Economics 134 L15. Water resources

Will Rafey

UCLA

November 24, 2025

Natural resources

We will spend the next few lectures looking at natural resources:

- oil (L13)
- conservation, biodiversity (L14)
- water (today)
- forests, wildfires (L16)

Water values

Source. Bonnie Keeler (University of Minnesota)

Basics

Water is essential to life and civilization

- Available supply of freshwater $\approx 10\times$ current global consumption
- But this conceals relative **scarcity** across space and time

Water scarcity:

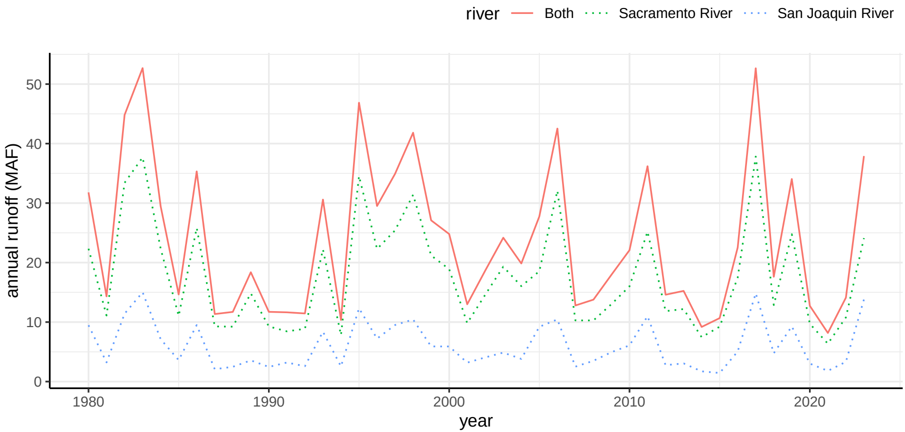
- Surface water **supply** fluctuates over time and space
- Groundwater **depletion** can occur more rapidly than recharge

This lecture: the efficient allocation of scarce water across competing uses.

Central theme:

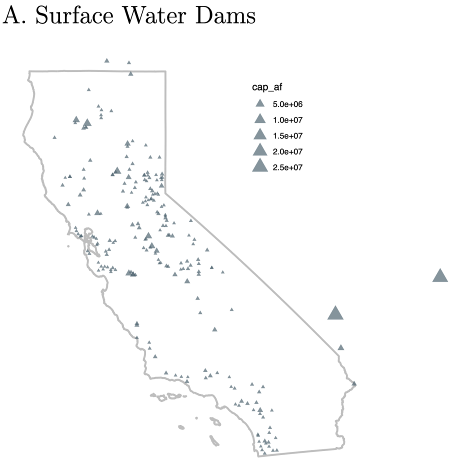
- property rights often incomplete or inflexible
- limited use of pricing

Large stochastic, cyclical components of water supply



River inflows from the two largest rivers in California, 1980–2023.

Water scarcity – California



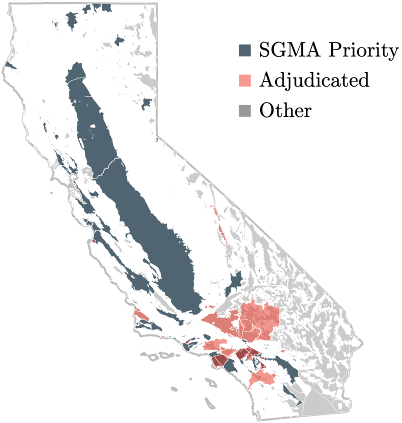
>20m af water storage in dams

Water scarcity – California

A. Surface Water Dams

$>$20m af water storage in dams

B. Groundwater Aquifers



gwtr is 41% total use in avg yr

Brief history of water rights in the U.S.

Early settlement in the American West: **riparian rights**

- water rights tied to the land

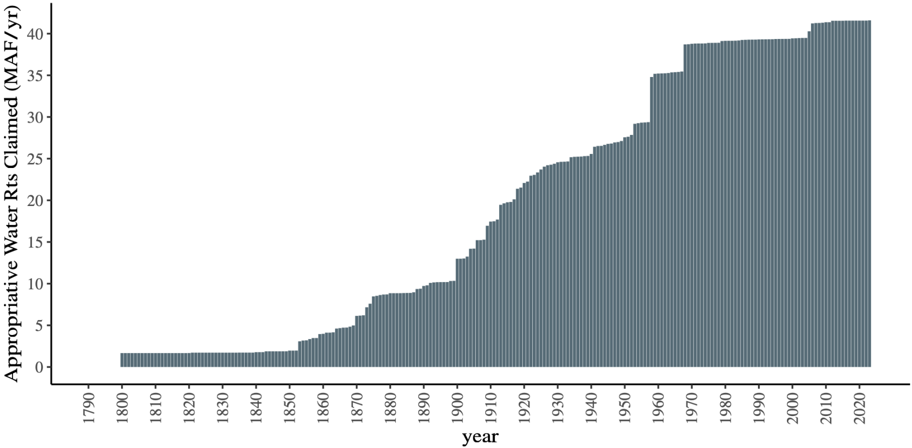
↪ problem: no provision to divert water to other locations

