WELL-FARE ECONOMICS OF GROUNDWATER DEVELOPMENT

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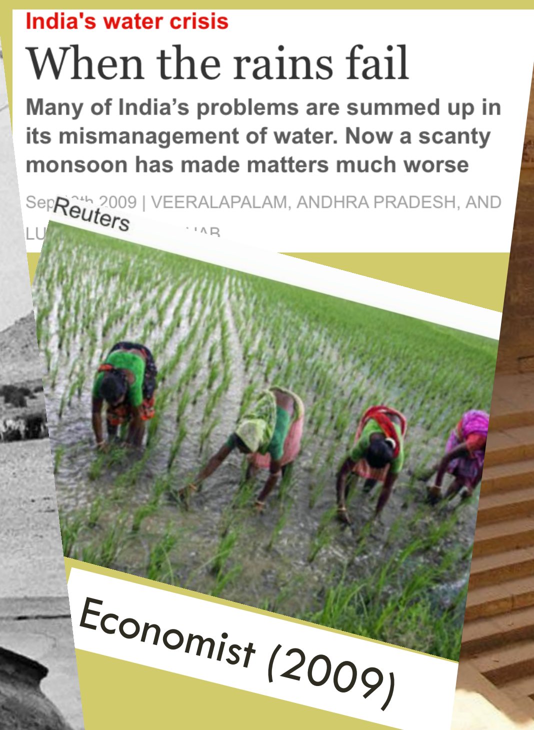
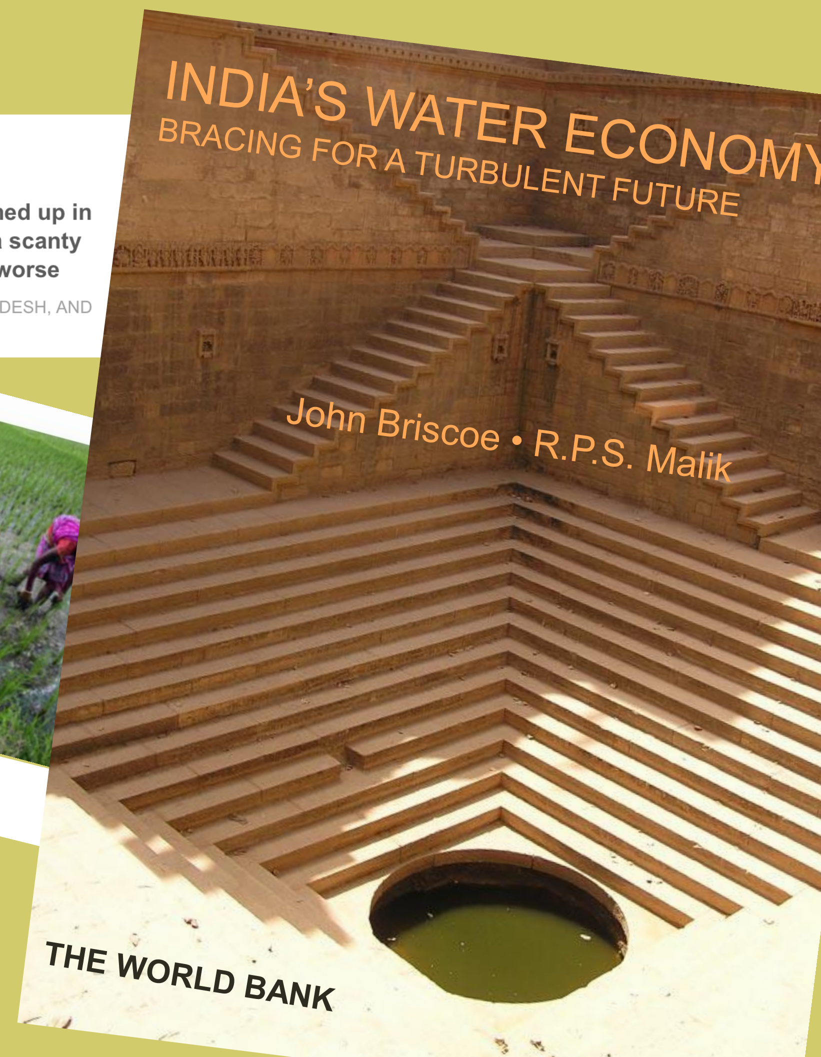
GROUNDWATER, A HIDDEN RESOURCE…

UNTIL NATURE REVEALS OTHERWISE

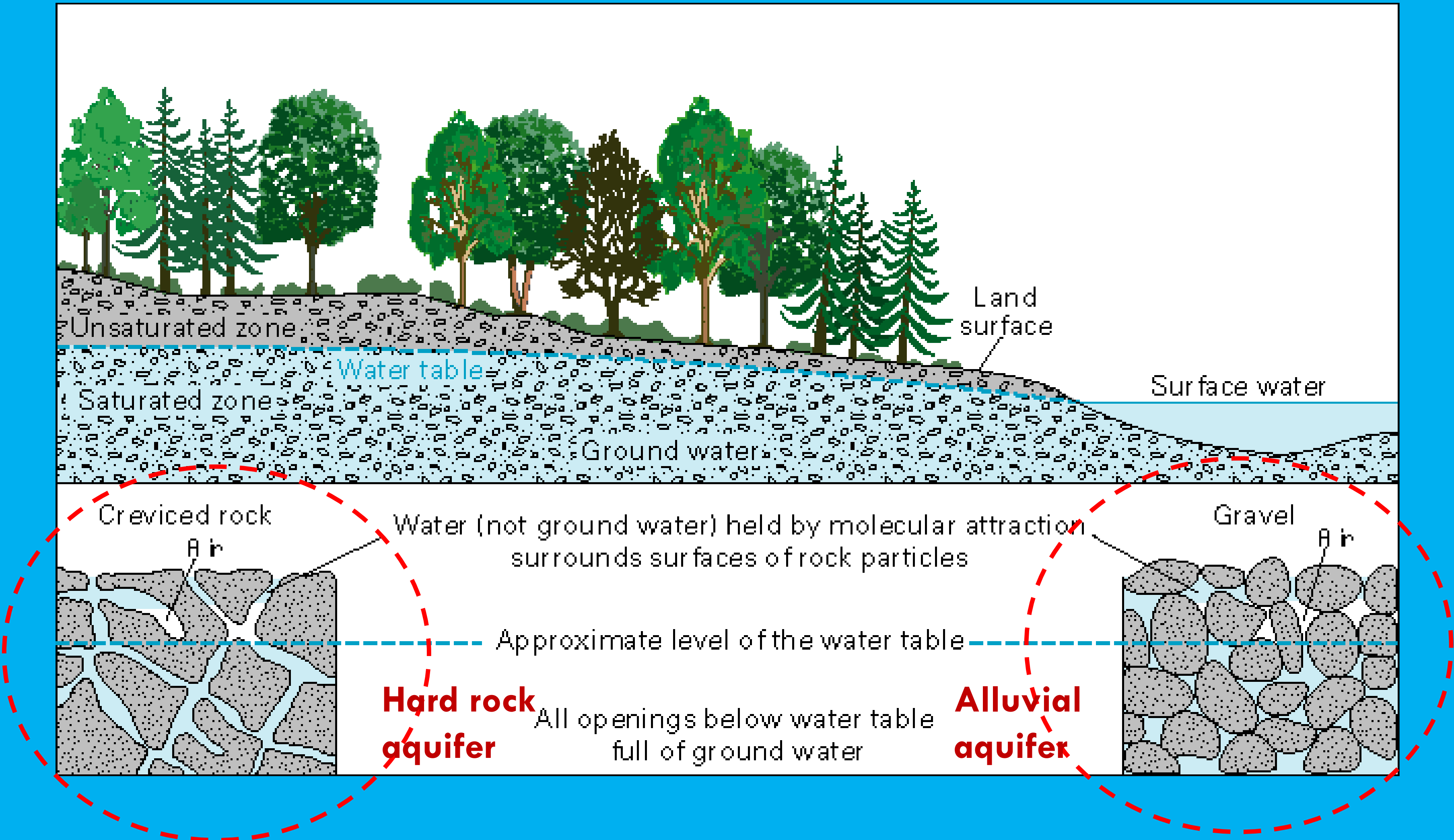
OLD NEWS IN INDIA



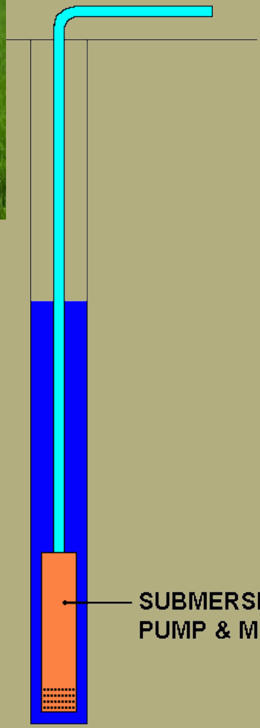


GROUNDWATER FACTS

WHAT IS IT?


Land surface
Unsaturated zone
Water table
Saturated zone
Surface water
Ground water
Creviced rock
Air
Water (not ground water) held by molecular attraction surrounds surfaces of rock particles
Gravel
Air
Approximate level of the water table
Hard rock aquifer
All openings below water table full of ground water
Alluvial aquifer

HOW IS IT PUMPED?



Centrifugal

- Surface motor, typically diesel, sometimes electric.
- Uses suction ⇒ Max lift 7-8 m.
- But pump can be underground.

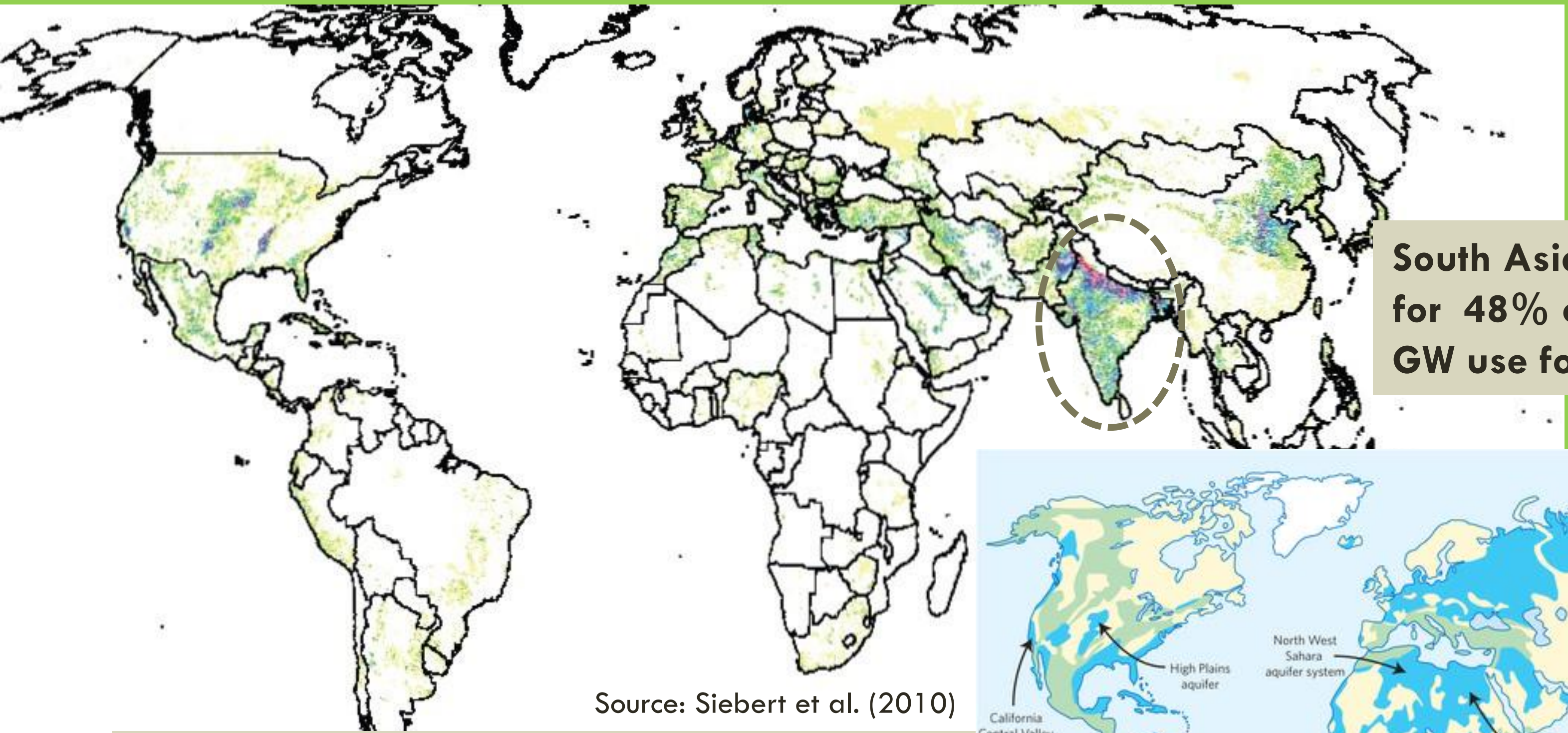
Submersible

- Integrated pump/motor
- Always electric
- 100+ m depth
- More expensive

Diesel motor

Deep set centrifugal pump with belt drive. Pump may be up to 7 meters below ground!

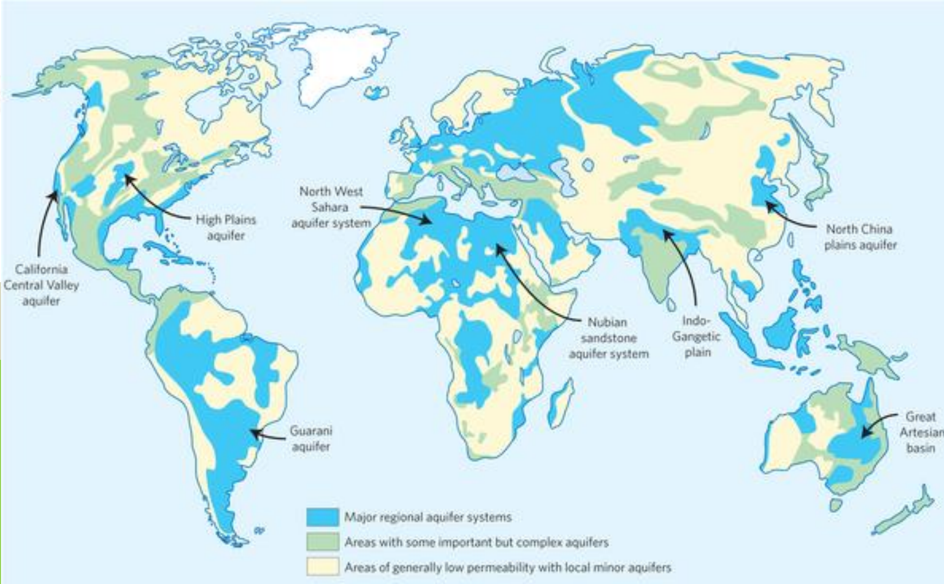
WHERE IN THE WORLD ARE FARMERS PUMPING GROUNDWATER?



