01	-0.00	-0.01	0.01
	(0.02)	(0.02)	(0.01)	(0.01)	(0.02)	(0.01)
Sample Mean	.25	.4	.2	.22	.3	.14
Mean Competition	.49	.49	.49	.49	.49	.49
Controls	Y	Y	Y	Y	Y	Y
Obs	1994	1994	1994	1994	1994	1994

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Cropping Areas

	Share of Area Cropped				Log Area with Calibrated EMV			
	Wet-season		Dry-season		Wheat		Sugarcane	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Comp. X Perm.	-0.04	-0.08*	0.21***	0.16***	1.90**	0.43	2.44**	1.37**
	(0.08)	(0.04)	(0.06)	(0.05)	(0.76)	(0.37)	(0.95)	(0.55)
Permeable	-0.04	0.05	-0.11**	-0.18***	-1.94***	-0.22	-1.67*	-0.81
	(0.06)	(0.05)	(0.05)	(0.05)	(0.69)	(0.44)	(0.85)	(0.73)
Competition	0.07	0.05	-0.09*	-0.08**	-0.62	-0.57**	-0.48	-0.06
	(0.06)	(0.03)	(0.05)	(0.04)	(0.53)	(0.28)	(0.70)	(0.40)
Sample Mean	.41	.41	.41	.41	58.25	6.53	9.31	3.96
Permeability at 25^{th}%ile Comp.	-.05	.03	-.05	-.13***	-1.38***	-.09	-.95	-.41
	(.04)	(.05)	(.04)	(.05)	(.5)	(.4)	(.62)	(.69)
Δ Comp over the IQR	-.01	-.03*	.08***	.06***	.71**	.16	.92**	.52**
	(.03)	(.02)	(.02)	(.02)	(.28)	(.14)	(.36)	(.21)
Controls		Y		Y		Y		Y
Obs	33924	33924	33924	33924	33924	33924	33924	33924

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Well Health

	Dry-season (February)		Summer season (May)		Probability Defunct		Share of Life Defunct	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Comp. X Perm.	-0.10**	-0.07*	-0.04	-0.02	0.17*	0.17*	0.21*	0.21*
	(0.04)	(0.04)	(0.04)	(0.03)	(0.09)	(0.09)	(0.12)	(0.12)
Permeable	0.08*	0.05	0.04	0.00	-0.13*	-0.13*	-0.21**	-0.21**
	(0.04)	(0.03)	(0.03)	(0.03)	(0.07)	(0.07)	(0.10)	(0.10)
Competition	0.04	0.02	0.01	-0.00	-0.07	-0.07	-0.06	-0.06
	(0.04)	(0.03)	(0.03)	(0.02)	(0.09)	(0.09)	(0.11)	(0.11)
Sample Mean	.26	.26	.19	.19	.27	.27	.36	.36
Permeability at 25^{th}%ile Comp.	.05	.02	.02	0	-.07	-.07	-.14**	-.14**
	(.03)	(.02)	(.02)	(.02)	(.05)	(.05)	(.07)	(.07)
Δ Comp over the IQR	-.03**	-.02*	-.02	-.01	.05*	.05*	.06*	.06*
	(.02)	(.01)	(.01)	(.01)	(.03)	(.03)	(.03)	(.03)
Controls		Y		Y		Y		Y
Obs	263847	263847	263847	263847	15495	15495	15495	15495

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Citizen-led Public Infrastructure Investments