Gold rush: **prior appropriation rights**

- first-come, first-serve: "senior" rights
- later claimants: "junior" rights
- adopted in legislation, court rulings, and state constitutions

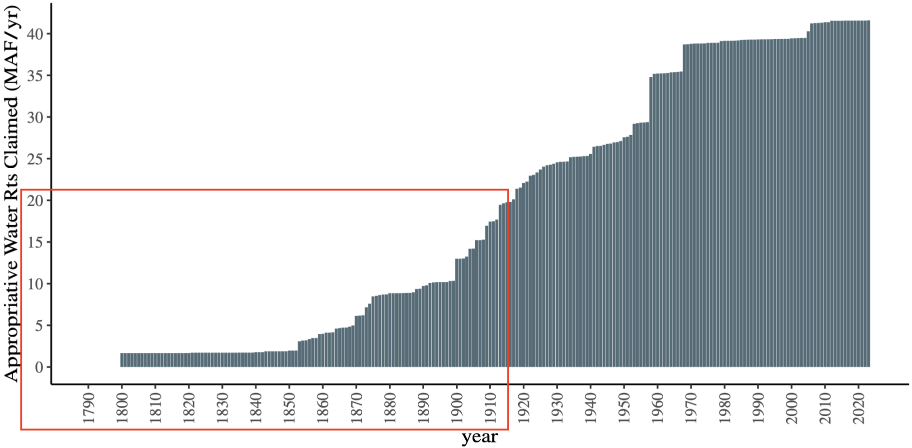
↪ allowed water to be reallocated to other uses, like mining and irrigation

Prior appropriation water right claims



Source. Author's calculations using the California State Water Resources Control Board Water Rights Information Management System. Central Valley irrigation water rights only.

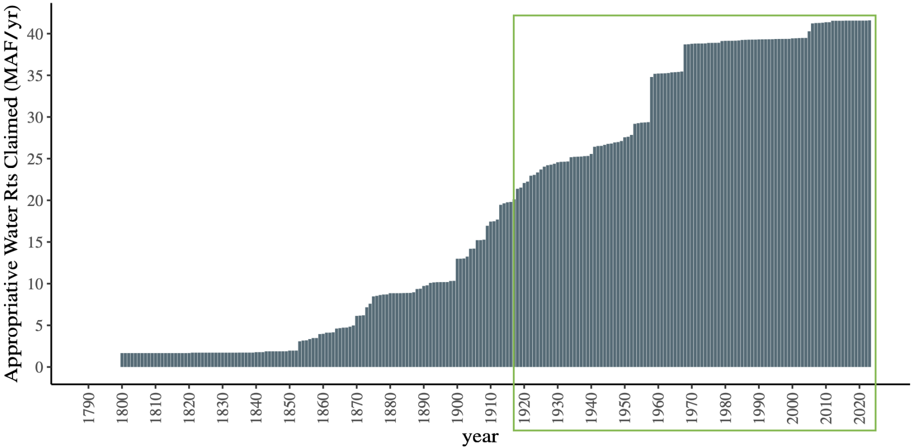
Prior appropriation water right claims



2,571 water rights claimed prior to 1914

Source. Author's calculations using the California State Water Resources Control Board Water Rights Information Management System. Central Valley irrigation water rights only.

Continued legacy of senior rights



3,069 water rights post-1914

Source. Own calculations using the California State Water Resources Control Board Water Rights Information Management System. Central Valley irrigation water rights only.

Water property rights

Over longer timeframes, who should keep their appropriative rights?

Various approaches:

- keep your water rights if you continue to irrigate ("use it or lose it")
  - obvious incentive problems
- administratively determined, proportional rules, based on your characteristics
  - e.g., each farm i gets some share ρ_i
  - hard to determine these shares
  - this is a form of command-and-control

Efficient water allocation

Suppose that farmers value a volume of water q in terms of profits $\pi_i(q)$.

The marginal value of water for farm i using q_i of water is $\pi_i'(q_i)$.

Consider a simple example with two farms, 1 and 2, with profits

$$\pi_1(q) = 8q - \frac{1}{2}q^2$$

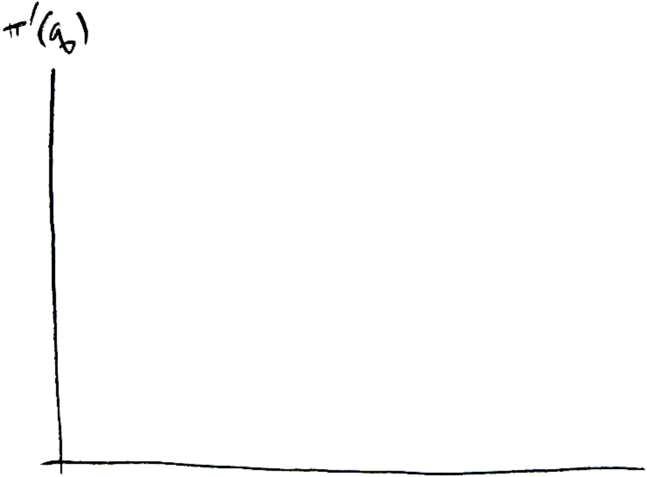
and $\pi_2(q) = 4q - \frac{1}{2}q^2$.