Source: Siebert et al. (2010)

% of grid-cell equipped for GW irrigation

South Asia accounts for 48% of global GW use for irrigation

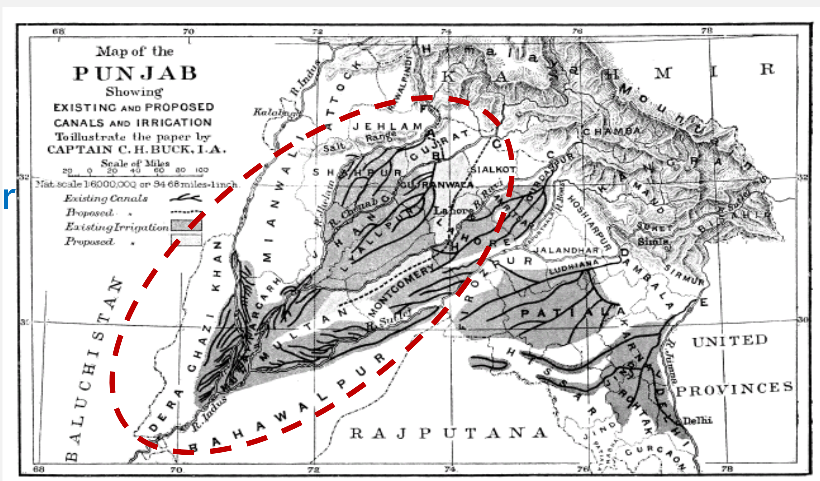


GROUNDWATER IN SOUTH ASIA

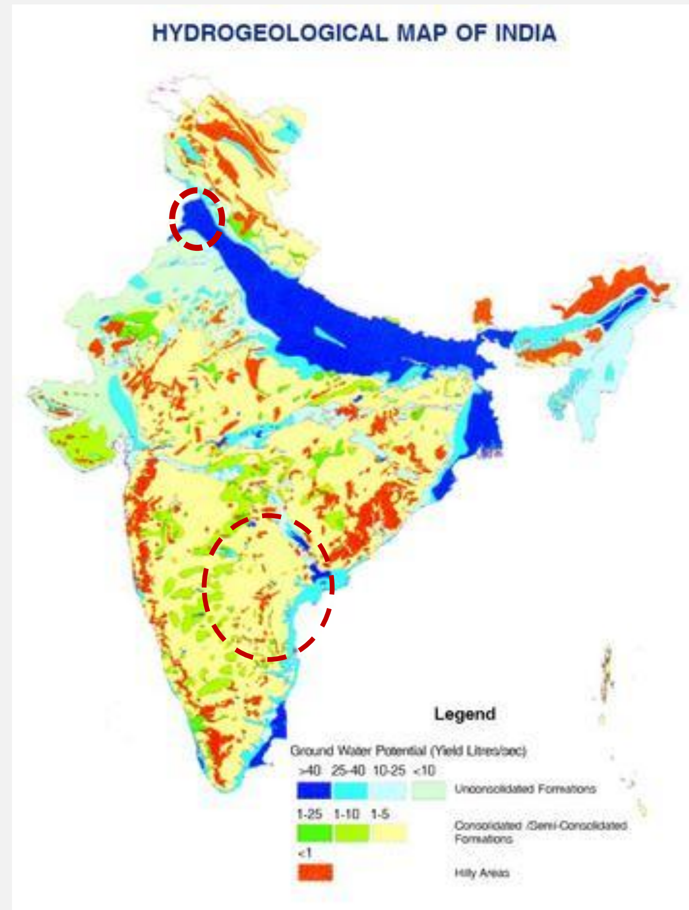
CONTEXT MATTERS…

- A tale of two Punjabs
  - Punjab, India: Deep alluvial aquifer
  - Punjab, Pakistan: " " + dense canal network

Another legacy of the Raj!



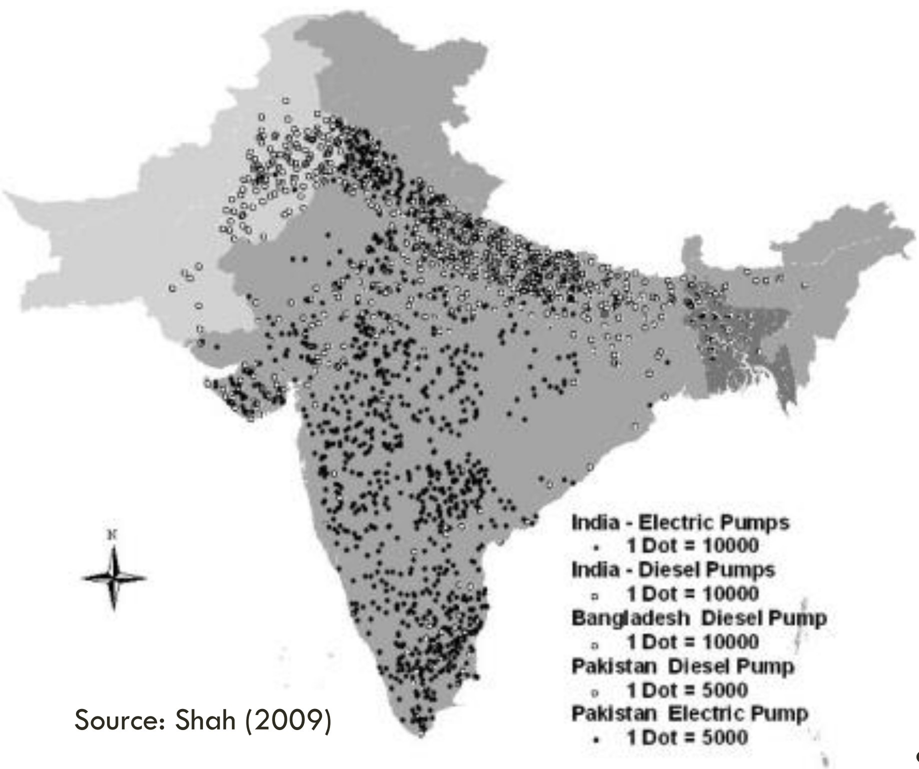
- Andhra Pradesh
  - Shallow hard-rock aquifer



Source: *Dynamic Groundwater Resources of India (as on March 2004), Central Ground Water Board, Ministry of Water Resources, 2006.*

SOUTH ASIA'S BOREWELL REVOLUTION

PRIVATE SECTOR DEVELOPMENT ON A GRAND SCALE

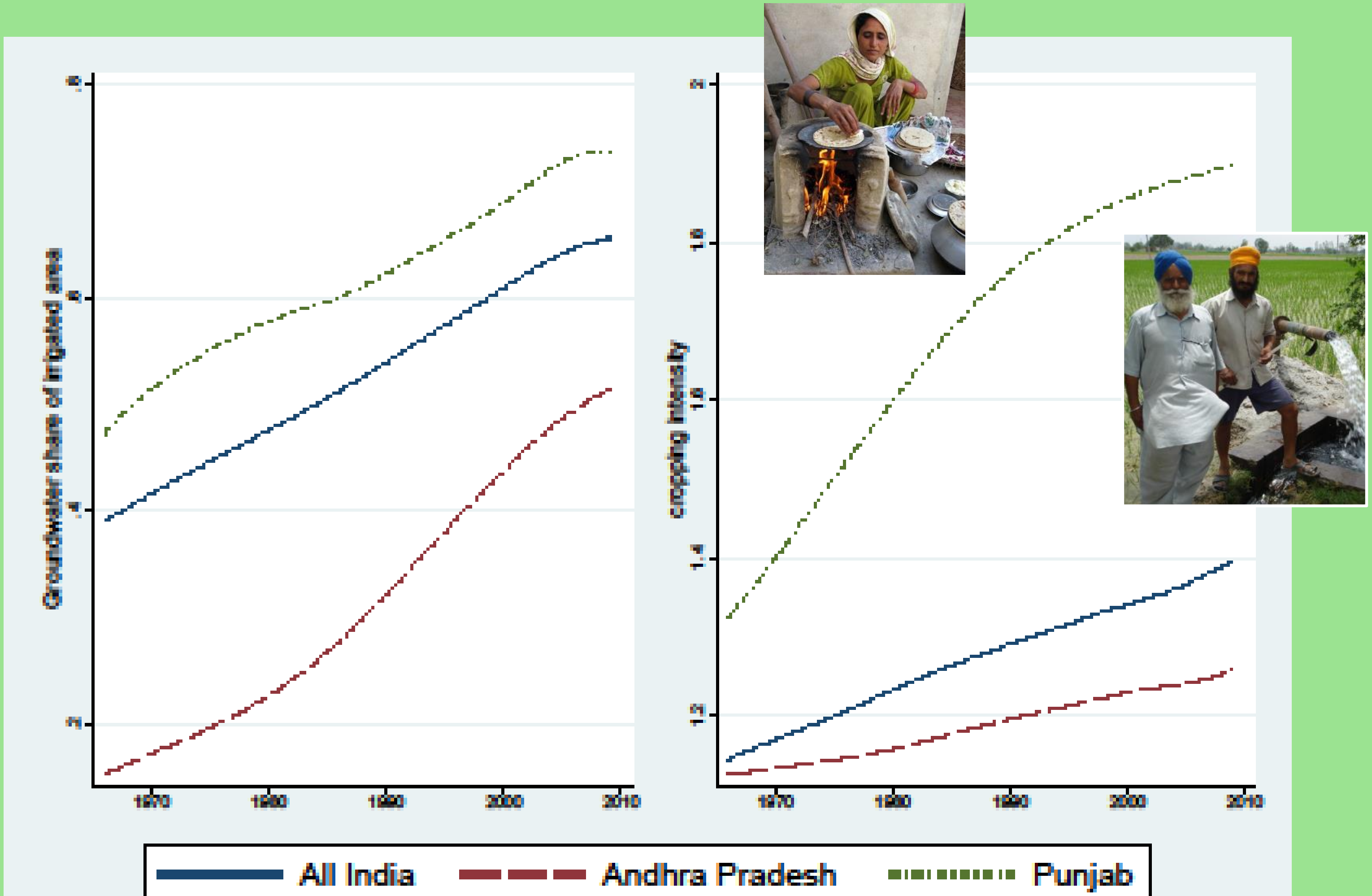


Source: Shah (2009)

		No. of borewells (millions) By motive power of pump		
	Census year	electric	diesel	total
Punjab, PK	1994	0.06	0.34	0.41
	2004	0.06	0.77	0.83
Punjab, IN	1995	0.82	0.67	1.49
	2010	1.17	0.27	1.44
Andhra Pradesh	1995	0.50	0.02	0.52
	2010	1.54	0.02	1.56

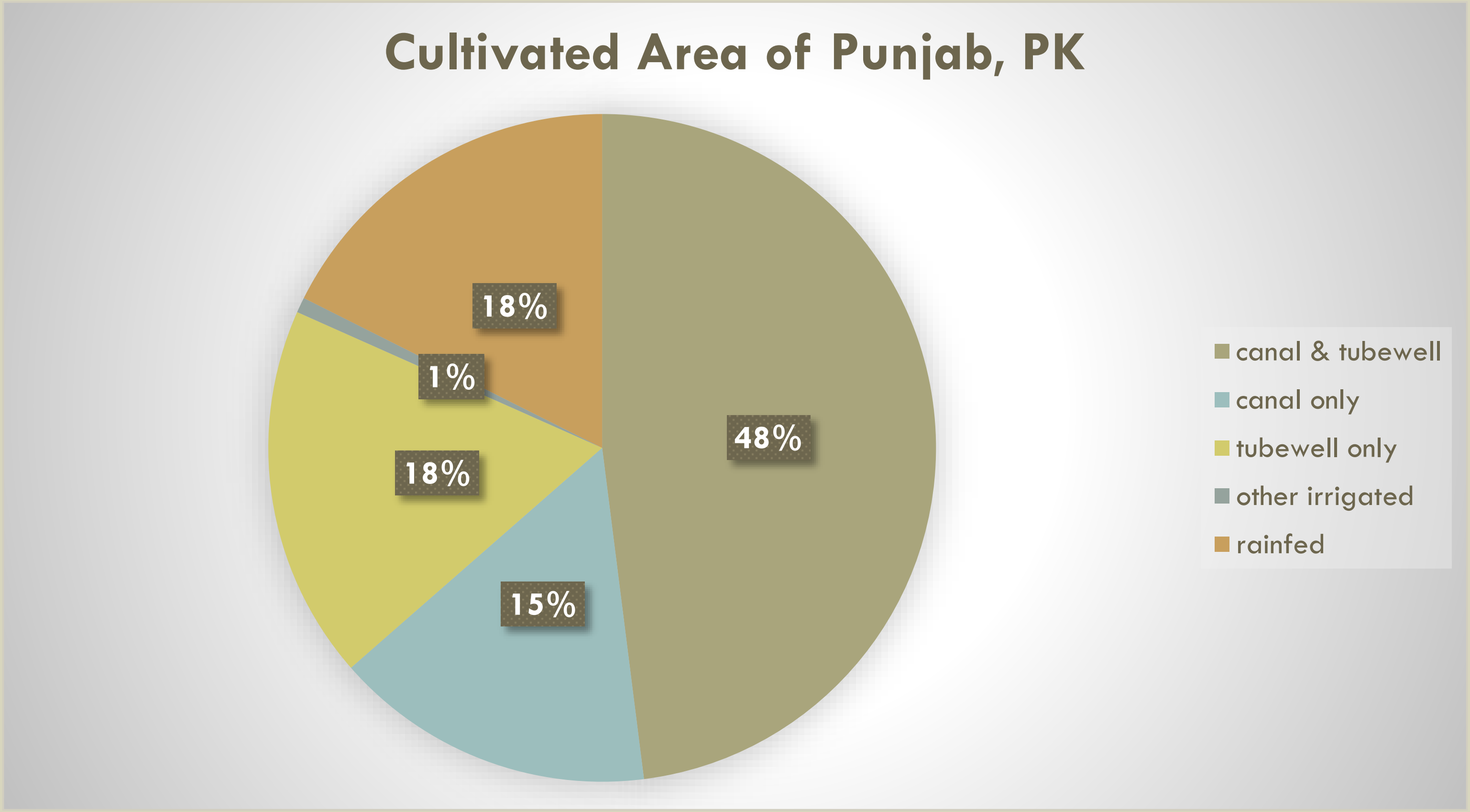
- Growth in India is in submersible pumps
- Growth in PK is in centrifugal pumps
- Why? India has lower WT and 'free' electricity!

INDIA: AGRICULTURAL INTENSIFICATION



Source: ICRISAT district level database.