	Take-up		Share of Total Projects			
	No Take-up (1)	Projects (2)	Ground-water (3)	Surface Water (4)	Ind Assets (5)	Rural Infra (6)
Comp. X Perm.	0.13***	-1.30***	-0.02**	-0.00	0.01	0.03
	(0.05)	(0.33)	(0.01)	(0.01)	(0.03)	(0.04)
Permeable	-0.08*	1.08***	0.04***	-0.02	-0.00	-0.06
	(0.05)	(0.38)	(0.01)	(0.01)	(0.03)	(0.04)
Competition	-0.08**	0.51**	0.01**	0.00	-0.01	0.03
	(0.03)	(0.23)	(0.01)	(0.01)	(0.02)	(0.02)
Sample Mean	.08	2095.85	.01	.01	.07	.41
Permeability at 25^{th}%ile Comp.	-.04	.61**	.03***	-.02	0	-.05
	(.04)	(.31)	(.01)	(.01)	(.03)	(.03)
Δ Comp over the IQR	.04***	-.41***	-.01**	0	0	.01
	(.01)	(.1)	(0)	(0)	(.01)	(.01)
Controls	Y	Y	Y	Y	Y	Y
Obs	14928	14928	13778	13778	13778	13778

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District Expenditure

	Credit: Per Area Sown				RKVY Expenditure			
	Total (Win)		Agri. (Win)		Total	Water	Diversif -ication	Farm Mechan.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Comp. X Perm.	0.45**	0.36	0.32**	0.28	0.20	0.63**	-0.20	0.67**
	(0.19)	(0.27)	(0.14)	(0.17)	(0.42)	(0.30)	(0.18)	(0.34)
Permeable	-0.24*	-0.12	-0.09	-0.17	0.26	-0.28	0.17	-0.15
	(0.13)	(0.20)	(0.10)	(0.17)	(0.42)	(0.30)	(0.15)	(0.33)
Competition	0.09	0.21	0.12	0.15	-0.36	-0.50*	0.10	-0.70**
	(0.17)	(0.20)	(0.13)	(0.14)	(0.38)	(0.27)	(0.16)	(0.30)
Sample Mean	18.45	18.45	2.94	2.94	3.41	.64	.33	1.59
Permeability at 25^{th}%ile Comp.	-.1	-.02	.01	-.09	.35	-.01	.08	.14
	(.1)	(.17)	(.07)	(.14)	(.46)	(.34)	(.15)	(.34)
Δ Comp over the IQR	.17**	.13	.12**	.1	.05	.14**	-.04	.15**
	(.07)	(.1)	(.05)	(.06)	(.09)	(.07)	(.04)	(.08)
Controls	Y	Y	Y	Y	Y	Y	Y	Y
Area FE X Perm.		Y		Y	Y	Y	Y	Y
Obs	25871	25871	25871	25871	5638	5638	5638	5638

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Environmental Variables

	Rain			Temperature			Obs.
	Comp. X Perm. (β_3)	Perm. Dummy (β_2)	Comp. (β_1)	Comp. X Perm. (β_3)	Perm. Dummy (β_2)	Comp. (β_1)	N
	(1)	(2)	(3)	(4)	(5)		
January	-4.88* (2.90)	3.37 (2.24)	6.29*** (2.41)	-0.09 (2.90)	0.00 (2.24)	-0.72* (2.41)	33924
February	3.03 (3.80)	0.55 (2.60)	1.05 (1.69)	-0.18 (3.80)	0.03 (2.60)	-0.44 (1.69)	33924
March	4.80 (5.71)	-6.32* (3.64)	3.55 (3.10)	-0.43 (5.71)	0.23 (3.64)	-0.13 (3.10)	33924
April	0.11 (6.15)	-2.30 (4.46)	-0.52 (3.30)	-0.60 (6.15)	0.42 (4.46)	0.37 (3.30)	33924
May	4.77 (11.08)	-2.79 (7.97)	-7.05 (4.60)	-0.92 (11.08)	0.74 (7.97)	0.97 (4.60)	33924
June	-26.86 (34.42)	24.96 (31.32)	4.71 (16.79)	-0.48 (34.42)	0.68 (31.32)	0.76 (16.79)	33924
July	-59.02 (57.35)	51.52 (55.91)	34.32 (32.33)	0.27 (57.35)	0.15 (55.91)	0.10 (32.33)	33924
August	-37.16 (44.98)	24.26 (42.55)	28.52 (29.78)	0.35 (44.98)	0.03 (42.55)	0.06 (29.78)	33924
September	-11.10 (20.72)	2.48 (18.71)	4.02 (10.56)	0.02 (20.72)	0.30 (18.71)	0.20 (10.56)	33924
October	7.80 (12.13)	17.37 (17.22)	-11.29 (9.26)	-0.25 (12.13)	0.50* (17.22)	-0.02 (9.26)	33924
November	-2.57 (10.28)	33.70 (22.21)	-5.48 (6.70)	-0.25 (10.28)	0.39 (22.21)	-0.34 (6.70)	33924
December	-3.35 (3.48)	14.27* (7.47)	-0.57 (2.14)	-0.16 (3.48)	0.20 (7.47)	-0.64* (2.14)	33924