The marginal values of water are then

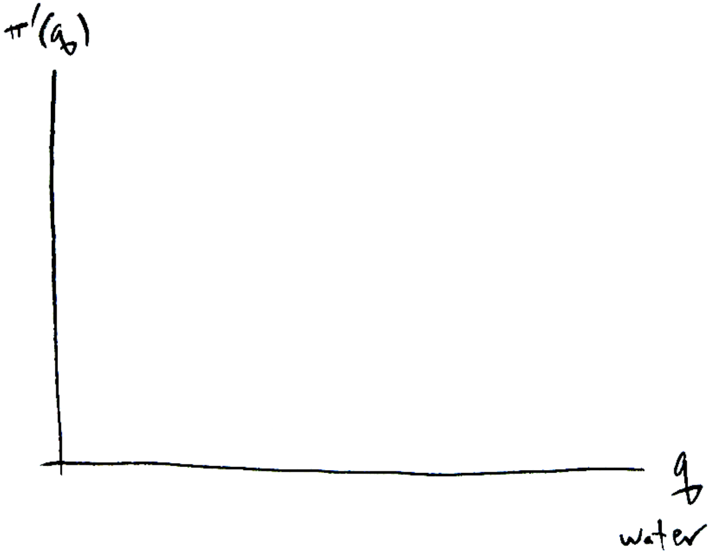
$$\pi_1'(q_1) = 8 - q_1$$

and $\pi_2'(q_2) = 4 - q_2$.