PAKISTAN: CONJUNCTIVE USE



Source: Ag census, 2010

GROUNDWATER AS A BUFFER

EVEN IN DRY SEASON

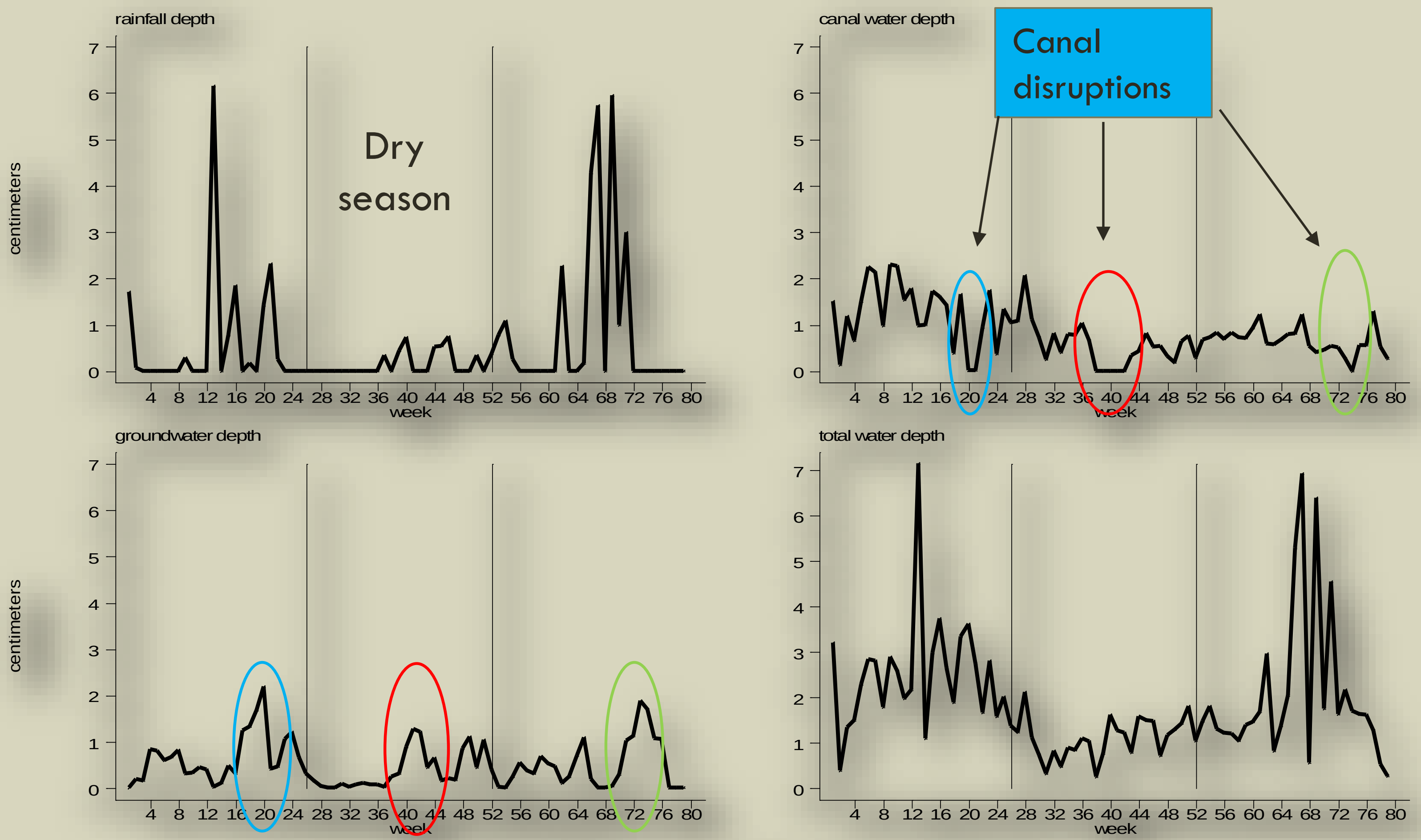
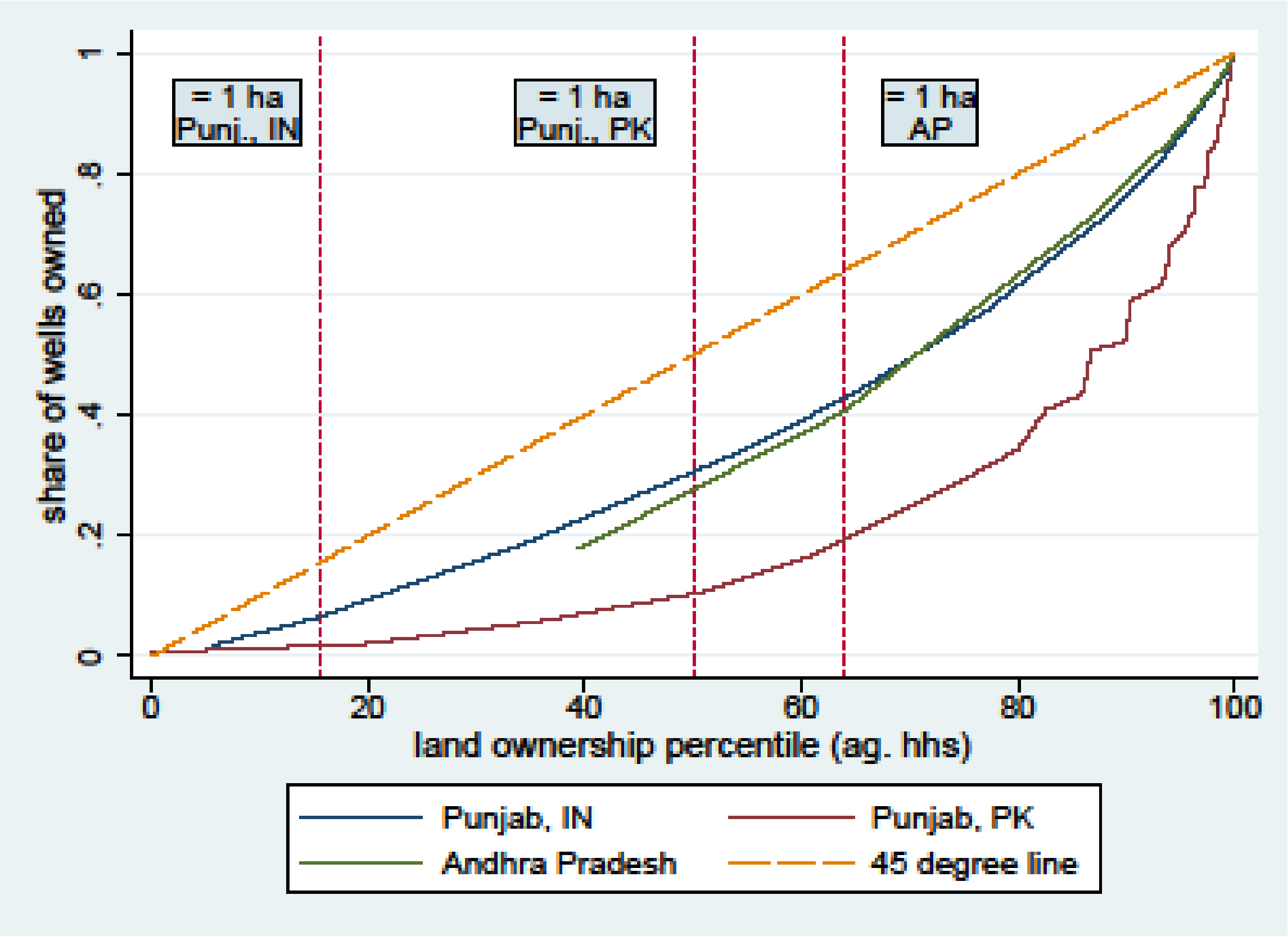


Figure 2. Weekly Irrigation Supply in Fd14R: Apr. 94-Oct. 95

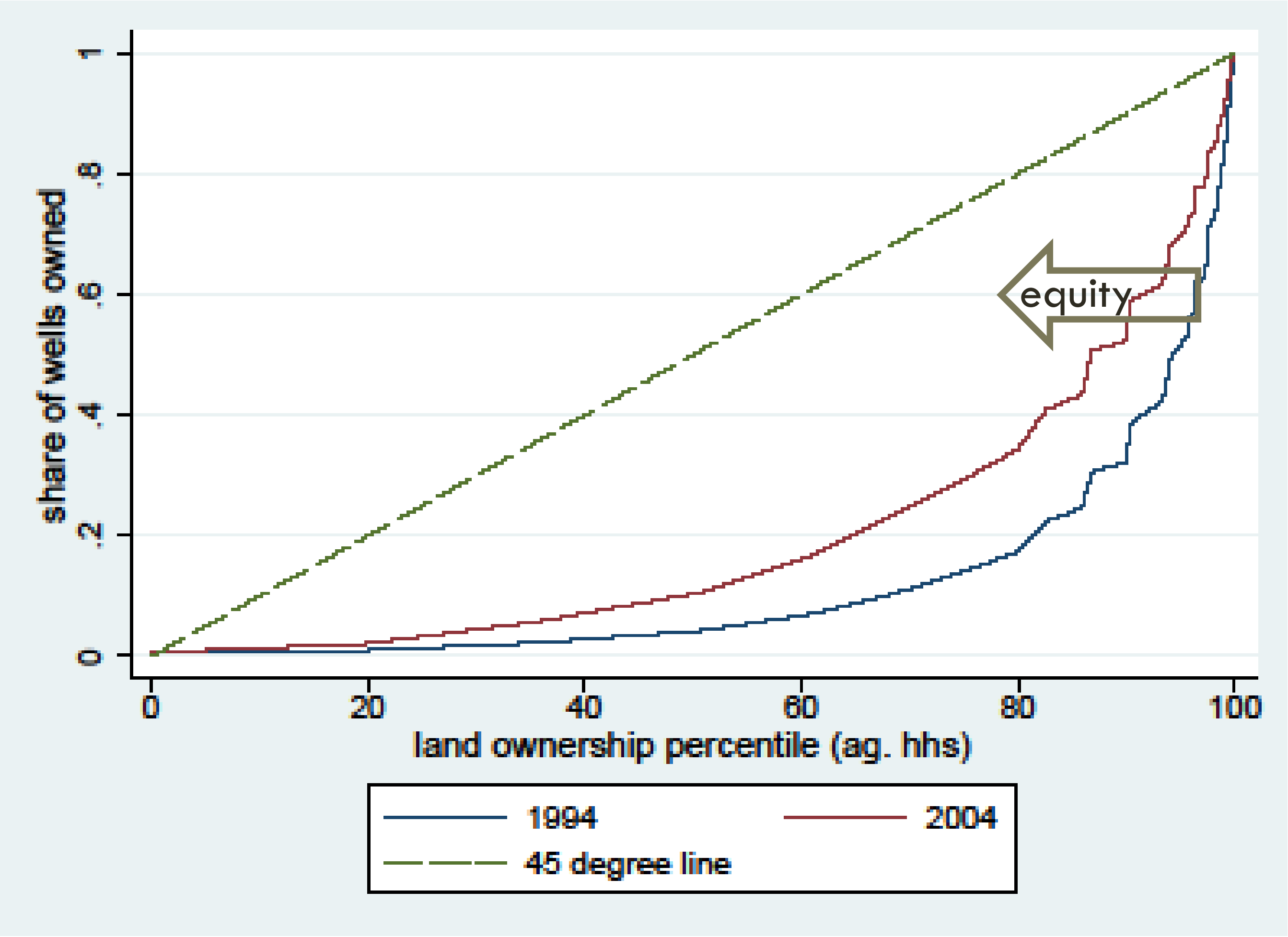
Jacoby, Murgai, Rehman (2004)

SHARED PROSPERITY?



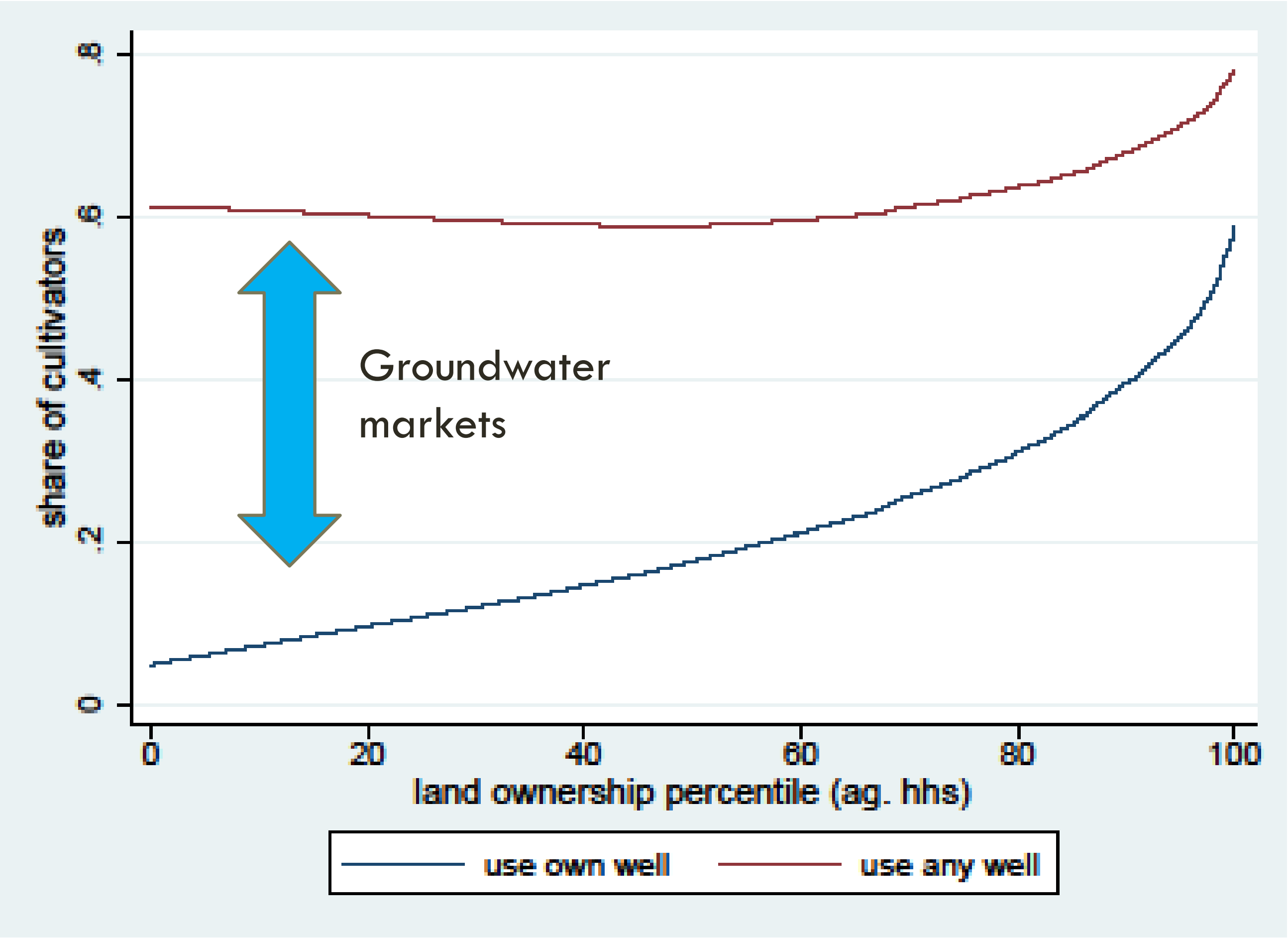
Source: Ag Machinery Census, 2004 (PK); Ag Census, 2010 (IN)