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Demographic Variables

	Competition X Permeability (β_3)	Permeability Dummy (β_2)	Competition Main Effect (β_1)	Sample Mean	N
	(1)	(2)	(3)	(4)	(5)
Panel C: Demographics 1961					
Dist. Area (1961)	-4.51*	13.08***	-5.86***	9.54	1391
Population	0.30	-0.48	-0.12	1428.83	1391
Pop. Density	12.11	-68.36**	8.65	183.04	1391
Fraction Rural	-0.03	-0.09	0.00	.84	1391
Fraction Literate	0.03	0.06*	-0.01	.21	1391
Fraction Sched. Caste	-0.00	0.05**	0.01	.15	1391
Fraction Sched. Tribe	0.02	-0.28***	-0.02	.09	1391
Fraction Agricultural	-0.00	0.01	0.01	.07	1391
Panel D: Analysis Sample					
Canal Access (1966)	-0.05	-0.01	0.09	.83	2170
Command Area Access (2015)	-0.08	0.04	0.00	.65	2170
Dist. Area	-0.13	-0.60	-1.32**	6.07	2170

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Agricultural Variables

	Competition X Permeability (β_3)	Permeability Dummy (β_2)	Competition Main Effect (β_1)	Sample Mean	N
	(1)	(2)	(3)	(4)	(5)
Panel A: Predominant Soil Type					
Red	-0.14	-1.06***	0.05	.15	1391
Deep Black	0.20	0.03	-0.02	.11	1391
Medium Black	0.26**	-0.17	-0.09	.15	1391
Red Black Mix	-0.22**	-0.75***	0.21**	.07	1391
Laterite	-0.07	-0.04	0.04	.08	1391
River Alluvial	0.21	0.03	-0.08	.44	1391
Coastal Alluvial	-0.03	0.09	0.01	.07	1391
Log pH	-0.03	0.09	0.08	6.88	1391
Panel B: Agricultural Outcomes, 1956-1965					
Share Sown	0.17**	-0.13	-0.13***	1.36	13910
Share Irrigated	0.03	0.07	0.02	.18	13910
Share Wheat	-0.01	0.05	0.01	.11	13910
Share Sugarcane	-0.00	-0.01*	0.00	.02	13910
Share Bajra	-0.02	0.12	-0.03	.06	13910
	-0.23	-1.39*	0.50*	2417.4	13910

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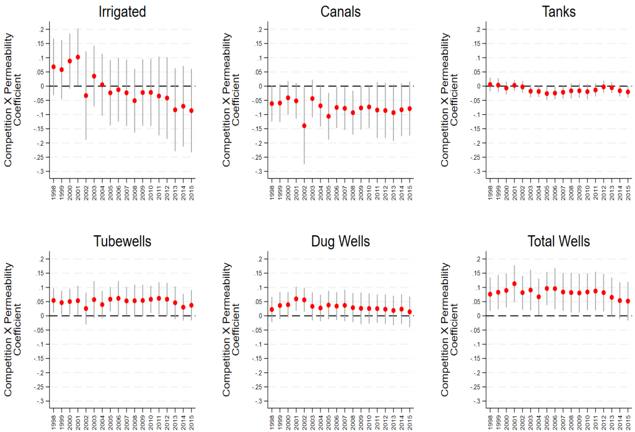
Area Irrigated by Source, Over Time