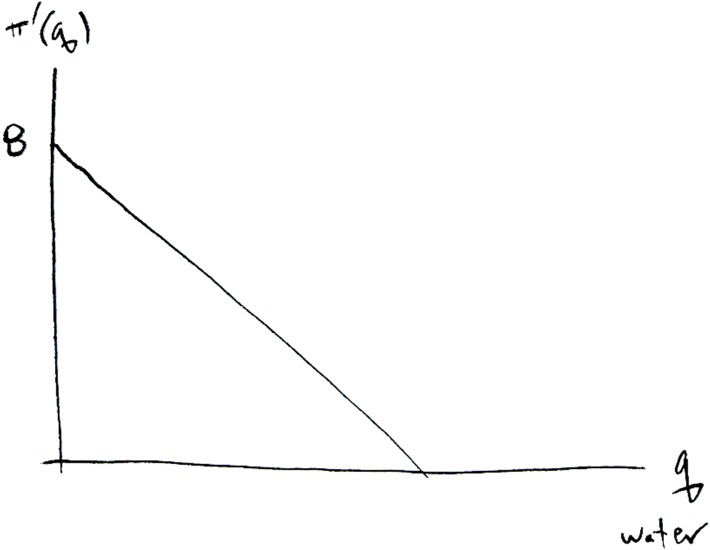
Marginal private values



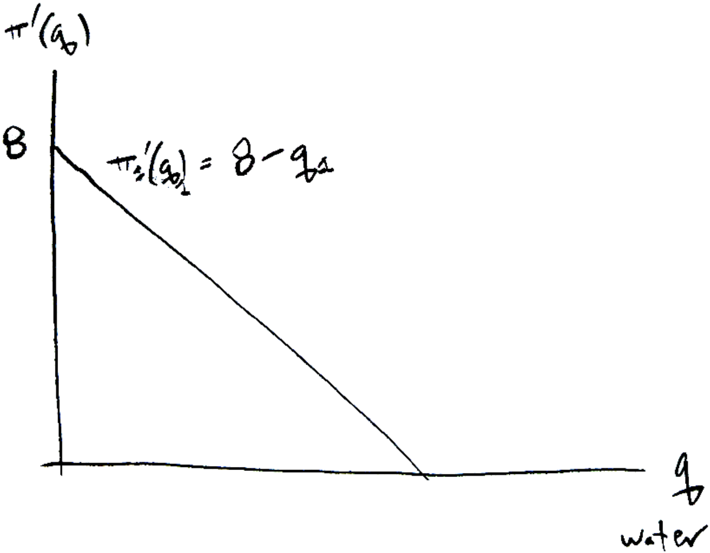
Marginal private values



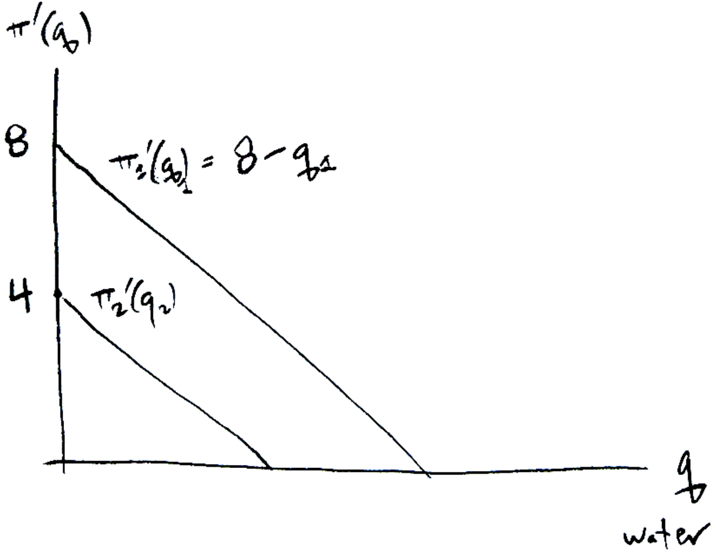
Marginal private values



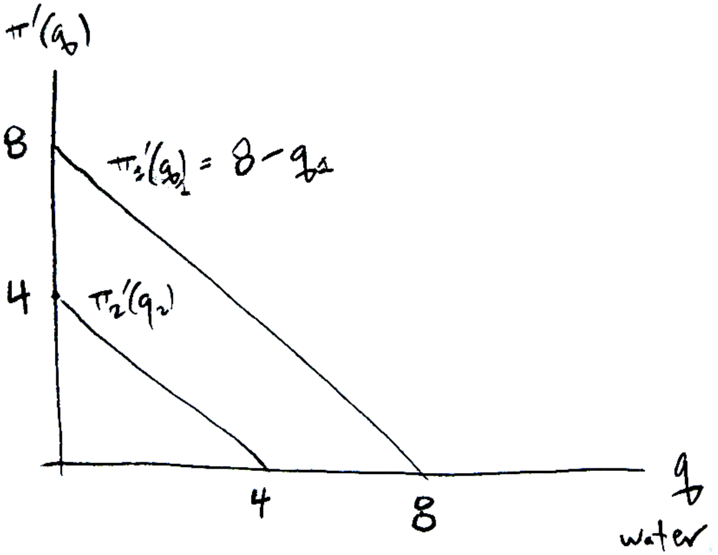
Marginal private values



Marginal private values



Marginal private values



Example, cont'd

Water has a price of zero, but there is only $\overline{q}$ in total.

The **water allocation problem** is how to assign a total volume of water $\overline{q}$, across the two farms, such that

$$q_1 + q_2 = \overline{q}.$$

Property rights determine this allocation.

For example, suppose farm 1 arrived first, but farm 2 owns the land next to the river. Then:

- **riparian rights**
  - only farm 2 can take the water!
- **prior appropriation**
  - farm 1 takes water until $\pi_1'(q) = 0$,
  - then farm 2 can take water.
- **proportional**
  - e.g., 1 can take $\rho\overline{q}$, then 2 can take $(1-\rho)\overline{q}$.

First-best

First-best outcome. To attain efficiency, we maximize

$$[\pi_1(q_1) + \pi_2(q_2)]$$

over all (q_1, q_2) such that $q_1 + q_2 \leq \overline{q}$. Let

$$\Pi(\overline{q})$$

be the first-best aggregate profit for a total quantity of water $\overline{q}$.

First-best marginal value of water

What is the marginal social value of water, when water is allocated across farms efficiently?

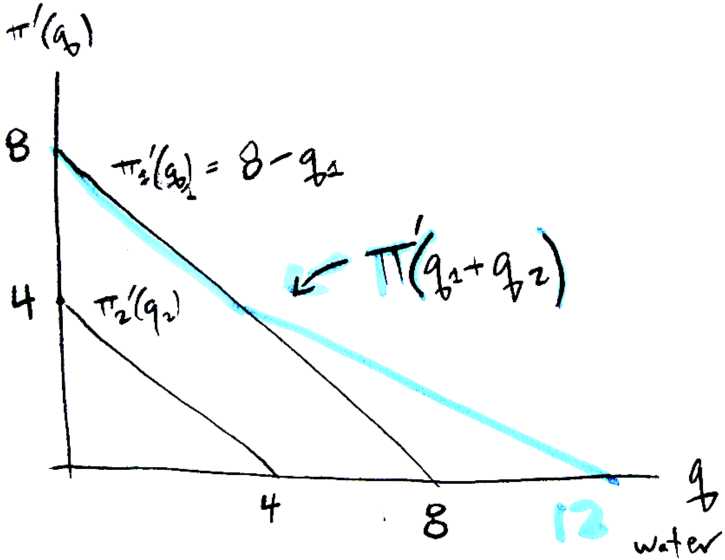
$\hookrightarrow$ Depends on how much water there is!

- If total water availability $\overline{q} < 4$, allocate **all** water to farm 1.
- If $\overline{q} \geq 4$, allocate the first 4 units to farm 1, then evenly distribute the rest across the two farms!
- Once $\overline{q} > 12$, no more water can be used productively.