A DISTRIBUTIONAL SHIFT: PUNJAB, PK



Source: Ag Machinery Census, 1994 & 2004

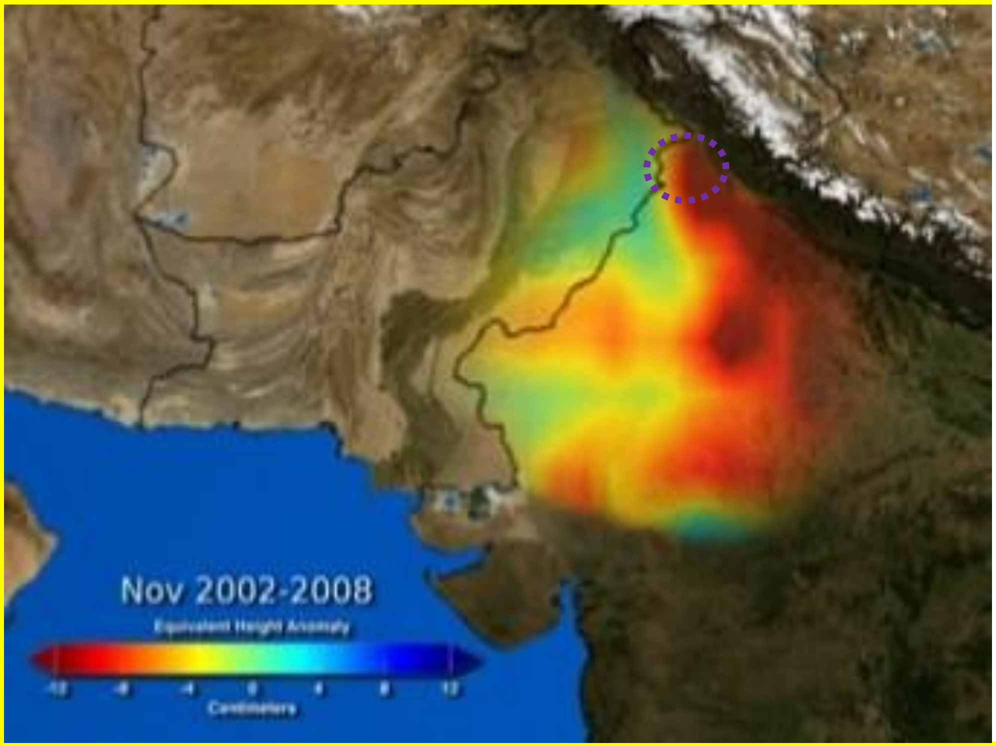
SHARED ACCESS: PUNJAB, PK

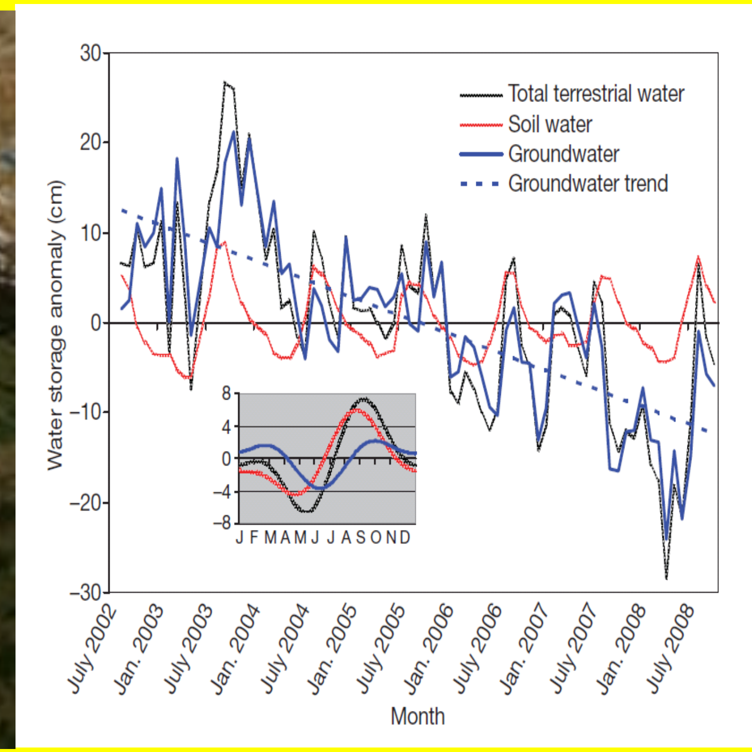


Source: Ag census, 2010

GROUNDWATER DEPLETION IN SOUTH ASIA

PUNJAB, IN

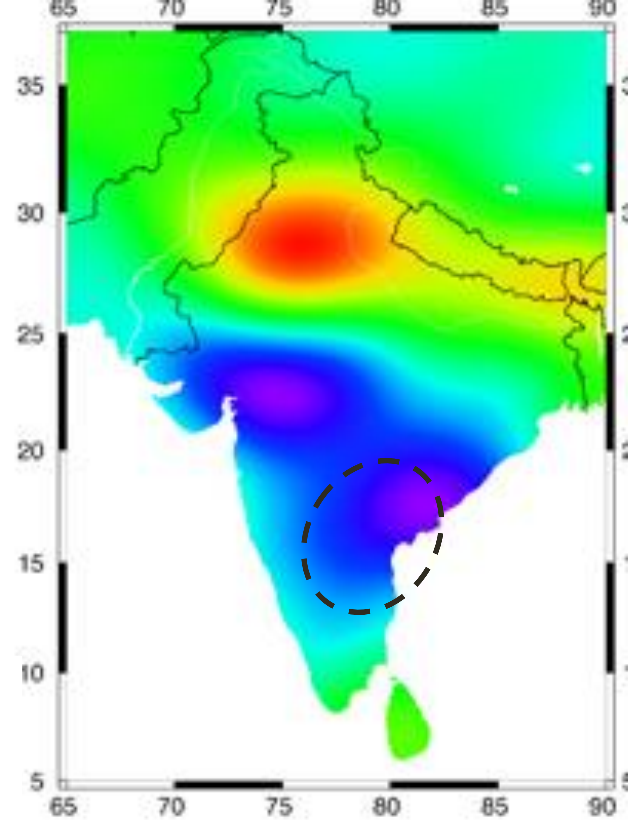


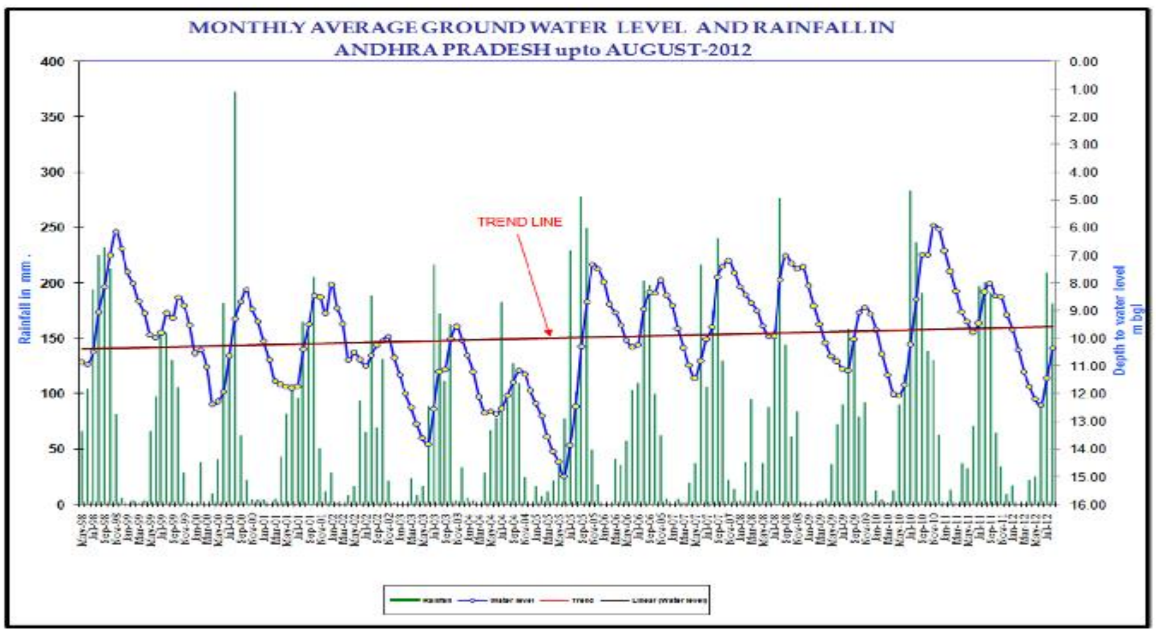


NASA GRACE satellite shows that groundwater withdrawals in Rajasthan, Punjab, & Haryana led to water table decline of 33 cm/year for 2002-2008 (source: Rodell et al. 2009).

ANDHRA PRADESH

- High intra-year variability as monsoonal recharge is extracted during dry season, but…



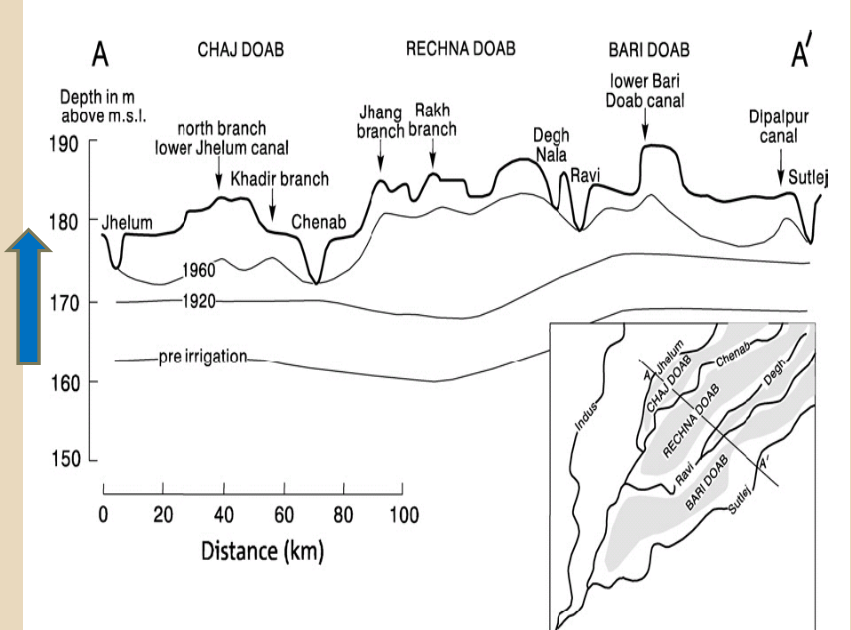


- Piezometer data show virtually zero trend 1998-2012.
- GRACE data show GW ***gains*** from 2002-2008.

PUNJAB, PK

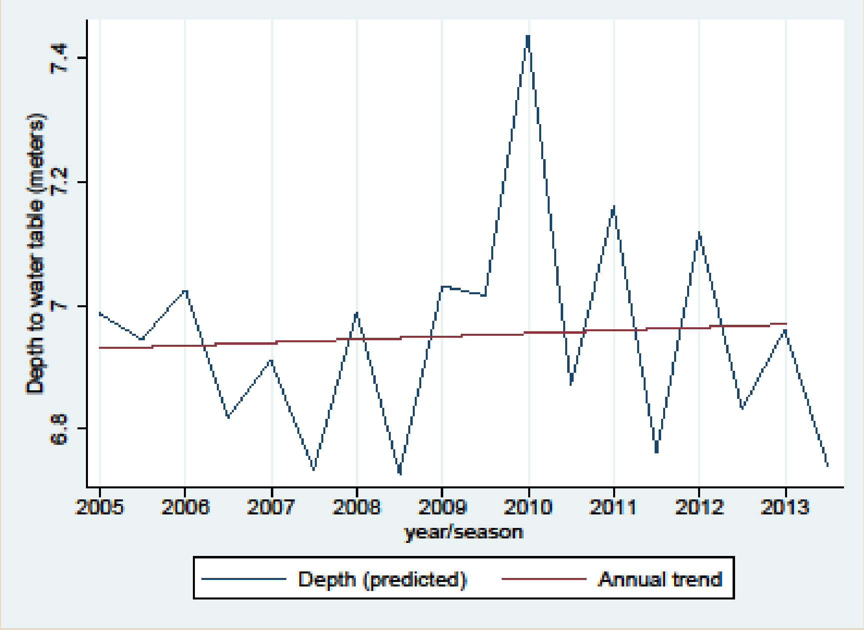
Historically

Rising groundwater levels after the introduction of canal irrigation (Wolters and Bhutta, 1997).

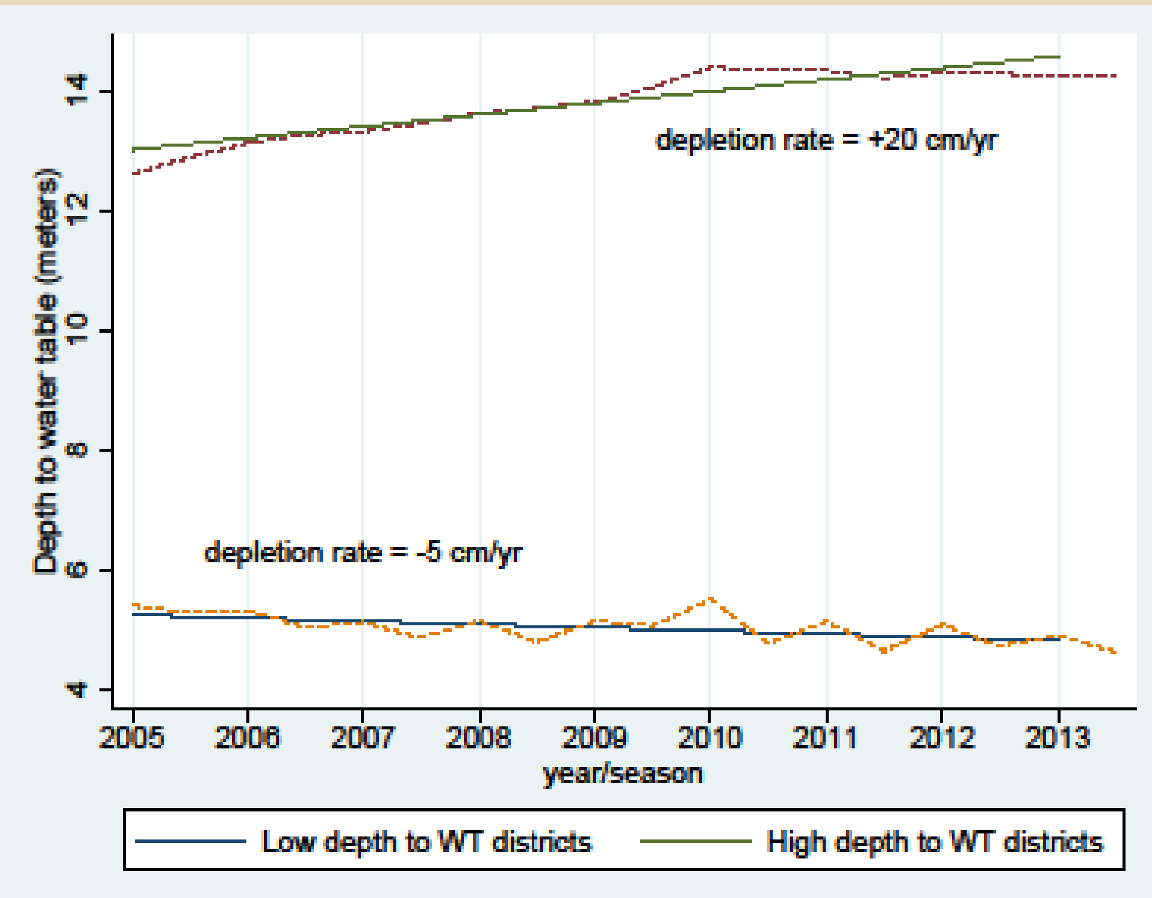


Recently

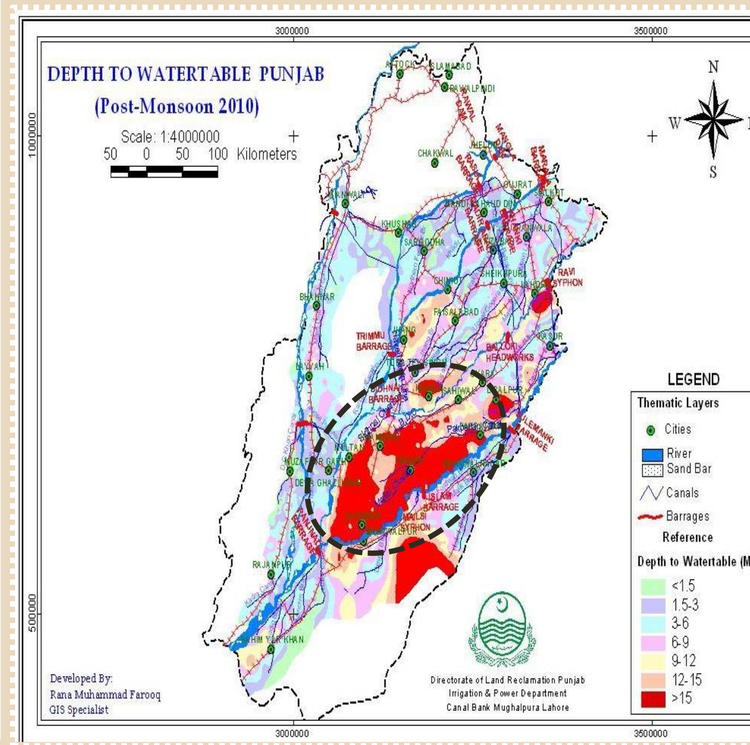
~3000 piezometers in canal command areas reveal a minimal depletion trend of 0.5 cm/year.



HETEROGENEITY



But, depletion is concentrated in 6 high depth to water-table districts of south-central Punjab.

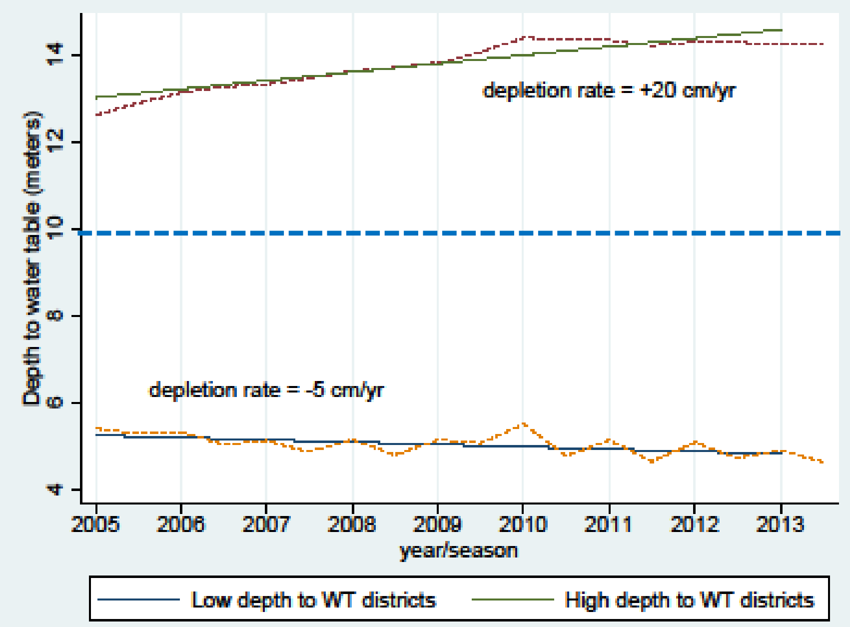


TUBEWELL DEVELOPMENT & DEPLETION

- Establishing causality is tricky!
- Ag Machinery Census, 2004: WT changes matched to no. of tubewells *by year of installation* in corresponding Union Council.
- Conclusion: faster tubewell development leads to faster depletion, but only in areas with initially high depth to WT.
- In zones of plentiful recharge, tubewell development has not created problems (circa 2004).