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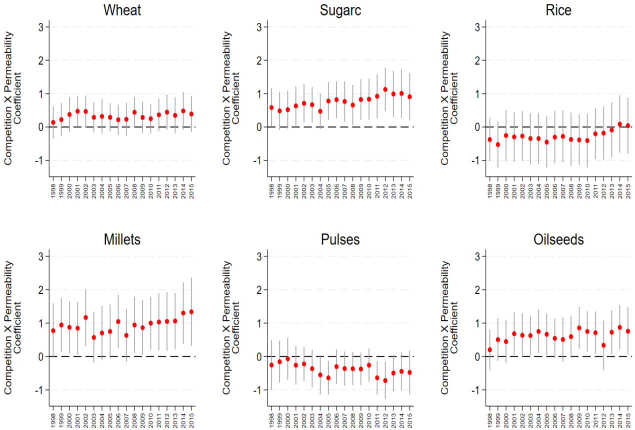
Cropping Areas, Over Time



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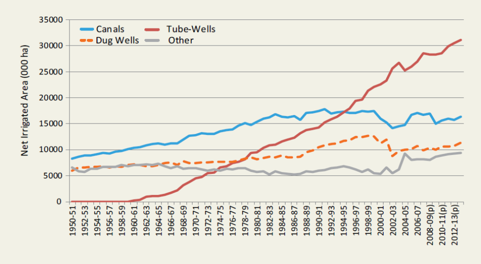
Green Revolution Era

"The adoption of the H.V.P. was facilitated by the **"Intensive Agricultural District Programme" (I.A.D.P.)***, which was built into the existing community development organisation." (Chakravarti 1973)*

"The Framework Action Plan, therefore, noted that the Seventh Plan's irrigation targets were not being met and provided for **detailed funds at the project/district level** *to achieve potential." (Alagh 1990)*



Source: (DES, MoA, 2016)

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Results

Agricultural Credit

*"...***credit plans decided at district level** *by NABARD. NABARD by virtue of its Financial, Developmental and Supervisory role is touching almost every aspect of rural economy,..."*

"...The cornerstone of agriculture credit is the Scale of Finance (SoF) **being fixed for every crop at the district level** *which forms the basis for determining the eligible credit for each crop and farmer."*

- National Bank for Rural Development Report

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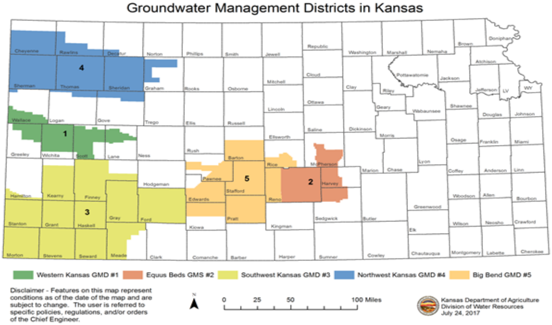
Kansas: Groundwater Districts

B. The basic requirement to form a local GMD is the existence of an aquifer system of sufficient size to support a district which is experiencing groundwater problems of a quantity or quality nature. If an area of the state demonstrates such a viable hydrologic community of interest, a local GMD can be formed upon local initiative only - the process is begun by local petition.



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Model: Tragedy of the Commons

2 districts (i, j), 1 resource with permeability in groundwater flow $\implies$ externalities from relative extraction

2 time periods: agricultural cycle and summer
$\rightarrow$ concave returns to water in both times periods $[R(w), \pi(W)]$
$\rightarrow$ convex costs for own extraction $[C(w)]$

Claim 1: Resource extraction is higher under a decentralized regime as opposed to a social planner

Say w_{i+j}^{SP} is extraction under a social planner's regime. Case 1

Say w_{i+j}^{Dec} is extraction under a decentralized regime where both districts have asymmetric access to the resource. Case 2