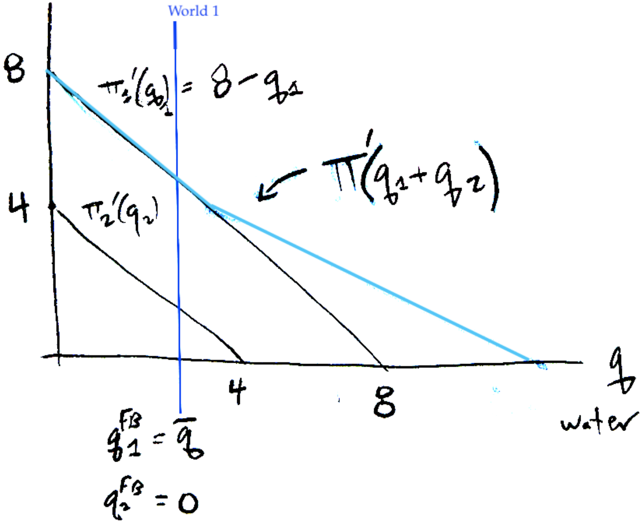
Summarizing, we have

$$\Pi'(\overline{q}) = \begin{cases} 8 - \overline{q} & \text{if } \overline{q} < 4 \\ 4 - \frac{\overline{q}-4}{2} & \text{if } \overline{q} \in [4, 12] \\ 0 & \text{if } \overline{q} > 12. \end{cases}$$

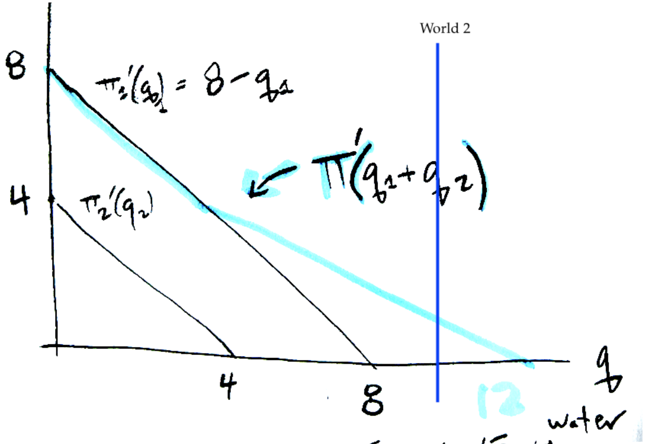
Marginal social value



(a) Extreme scarcity



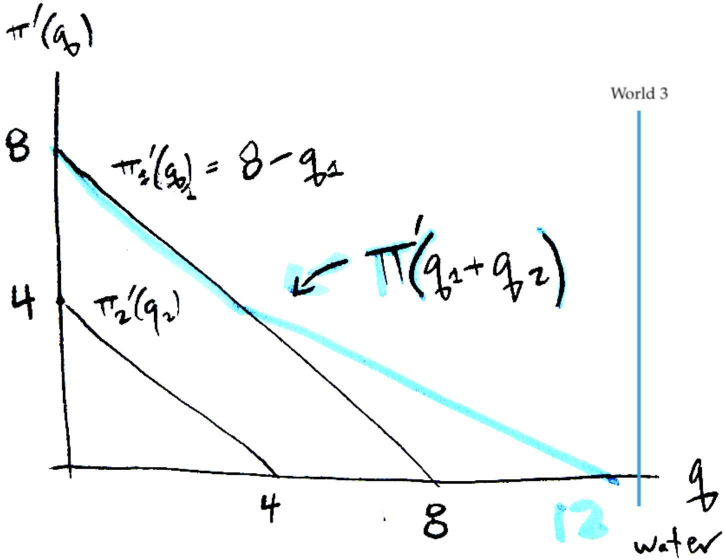
(b) Relative scarcity



$$q_1^{FB} = 4 + \frac{(\bar{q}-4)}{2}$$

$$q_2^{FB} = \frac{\bar{q}-4}{2}$$

(c) Abundance



Comparing first-best and appropriative rights

(a) Suppose $\overline{q} = 3$. Then:

- first-best outcome:

$$8\overline{q} - \frac{1}{2}\overline{q}^2 = 24 - \frac{9}{2} = \frac{39}{2}$$

- prior appropriation, with farm 1 first:

$$8\overline{q} - \frac{1}{2}\overline{q}^2 = \frac{39}{2}$$

- prior appropriation, with farm 2 first:

$$4\overline{q} - \frac{1}{2}\overline{q}^2 = 12 - \frac{9}{2} = \frac{15}{2}$$

- proportional rights: something between $\frac{15}{2}$ and $\frac{39}{2}$

Comparison, cont'd

(b) Suppose $\overline{q} = 6$. Then:

- first-best outcome: $q_1^{\mathrm{FB}} = 5$, $q_2^{\mathrm{FB}} = 1$.
- prior appropriation, with farm 1 first: $q_1 = 6$.
- prior appropriation, with farm 2 first: $q_2 = 4$, $q_1 = 2$.
- proportional rights: $q_1 = 6\rho$, $q_2 = (1 - \rho)6$.