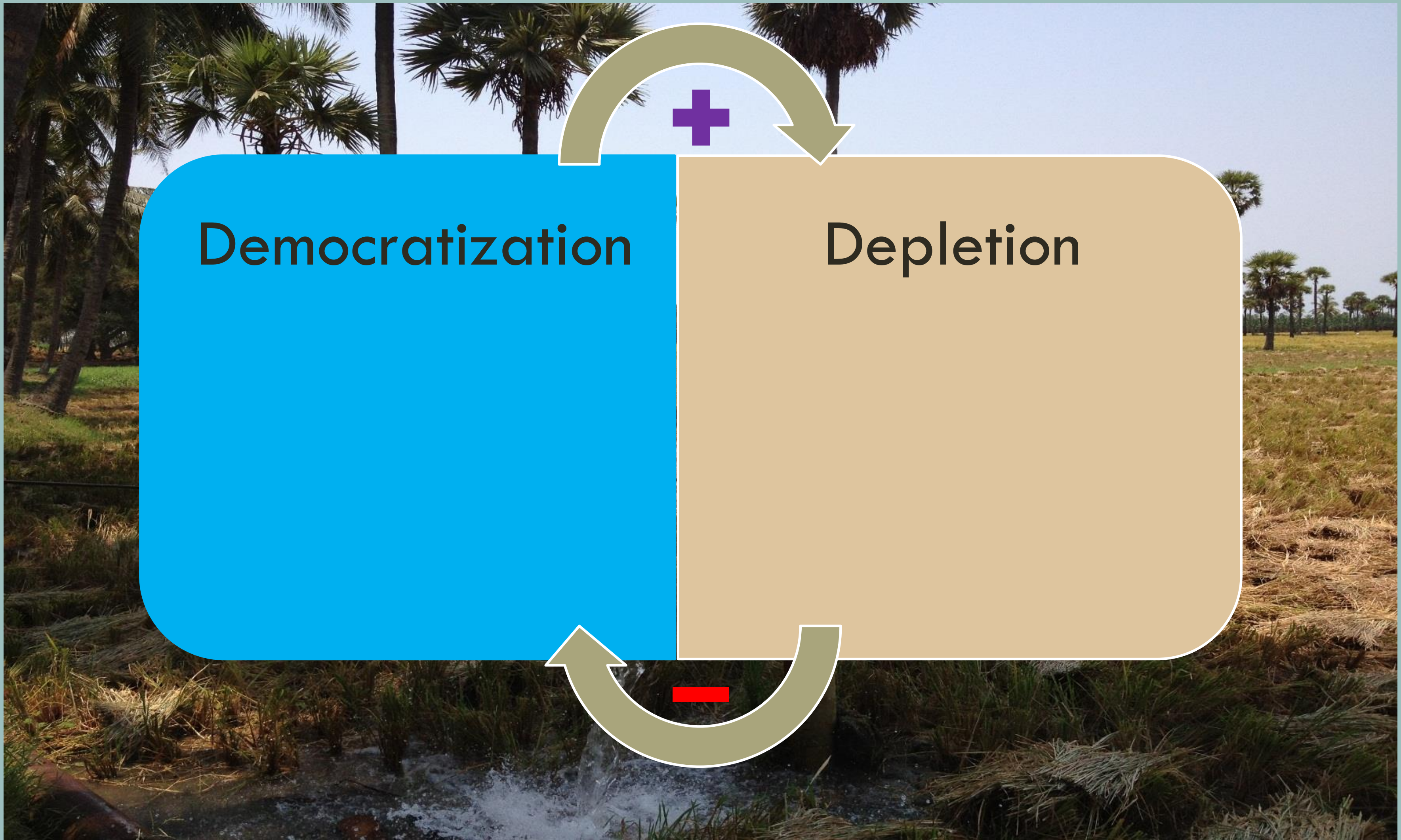
	ΔWT/year (meters/yr)		
	All	Tehsil mean WT < 10m	Tehsil mean WT >10m
ΔTubewells/year	0.1206	-0.0004	0.3738
(in hundreds)	(0.0458)	(0.0505)	(0.0935)
No. of UC	2,663	862	1,801
Observations	72,253	32,410	39,843
Fixed effects	Year & UC	Year & UC	Year & UC

Notes: Cluster robust standard errors in parentheses.



SOUTH ASIA'S GROUNDWATER DILEMMA

IN A NUTSHELL



4 WELL-FARE ECONOMICS QUESTIONS

(1) WHAT IS THE ECONOMIC RETURN TO WELL-DRILLING?

WELL-DRILLING IN AP

- 2010 weather insurance survey (~1500 hhs/44 villages) in two drought-prone districts of interior AP (w/Xavi Giné).
- Estimate gross return to a borewell.
- Estimate private cost of a borewell.

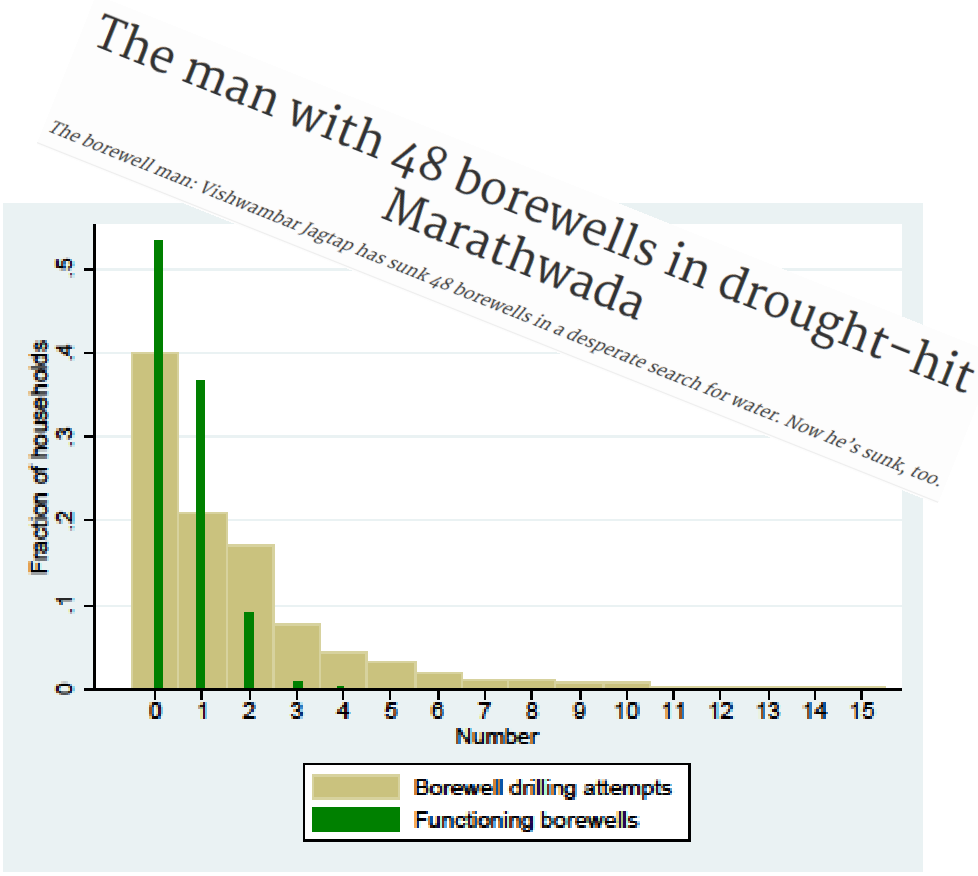
HEDONIC ESTIMATE

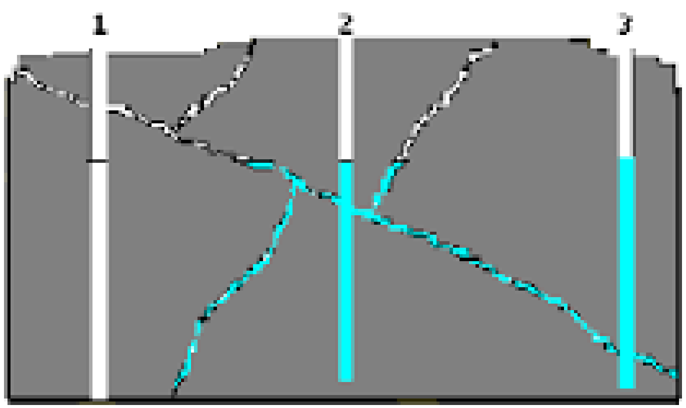
"If you were to sell this plot today, ***including the associated water rights***, how much would you receive in `000 Rs./acre?"

	log(value/acre)	
Functioning owned wells/acre	0.487	0.459
(accounting for fractional ownership)	(0.113)	(0.066)
log plot area	0.095	0.048
	(0.025)	(0.017)
soil depth	0.004	0.028
	(0.025)	(0.021)
black soil	0.137	0.101
	(0.052)	(0.037)
Number of groups	44	955
Observations	3,018	2495
Fixed effects	Village	Household

Notes: Cluster-robust standard errors in parentheses.

HARD ROCK LOTTERY





HT: Ram Fishman, GWU

LOTTERY WINNERS AND LOSERS

“The rapid spread of groundwater irrigation throughout the dry-land areas has been gradually increasing the density of green specks in this otherwise brown terrain” (Shah, 2009)

Rabi season 2015, Anantapur, AP

CONSUMPTION-BASED ESTIMATE

	log(total hh expenditure)		
	All	No. of attempts > 0	
functioning owned wells/acre	0.191	0.220	0.161
(accounting for fractional ownership)	(0.039)	(0.045)	(0.046)
log(hh size)	0.481	0.424	0.425
	(0.022)	(0.042)	(0.042)
log(area owned)	0.139	0.180	0.230
	(0.013)	(0.024)	(0.025)
log(no. drilling attempts/acre)			0.085
			(0.016)
No. of groups	44	44	44
Observations	1,484	891	891
Fixed effects	Village	Village	Village

Notes: Cluster-robust standard errors in parentheses.

SIMPLE ARITHMETIC OF WELL-DRILLING

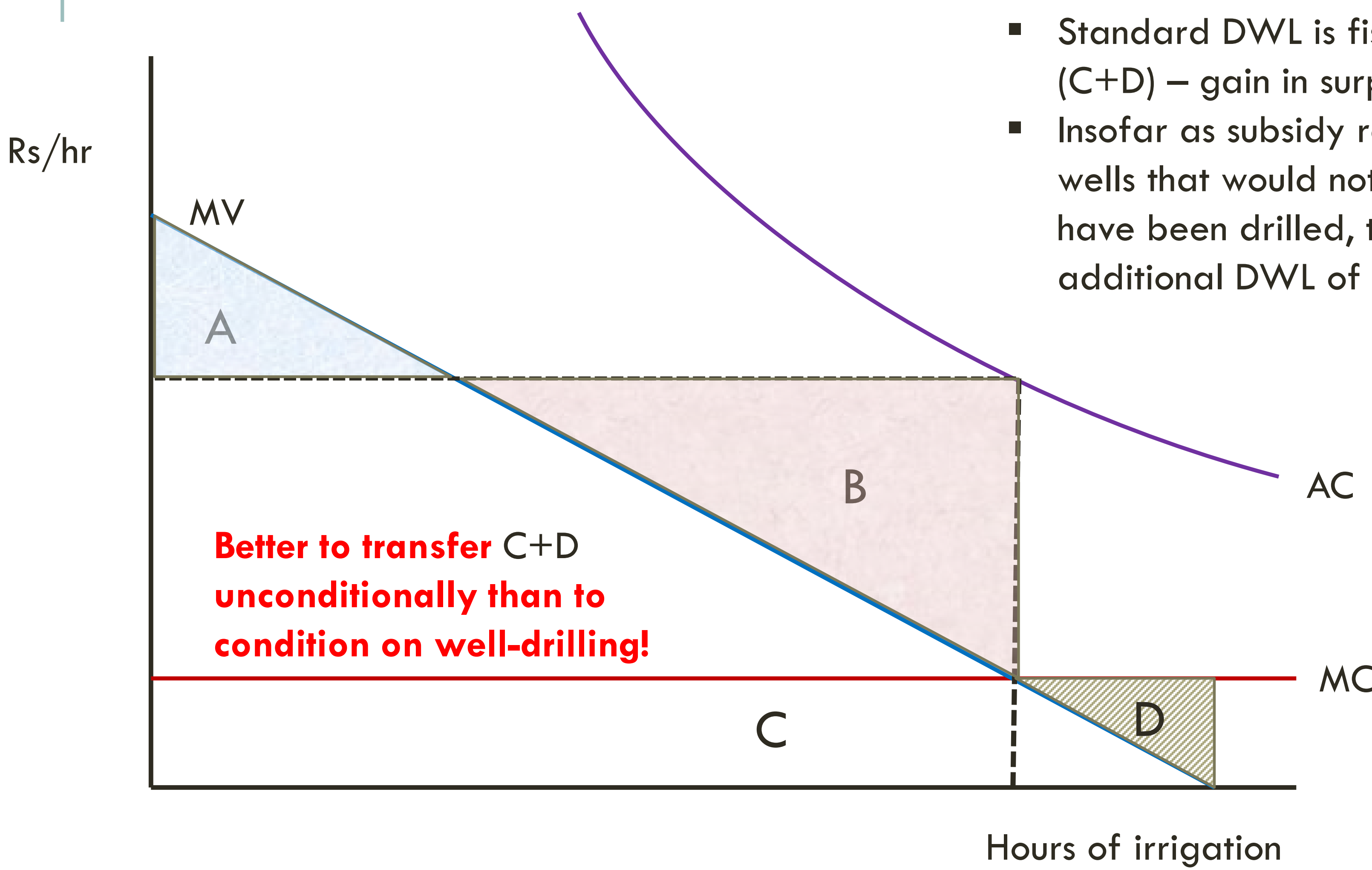
- What discount rate reconciles hedonic (capitalized) and consumption-based (income flow) gross return estimates? Answer: 5.6%
- What is the cost of a successful borewell?
  - Installation cost (drilling, casing, connection) = C (= 23 thousand Rs.)
  - Cost per failed attempt = 0.5 x C (only bear cost of drilling)
  - Expected private cost = C + 0.5 x C x E[no. failures | success]
- In this example:
  - Gross return (p.v.) to well ownership = 79.8 thousand Rupees
  - Private cost = 45.7 ($\gg$ 23!)
  - Net private return = 34.1
  - Equivalent to around 3% of permanent income.

ECONOMICS OF ELECTRICITY SUBSIDIES

- What if electricity to run pump is priced at cost rather than free?
- Assume:
  - Pump uses 4.7 kwh per hour of operation
  - Operates 900 hours per year
  - Cost of electricity = 0.75 Rs./kwh (off-peak ag. power tariff in W. Bengal)
- ➔ Capitalized power subsidy = 56.6
- ➔ Net private return = -22.6 !
- Conclusion: Without the heavy power subsidy, the marginal borewell would not be economically viable.

RENT-SEEKING AND DEADWEIGHT LOSS

- Standard DWL is fiscal cost (C+D) – gain in surplus (C) = D
- Insofar as subsidy results in wells that would not otherwise have been drilled, there is an additional DWL of B – A.



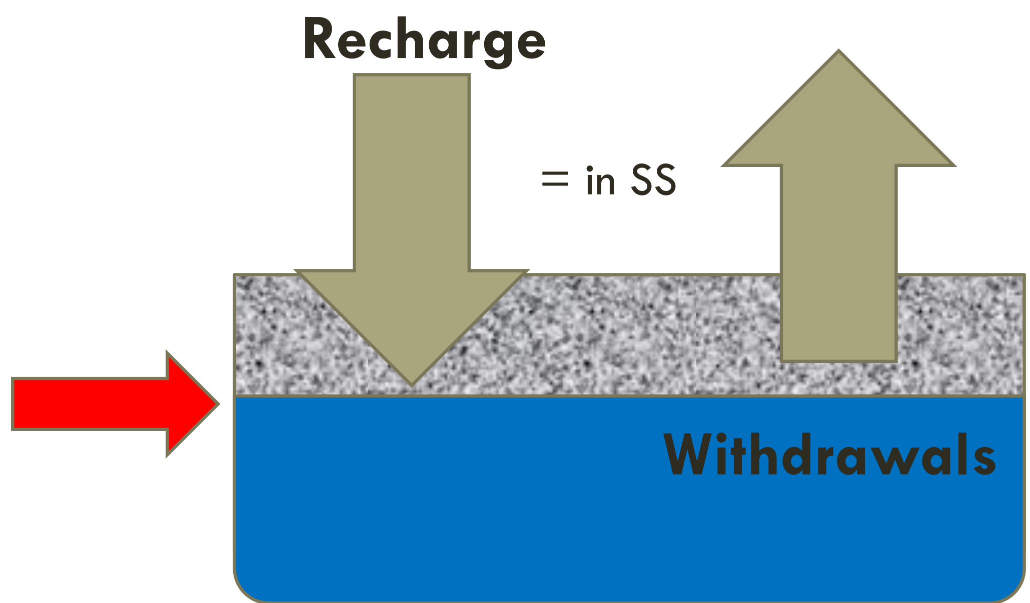
4 WELL-FARE ECONOMICS QUESTIONS

(2) IS GROUNDWATER BEING EXTRACTED TOO QUICKLY?