We see: $w_{i+j}^{SP} < w_{i+j}^{Dec}$

Compare

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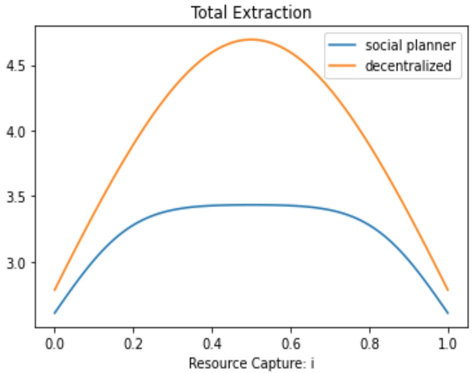
Model: Tragedy of the Commons

Claim 2: Is resource extraction higher when the resource-sharing is more competitive, but goes down as competition reduces.

Holding number of districts constant (at 2), comparative stats of w_i, w_j with α



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Case 1: Social Planner

Period 1 Stock: S^1, share α for i and $(1-\alpha)$ for j
Period 2 Stock: $S_i^2 = \alpha S^1 - w_i - k((1-\alpha)w_j - \alpha w_i)$

In equilibrium,

$$w_{i,j}^{SP} : \max_{w_i, w_j} \Big[R(w_i) + R(w_j) - C(w_i) - C(w_j) + \delta\pi\big[\alpha S^1 - w_i - k((1-\alpha)w_j - \alpha w_i)\big] + \delta\pi\big[\alpha S^1 - w_j - k(\alpha w_i - (1-\alpha)w_j)\big] \Big]$$

$$\implies w_i^{SP} : \Big[\frac{\partial R(w_i)}{\partial w_i} - \delta(1-\alpha k)\frac{\partial \pi}{\partial w_i}(S_i^2) - \delta(1-\alpha)k\frac{\partial \pi}{\partial w_i}(S_j^2)\Big] = \frac{\partial C(w_i)}{\partial w_i}$$

$$\text{and, } w_j^{SP} : \Big[\frac{\partial R(w_j)}{\partial w_j} - \delta(1-(1-\alpha)k)\frac{\partial \pi}{\partial w_j}(S_j^2) - \delta\alpha k\frac{\partial \pi}{\partial w_j}(S_i^2)\Big] = \frac{\partial C(w_j)}{\partial w_j} \quad (2)$$

Note here, $MR_{\{i,j\}}^{SP} = MC_{\{i,j\}}^{SP}$.

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Case 2: Decentralized Regime

In equilibrium, each district optimizes over their own returns and costs:

$$
\begin{aligned}
w_i^{Dec} &: \max_{w_i | w_j} \left[R(w_i) - C(w_i) + \delta\pi\left[\alpha S^1 - w_i(1-\alpha k) - k(1-alpha)w_j\right]\right] \\
\implies w_i^{Dec} &: \frac{\partial R(w_i)}{\partial w_i} - \delta(1-\alpha k)\frac{\partial \pi}{\partial w_i}(S_i^2) = \frac{\partial C(w_i)}{\partial w_i} \\
\text{and, } w_j^{Dec} &: \frac{\partial R(w_j)}{\partial w_j} - \delta(1-(1-\alpha)k)\frac{\partial \pi}{\partial w_j}(S_j^2) = \frac{\partial C(w_j)}{\partial w_j} \qquad (3)
\end{aligned}
$$

$MR_{\{i,j\}}^{Dec} = MC_{\{i,j\}}^{Dec}$.

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Compare Case 1 to Case 2

$MR^{Dec} > MR^{SP}$, as $\delta > 0$, $k \in (0,1]$, and $\frac{\partial \pi}{\partial w_j}\left(S_i^2\right) > 0$ implying there are uninternalized externalities.

The marginal cost function is unchanged $MC^{Dec} = MC^{SP}$.

Given, concave $R(.)$ and $\pi(.)$ function and increasing $C(.)$ function, holding cost constant, if w is such that $MR = MC$, then,

$$w_{i+j}^{Dec} > w_{i+j}^{SP}$$

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