(c) Suppose $\overline{q} = 12$. Then all property rights regimes give the first-best outcome.

Discussion

Key takeaway: aggregate water scarcity dramatically changes the efficient allocation

1. when water is very scarce, want to prioritize highest-value users
2. when water is somewhat scarce, want to equalize marginal profits across farms
3. when water is abundant, it doesn't matter

Climate change, water scarcity, and trade

Water resources: increasingly scarce and variable in a changing climate

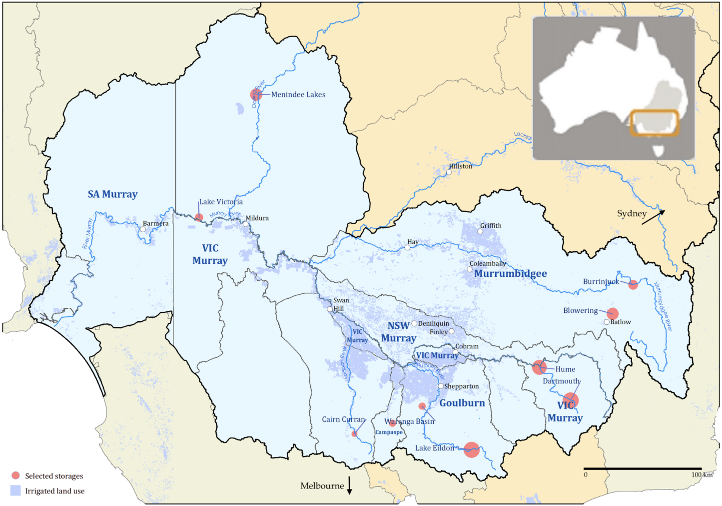
- historically not traded; allocated in non-market ways
- growing interest in **water markets** (Dales, 1968) to improve allocative efficiency
- but limited evidence that water markets deliver substantial benefits

In Rafey (2023), I measure the value of a water market, given that

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

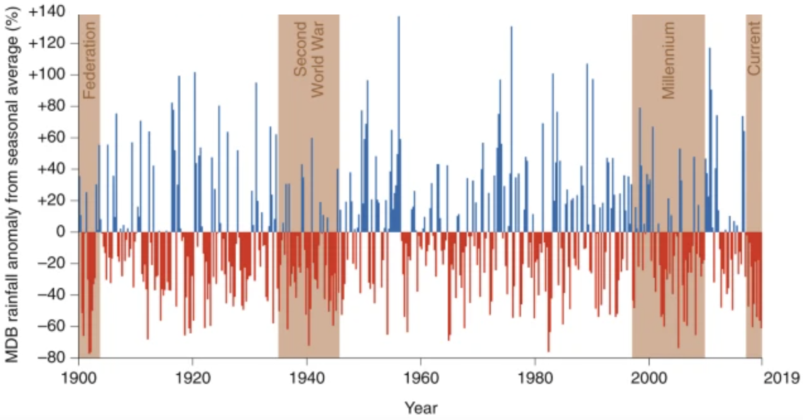
1. Australia's water market

Advanced water market in Australia's southern Murray-Darling Basin.



1. Water variability in Australia

Fig. 1: The recent drought in context and the drivers of seasonal rainfall variability in the Murray–Darling Basin of Australia.



1. Australia's water market

Advanced water market in Australia's southern Murray-Darling Basin.

Connected river network in southeastern Australia.

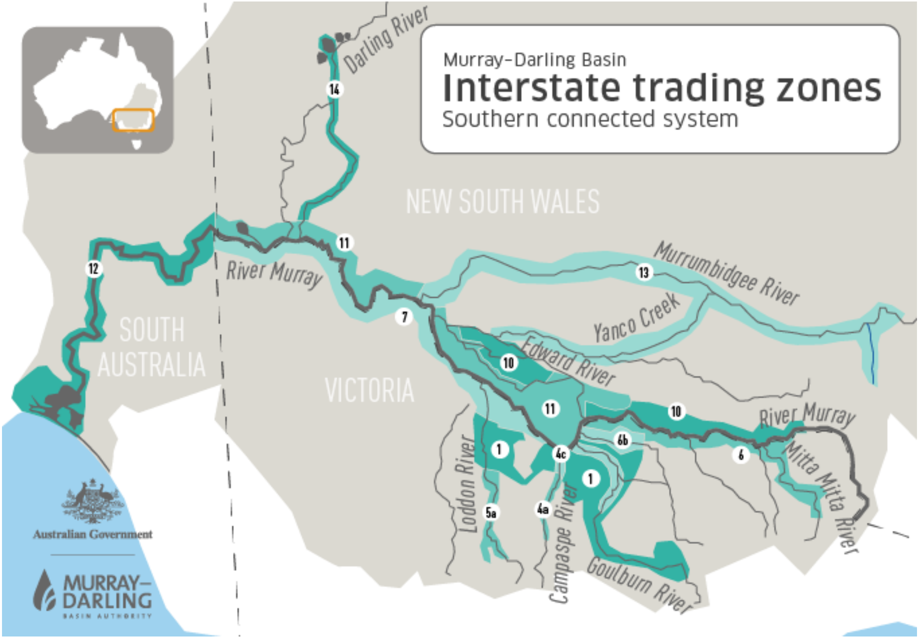
- $\approx 40\%$ of Australian agriculture
- rainfall **highly variable**