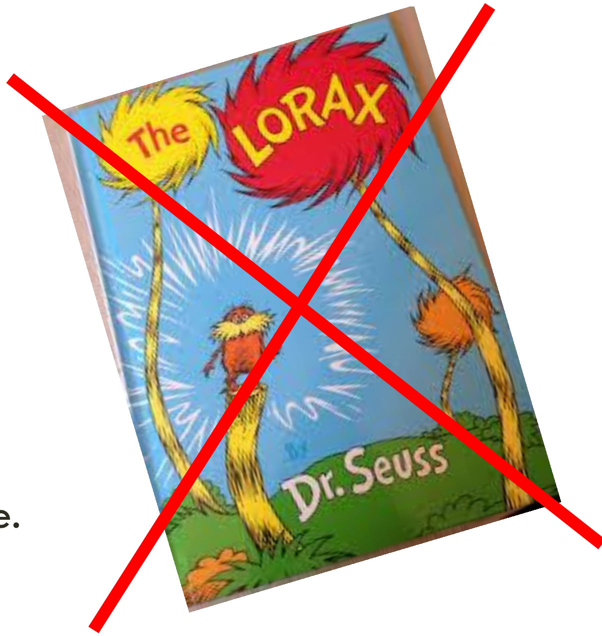
EXTRACTION ECONOMICS

DEPLETION $\not\Rightarrow$ OVER-EXPLOITATION

- Why? Optimal control of aquifer: maximize p.v. of revenue stream
  - subject to law of motion for water level (WL) in aquifer
  - taking account that extraction cost is a function of WL.
  - Solution is steady-state WL*
- $WL^* < WL_0 \Rightarrow$ optimal to deplete aquifer
- So what is ***over-exploitation***?...



TRAGEDIES OF THE COMMONS
EXTERNALITIES ASSOCIATED WITH GROUNDWATER

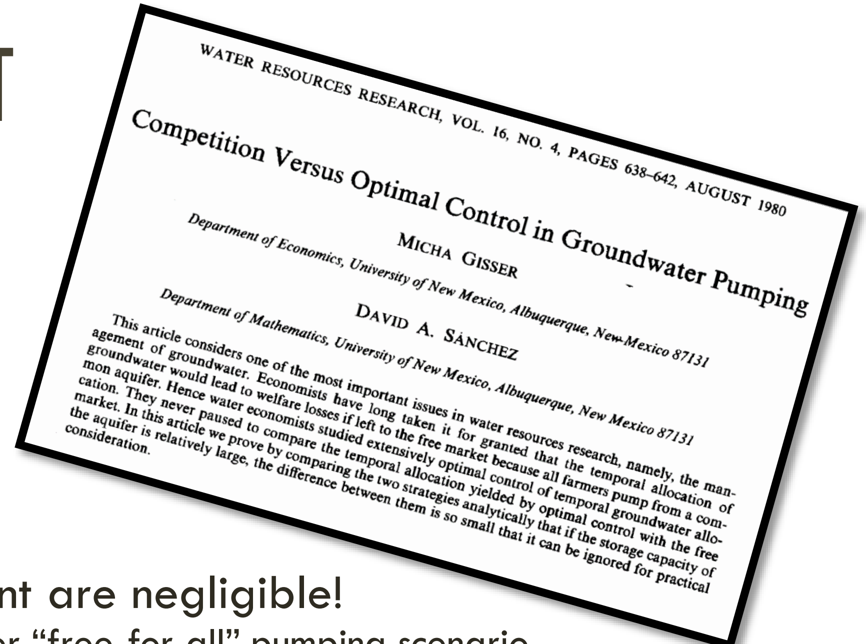


- Strategic externality
  - Does open access ("use-it-or-lose-it") ⇒ race to exhaustion?
  - Not if rising pumping costs eventually make extraction prohibitive.
- Pumping cost externality
  - Marginal extraction cost is the binding constraint.
  - Each irrigator only takes into account the (typically infinitesimal) impact of their extraction on their ***own*** future pumping cost, not on the future pumping costs of others.
  - Compared to WL*, steady state WL will be too low in a free-for-all.

TRAGEDIES OF THE COMMONS
EXTERNALITIES ASSOCIATED WITH GROUNDWATER

- Uncertainty (risk) externality
  - Amount of groundwater extracted varies stochastically depending on WL. (Alternatively, surface water is stochastic in a conjunctive use environment).
  - Individual irrigators do not fully internalize the cost of higher production uncertainty (or income risk) and thus over-extract relative to a managed aquifer.
- Environmental externalities
  - Land subsidence
  - Seawater intrusion or secondary salinity (important in Punjab, PK)
  - Positive externality: Vertical drainage alleviates waterlogging (Punjab, PK)

GISSER-SANCHEZ RESULT
PUMPING COST EXTERNALITY


WATER RESOURCES RESEARCH, VOL. 16, NO. 4, PAGES 638–642, AUGUST 1980

Competition Versus Optimal Control in Groundwater Pumping

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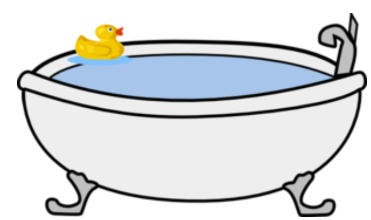
This article considers one of the most important issues in water resources research, namely, the management of groundwater. Economists have long taken it for granted that the temporal allocation of groundwater would lead to welfare losses if left to the free market because all farmers pump from a common aquifer. Hence water economists studied extensively optimal control of temporal groundwater allocation. They never paused to compare the temporal allocation yielded by optimal control with the free market. In this article we prove by comparing the two strategies analytically that if the storage capacity of the aquifer is relatively large, the difference between them is so small that it can be ignored for practical consideration.

- Welfare gains to groundwater management are negligible!
  - When calibrated to a U.S. aquifer, WL* ≈ WL under "free-for-all" pumping scenario.
  - i.e., the pumping cost externality is vanishingly small.
- Is this result applicable to the South Asian context(s)?
- Gisser-Sanchez assumes
  - No uncertainty in irrigation supply
  - Single-cell (bathtub) aquifer ⇒ pumping cost externality is global
  - Number of wells exogenously fixed



- Let's return to the last two assumptions after some investigation in AP.

DEMISE OF THE DUGWELL

- Once the dominant well-type in peninsular India, shallow dugwells have reportedly been drying up at a prodigious rate over the last decade.
- Results from our 6-district 2012 GW markets survey (GWMS) for 62 villages having at least one dugwell in 2007.

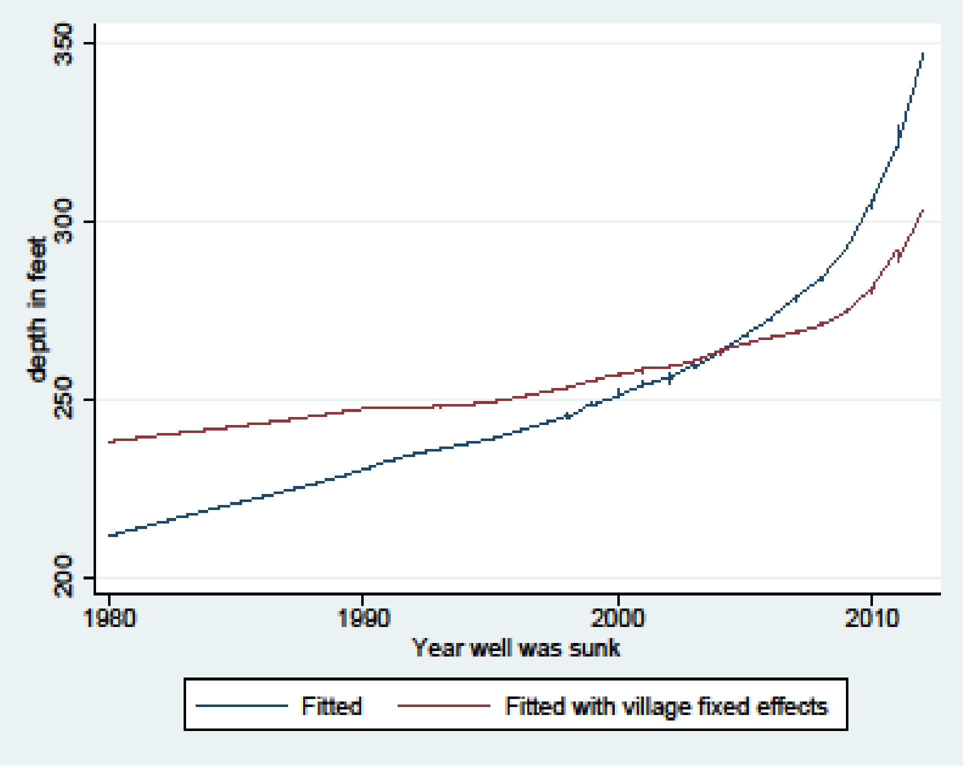
Mean number of	2007	2012
Functioning dugwells	16.1	4.2
Non-functioning dugwells	9.9	20.9

In the mid 2000's, there were more than 9 ml. open dugwells with mechanized pumps.

About a million alone in AP.

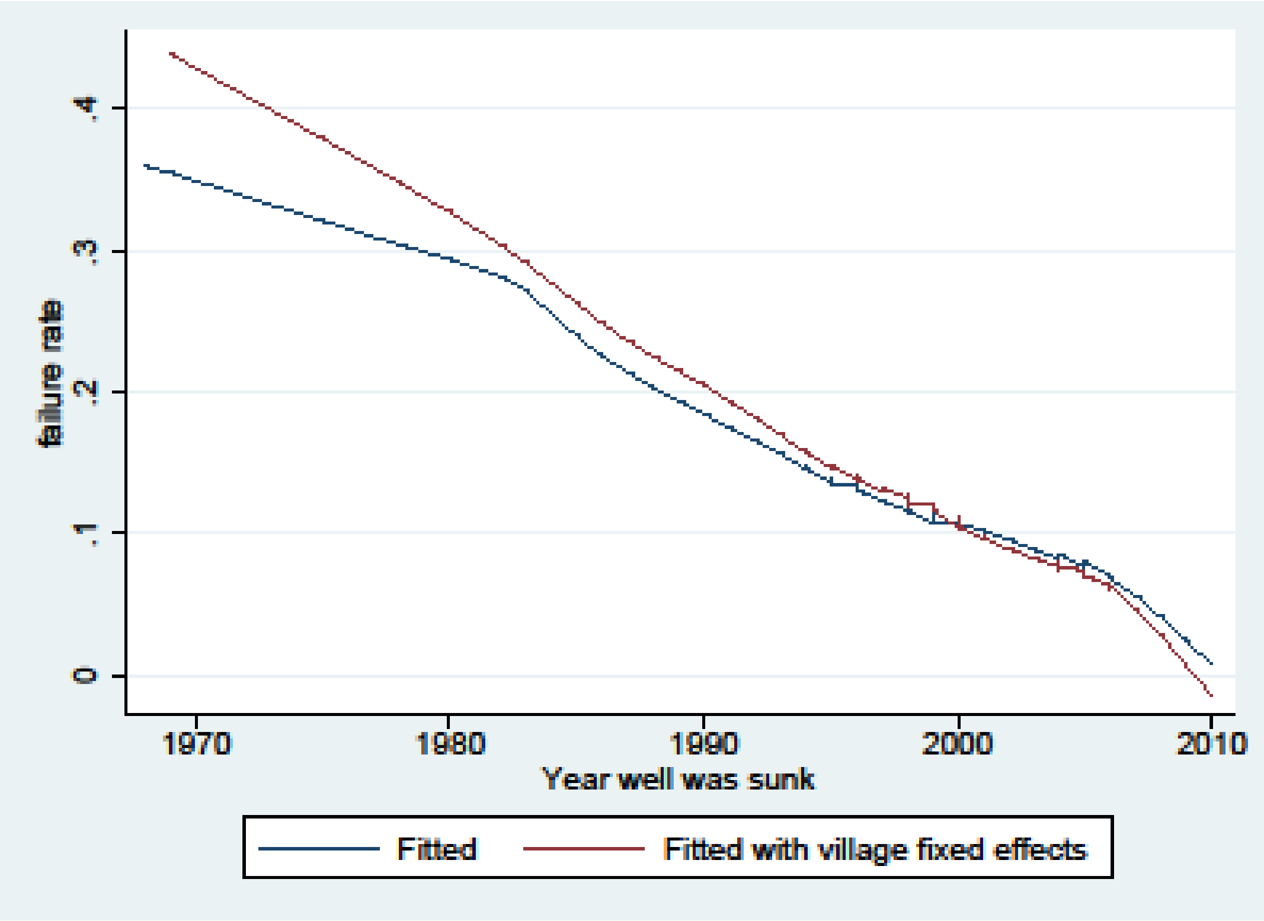
DRILLING DEEPER

- GWMS survey covers ~2400 borewells in 144 villages.
- Since borewells may have been sunk first in villages with high WT (⇒ early wells are shallower), control for village fixed effects.
- Conclusion: within a village, more recently sunk borewells are deeper. Trend is accelerating!
- ⇒ drilling cost ↑, pump HP ↑