Surface water used primarily for irrigation

- irrigated farms: 80–90% of water diversions in the sMDB
- irrigated agriculture: $\approx 70\%$ of all freshwater diversions globally

Regulated river system:

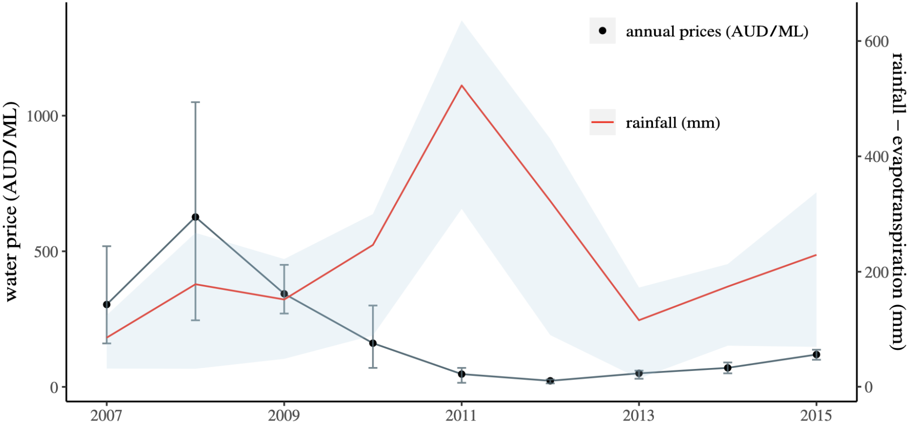
- environmental regulation $\times$ distribution of permanent water rights $\implies$ initial allocation of water in each year,
- then continuous water trading throughout the growing season.


Murray-Darling Basin
Interstate trading zones
Southern connected system
NEW SOUTH WALES
SOUTH AUSTRALIA
VICTORIA
Darling River
River Murray
Murrumbidgee River
Yanco Creek
Edward River
River Murray
Mitta Mitta River
Loddon River
Campaspe River
Goulburn River
14
11
12
13
7
10
11
10
6b
6
4c
1
1
5a
4a
Australian Government
MURRAY–DARLING
BASIN AUTHORITY

Data sources

1. Farm-level panel data from a survey of irrigators in the sMDB, 2007–2015 (Australian Department of Agriculture)
2. Climate data: farm rainfall, evapotranspiration (Bureau of Meteorology)
3. Administrative data on regional allocations, water prices
   - from regulatory MDBA, state gov't records

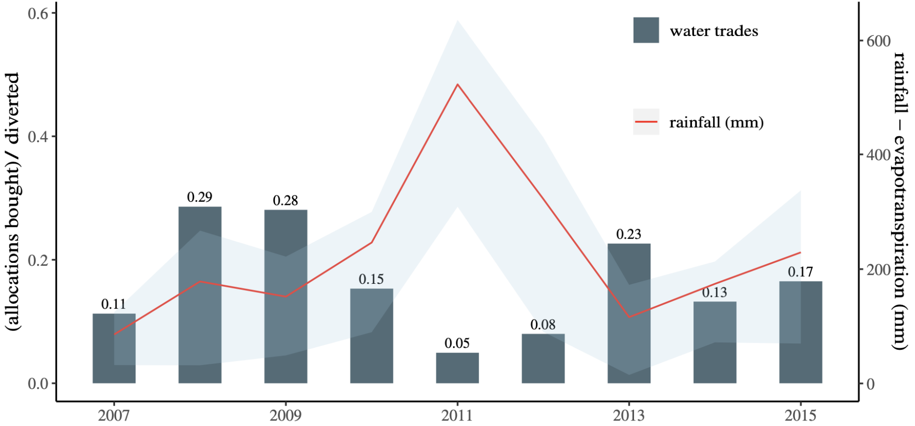
Water prices and rainfall



Blue line (whiskers): Average water allocation prices, AUD/ML (interdecile range)
Line (ribbon): Average farm-level rainfall net of evapotranspiration (interdecile range).

Source: MDBA, private broker, and state government water registries; Australian Bureau of Meteorology.

Water-trading volumes and rainfall



Bars: Fraction of total irrigation volume traded in the annual market

Red line: same rainfall series

Source: Australian Department of Agriculture survey data; Australian Bureau of Meteorology.

Measuring the value of water reallocation

Approach:

1. estimate irrigation production functions to value water across users
   - use data on water rights, irrigation, and agricultural production

2. apply to value actual market-based water reallocation:
   1. how do pre- and post-trade farm profits differ?
   2. how does the value of the market interact with water variability?
      $\hookrightarrow$ use variation in relative water scarcity across the basin and over time

2. A model of irrigated agricultural production

Fixed set of farms, producing different crops.

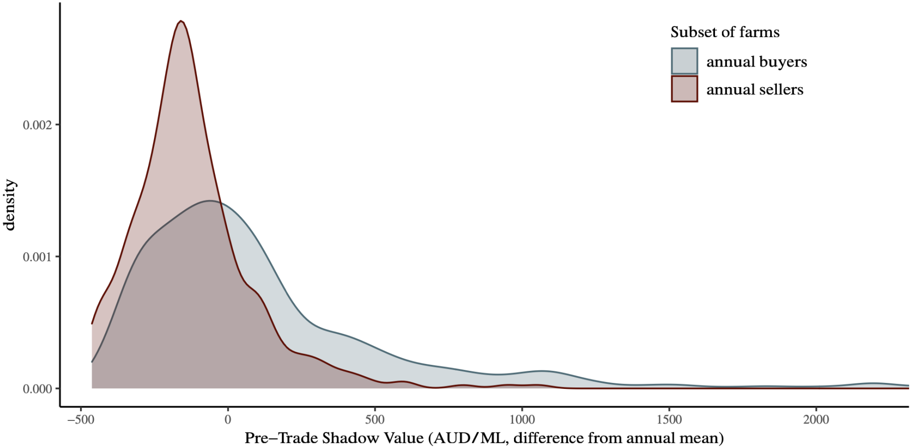
A farm's output depends on its observed inputs

- irrigation,
- land,
- rainwater,
- labor and materials.

Output also depends on a farm's unobserved **productivity**, which is

- specific to each farm for each crop type;
- flexibly correlated over time

Water shadow values (marginal products)



3. Valuing the realized trades

For each farm i,

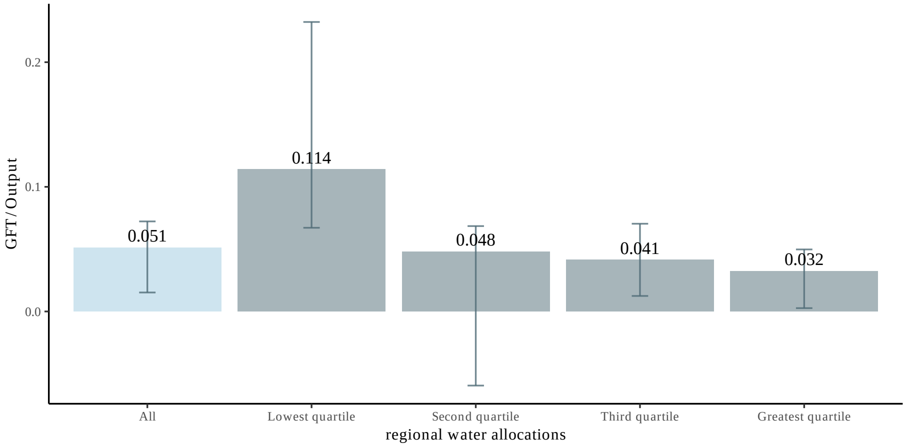
1. compare post-trade irrigation W with pre-trade endowments W^a
2. water + production functions $\longmapsto$ expected profits at harvest, $\pi_i(W)$
3. realized **gains from trade** = the difference between $\pi_i(W)$ and $\pi_i(W^a)$

Summed over all farms gives **5.1%** [1.6%, 7.1%] of output from 2007–2015.

Interpreting this number:

- -5.1% output from eliminating the market $\approx -10.5\%$ uniform decline in water resources
- cf. climate models: Murray-Darling surface water $\downarrow 11\%$ for 1°C warming (CSIRO, 2012)

Water variability and the value of annual trade



Value of annual allocation trading by regional water cap

Summary of findings

Given estimated production functions and observed trade flows,

1. how do pre- and post-trade farm profits differ?
   - find: water flows from low- to high-marginal productivity farms
     output $\uparrow$ 4–6%

2. how does the value of the market interact with climate change?
   - find: gains from trade increasing + highly convex in water scarcity
     output $\uparrow$ 10–12% during drought

Discussion

Worldwide: few active water markets ($<$1% traded annually)

Competing explanations:

1. inefficient persistence of institutions designed when water was more abundant
2. efficient response to the costs of establishing and monitoring transferable property rights

This paper:

- both explanations can be important!
- water market creates value, but remains imperfect
- water market has a nonlinear (very convex) value in water scarcity:
  - retrospective analyses may understate the prospective benefits of trade
  - water markets may be important for climate adaptation going forward

Next time

Last problem set due before lecture on Wednesday.

On Wednesday, we will discuss natural disasters and wildfires!

Next lecture occurring via **Zoom**, link via course website.