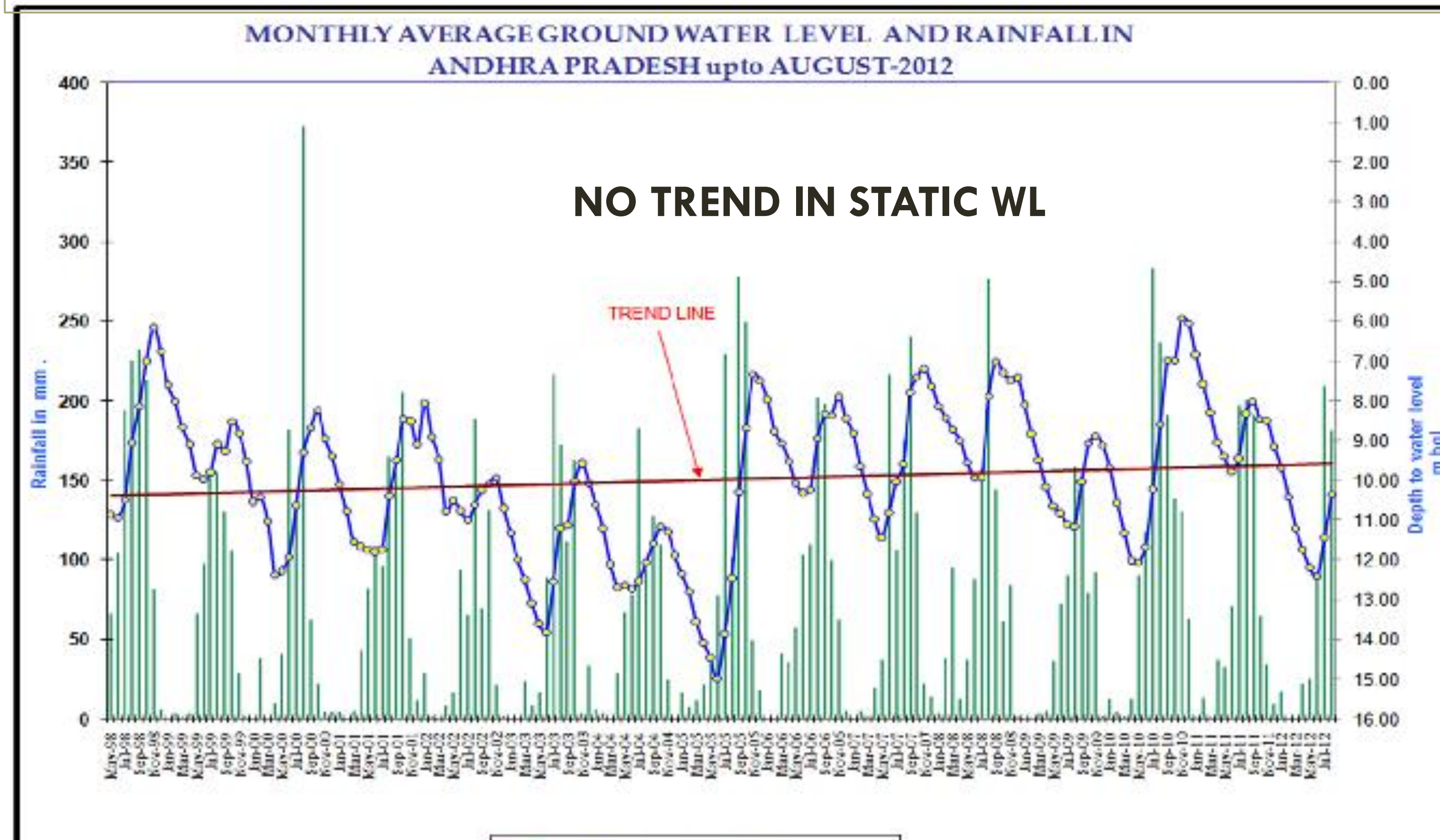
OLDER BOREWELLS ALSO FAILING

SUGGESTIVE OF FALLING WATER TABLE



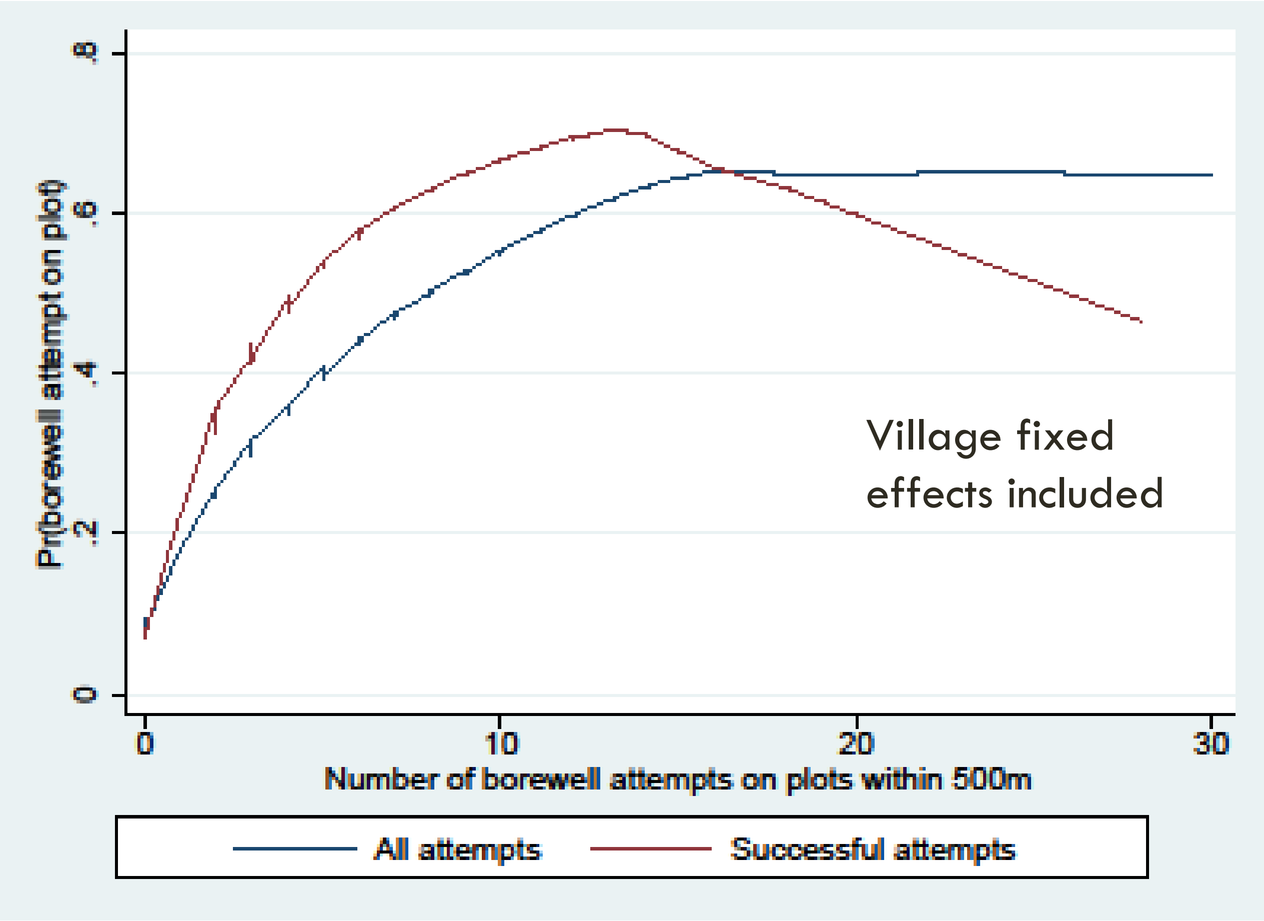
RECONCILING THE FACTS

"Groundwater, in hard rock areas is a local resource and [the] influence of [a] cluster of wells (which are about 30 or 40 metres deep) will be marginal beyond a radius of 2 or 3 km." (AP Groundwater Dept., 2007).



BOREWELL CLUSTERING

GETTING A PIECE OF THE ACTION!



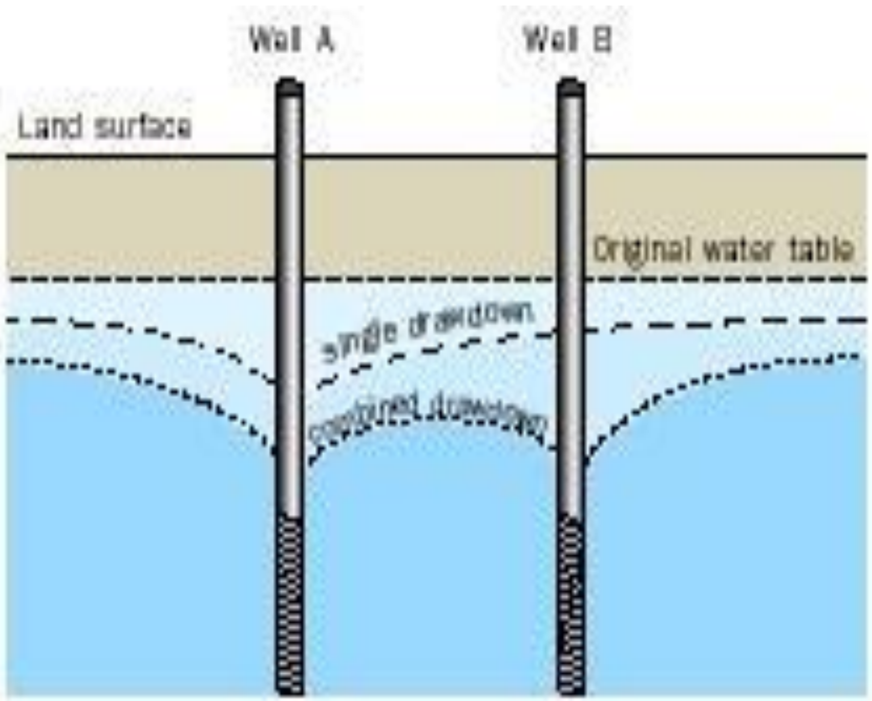
WELL INTERFERENCE

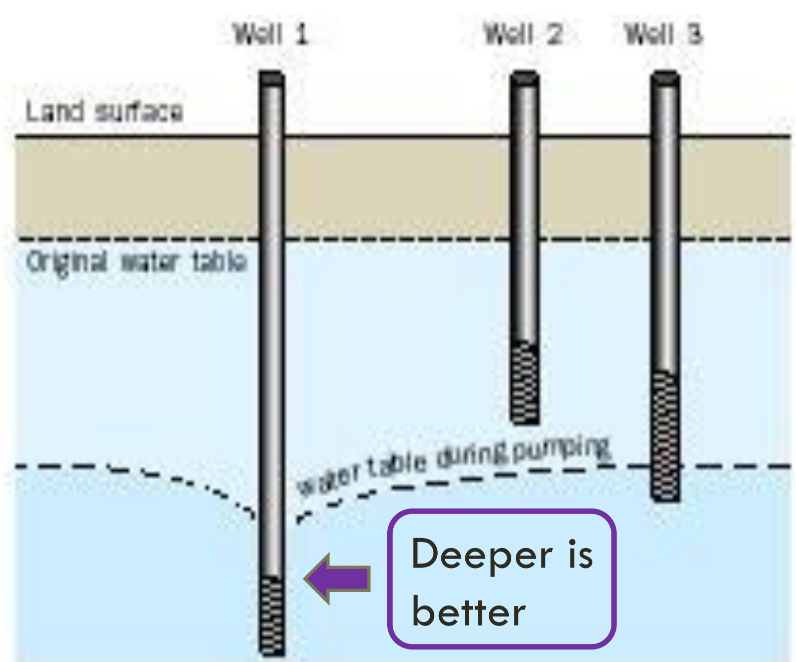
LOCALIZED PUMPING COST EXTERNALITY

In AP,

- Pumps run continuously for the few hours/day electricity is available.
- Low transmissivity ⇒ greater drawdown

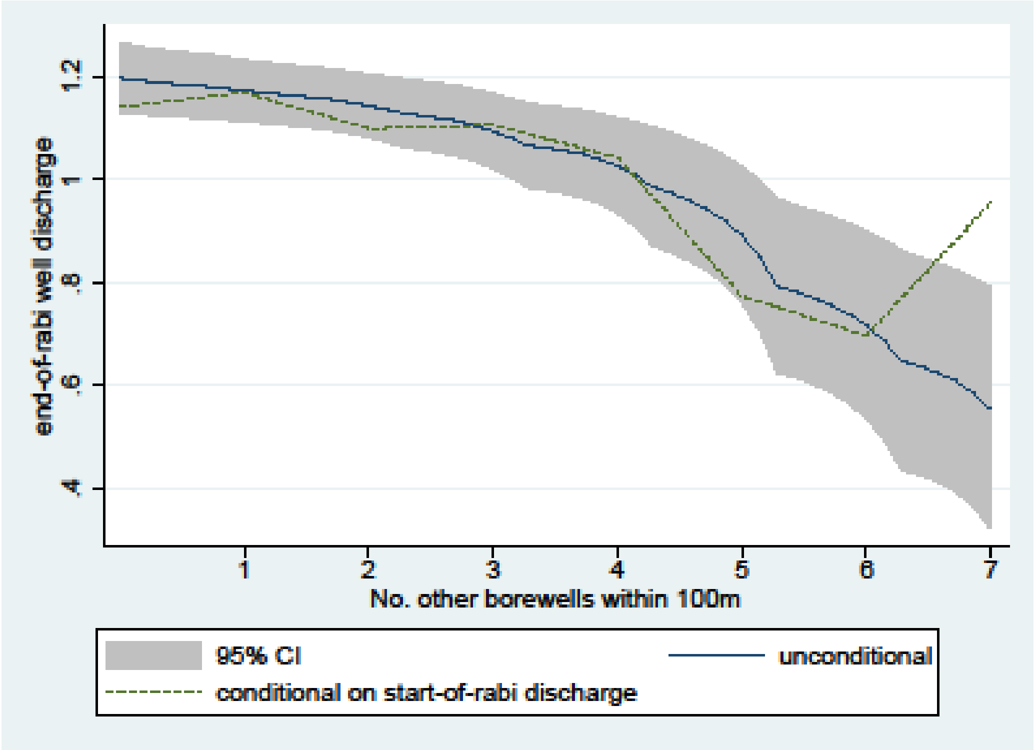
Combined discharge ≪ 2 x individual





CLUSTERING AND WELL DISCHARGE

- "Circle" survey: Census of borewells within 100 meter radius of 369 randomly chosen reference borewells.
- Median of 2 other wells/circle.
- Conclusion: greater clustering attenuates well discharge.
- ⇒ In hard-rock zone, widespread well failure & well deepening is consistent with zero trend in static WL.



GISSER-SANCHEZ REVISITED
CONSEQUENCES OF WELL INTERFERENCE

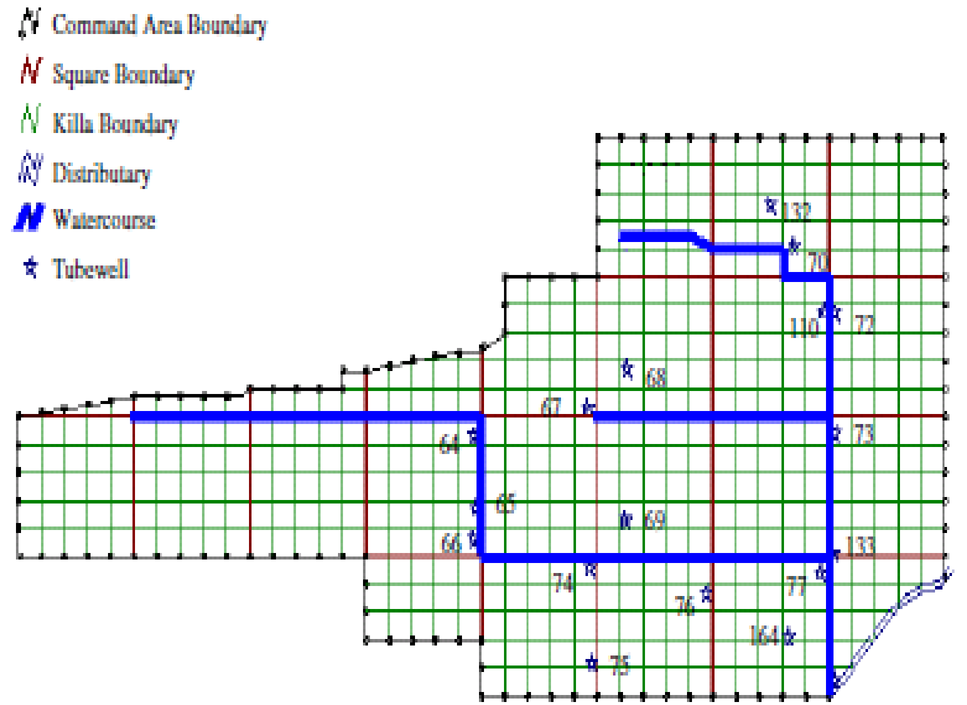
- Localized pumping cost externality
  - *"…if wells are clustered together in a relatively small area within an aquifer with much larger surface area, then a spatially explicit model will predict much larger welfare gains from optimal management than a single-cell model."* (Brozović et al. 2010)
  - i.e., given well interference, the external costs of any single well's pumping are no longer diluted across the entire extent of the aquifer.
- Rent-seeking
  - Well interference ⇒ marginal well adds little to net extraction
  - but it entails a large fixed cost ⇒ surplus dissipated as more wells are sunk.
  - So, welfare losses from "free-for-all" may ultimately be huge.
- In sum, there may yet be an economic rationale for public intervention in groundwater management!

4 WELL-FARE ECONOMICS QUESTIONS

(3) HOW WELL DO GROUNDWATER MARKETS FUNCTION?

MONOPOLY POWER: PUNJAB, PK
EQUITY & EFFICIENCY

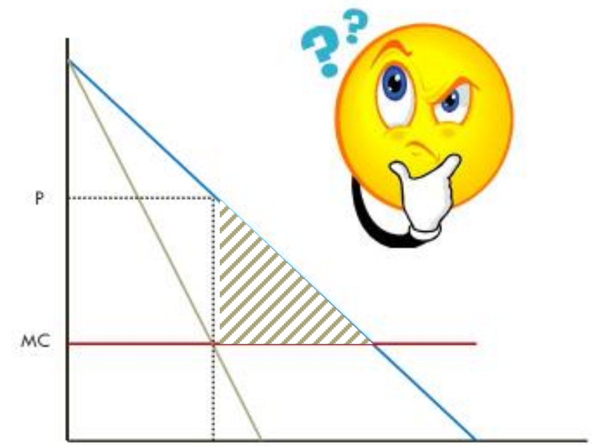
- Markets in groundwater are inherently fragmented and local.
- Jacoby, Murgai, Rehman (2004): sellers in Fd14R charge lower prices (= MC) to their share-tenants than to other buyers.
- Inefficiency: deadweight loss 7% of total groundwater expenditures in watercourse.
- Inequity: monopoly pricing has small distributional impact.
- Conclusion: shared access ⇏ shared prosperity



Note: 1 killa square = 1 acre

FIGURE 1
Fd14R watercourse map

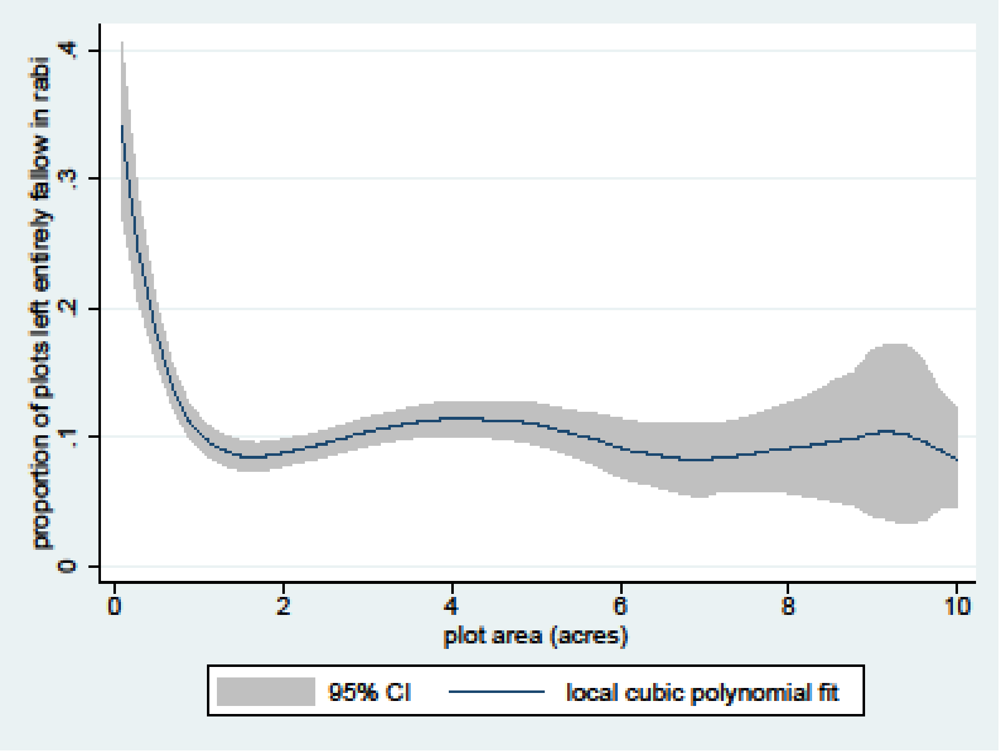
WHAT'S THE CONTRACTING FAILURE?



- Why can't farmers contract around deadweight loss?
  - E.g., why not price groundwater at marginal cost and charge buyers a lump-sum fee equal to their consumer surplus.
- Conjecture: demand uncertainty ⇒ renegotiation/hold-up problem (contracting breaks down).
- More generally, can uncertainty (in demand or supply) explain the organization of groundwater markets?

EFFICIENT MARKETS? AP

- efficient groundwater market ⇒
  - small plots (without a borewell, but adjacent to one) should be just as likely as large plots to be left fallow.
  - But this is not the case in AP…
- Giné and Jacoby (2015): uncertainty about end-of-season borewell discharge
  - Influences form of groundwater contracts
  - Accounts for lack of groundwater sales—up to a point.



HOW DO GROUNDWATER MARKETS INTERACT WITH WELL-DRILLING?

Coordination failure

	Drill	Not drill
Drill	12, 12	20, 10
Not drill	10, 20	0, 0

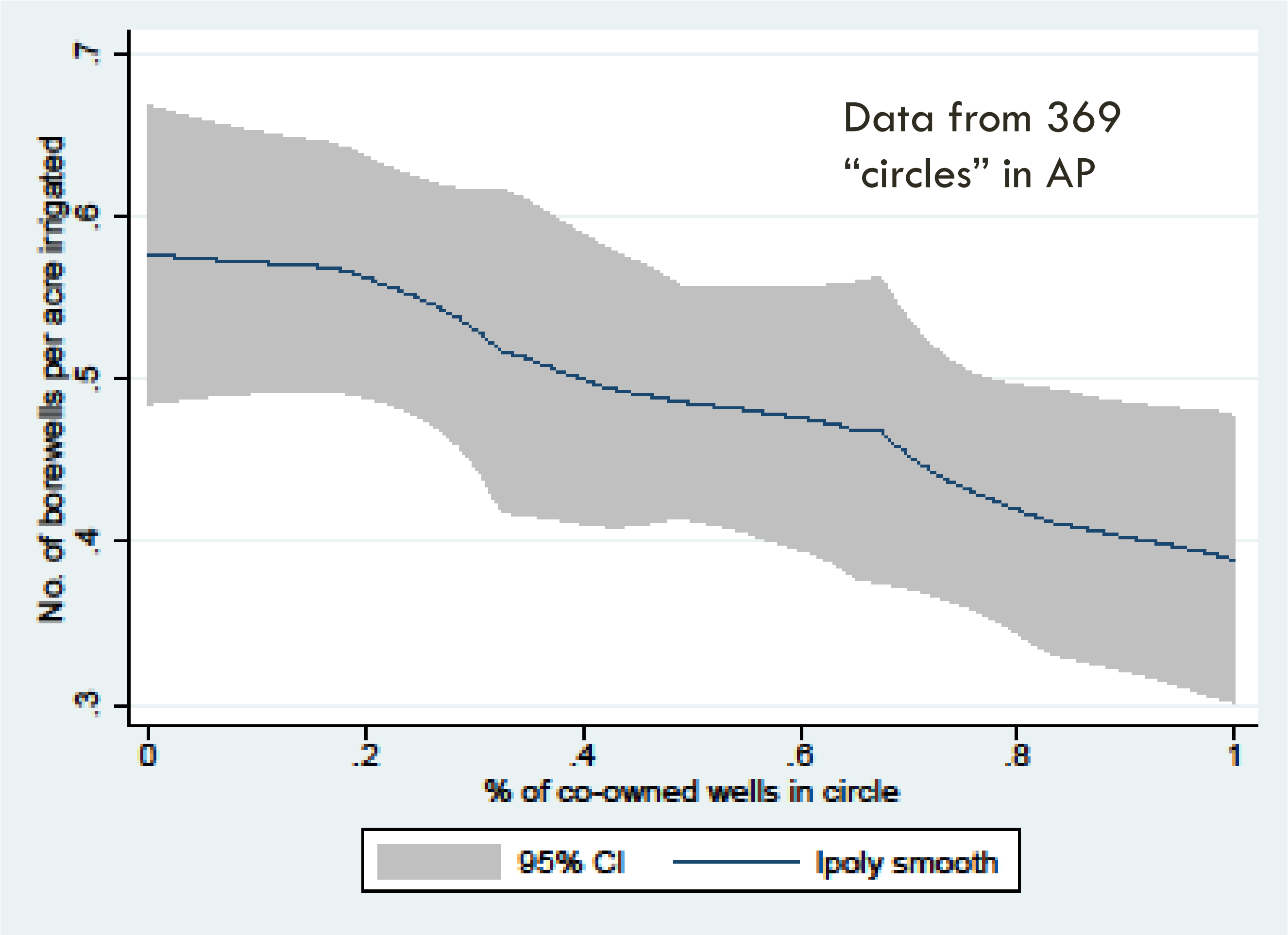
- Farmer that doesn't drill must buy water from farmer that does drill.
- Seller always has monopoly power, hence unequal surplus.

Anti-coordination success

	Drill	Not drill
Drill	12, 12	15, 15
Not drill	15, 15	0, 0

- Same total surplus but divided equally, as through co-ownership.
- No wasteful drilling—equity enhances efficiency!

WELL DENSITY AND CO-OWNERSHIP



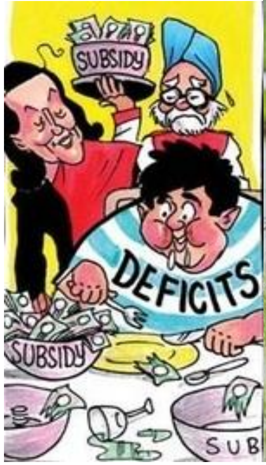
4 WELL-FARE ECONOMICS QUESTIONS

(4) WHAT POLICIES CAN ARREST GROUNDWATER DEPLETION?

POLICY FRAMEWORK

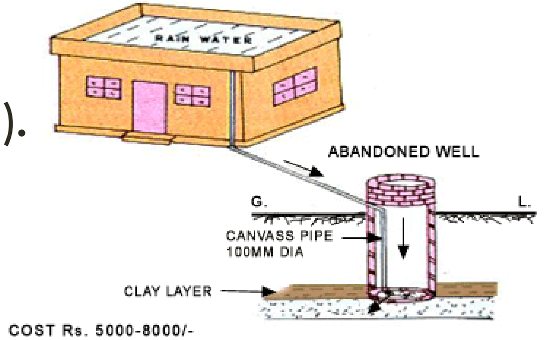
- We have seen that, in some contexts, controlling groundwater depletion may be economically justified.
- But not in all contexts….
  - Canal commands of Punjab, PK with reliable surface water
  - Parts of northeastern India and W. Bengal
  - In these places, we may want to ***encourage*** access to groundwater
    - Credit constraints may limit profitable well investment opportunities.
    - Positive vertical drainage externalities.

ANTI-DEPLETION POLICIES



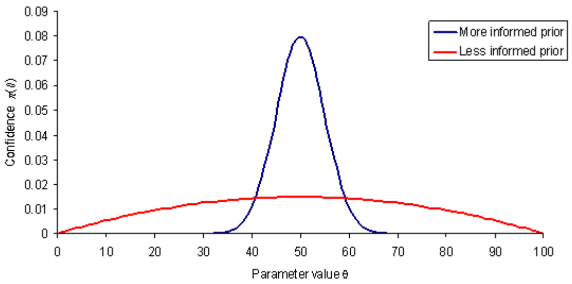
- Remove price subsidies for groundwater-intensive crops (rice, wheat)
- Meter electricity and charge per kwh
  - Voltage stability mitigates pump burnout (WB, 2001).

- Permit system for well-drilling or power connections.
  - Enforcement of existing regulation virtually non-existent
- Public tubewells?
  - Governance problems (as in public surface irrigation).
  - Can’t put private genie back in the bottle!
- Artificial recharge (a local solution in hard-rock areas).

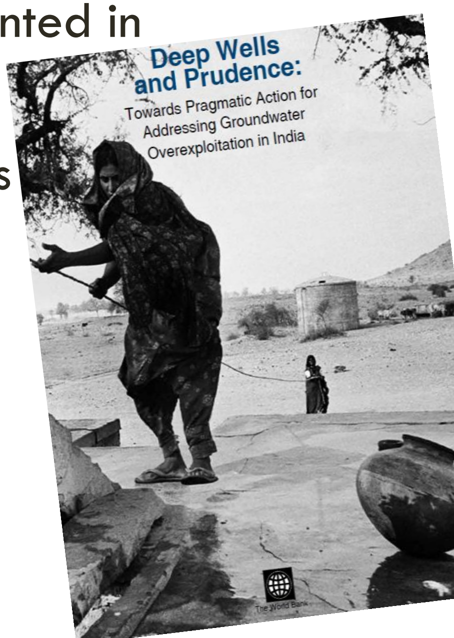


Recharge Through Abandoned Dug Well

COMMUNITY GROUNDWATER MANAGEMENT

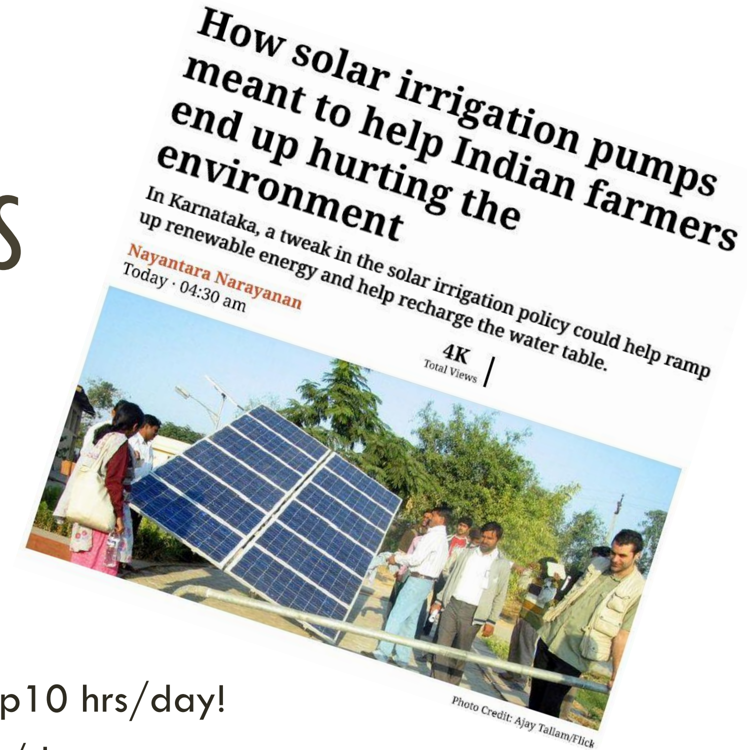


- APFAMGS: Community monitors groundwater balance in local aquifer to inform dry season planting decisions.
- Essentially tightens priors around variance of end-of-season groundwater supply.
- Giné and Jacoby (2015): Higher variance ⇒ less area planted in the dry season ("precautionary planting")
- Although pilot looks promising, jury is still out on whether this intervention is cost-effective and sustainable.



SOLAR-POWERED PUMPSETS

TO SUBSIDIZE OR NOT?


How solar irrigation pumps meant to help Indian farmers end up hurting the environment

In Karnataka, a tweak in the solar irrigation policy could help ramp up renewable energy and help recharge the water table.

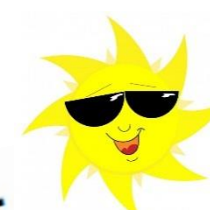
Nayantara Narayanan

Today · 04:30 am

4K Total Views

Photo Credit: Ajay Tallam/Flickr

- Subsidy likely to encourage depletion.
- But drilling incentives are already distorted
  - 5-hour daily power ration ⇒ 2 borewells needed to pump10 hrs/day!
  - Solar pump ⇒ only one borewell needed to pump 10 hrs/day.
- Solar subsidy may **reduce** rent-seeking (wasteful drilling) even as it **increases** depletion (more drilling/pumping overall).
- Punjab (IN) will condition its solar subsidy on adopting drip irrigation.

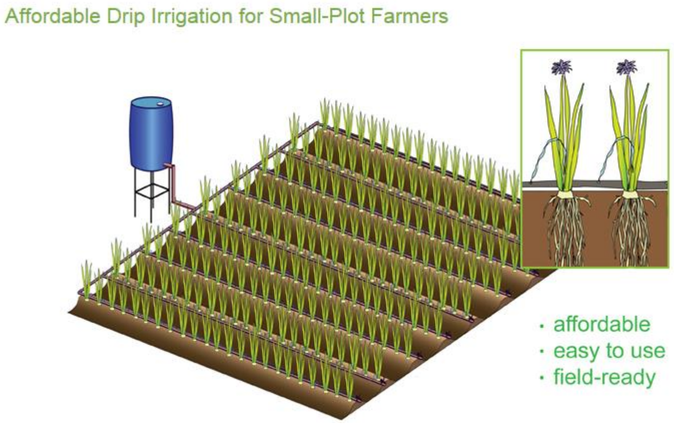


India Plans to Install 26 Million Solar-powered Water Pumps

Solar tube-well installation: 'government to give 80 percent subsidy'

DRIP IRRIGATION

- Given that policies to raise the cost of groundwater extraction are political landmines, what about subsidizing water-saving technology?
- Drip irrigation uses water more efficiently, but will it save water?
- Insofar as farmers expand irrigated area, it may not!
  - Depends on organization of groundwater markets
- RCT planned in AP will examine this question.
- Results (hopefully) in near future!



THANK YOU!