Climate sensitive water allocation systems and economic instruments

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A caveat

- I will be talking about what has happened in the western United States.
- That is because this is what I know best.
- It is not because I regard the western US as an exemplar or a role model – to the contrary, I do not regard it as an exemplar.
- Many things with water management and allocation are dysfunctional in the US.
  - Some of these dysfunctions may be common with water elsewhere.
    - But you will know how much that is true much better than I.
- I am looking forward to what I will learn from all of you through our collaboration in TRANSCEND!

An observation

- While climate change is the crucial motivation for TRANSCEND, and while climate change does add layers of complexity to the issues of water allocation and the choice of economic instruments, both water allocation and choice of effective economic instruments have remained largely unsolved problems even without climate change.
- So, we are dealing with the legacy of unsolved management problems that pre-date climate change while also struggling to adapt to climate change.

Conclusions

- Water allocation: water is not allocated in the US
- Water markets: don’t function the way economists typically assume
- For many policy issues, bargaining is the preferred lens, not optimization
- Economic instruments: not a major determinant of water use in the US
- Agricultural demand is often different from how we model it
- Climate change: the key is to account for the impact of local extreme events
- The key obstacle to climate adaptation is procrastination and unwillingness to make difficult decisions in advance
- The central focus of climate change policy should be risk measurement, modeling and management
- Pay attention especially to downside risk
- Water is about politics. To succeed you need to get the politics right, not just the economics.

Water allocation

- Effective water allocation is hampered unless:

1. There exist some agency possessing the legal authority to allocate or oversee the allocation of water.
2. That agency has the political will and ability to exercise its authority.

- These are generally lacking in the United States.

Water allocation in the US

- In a sense, water is not consciously allocated in the US. It is property that has been acquired.
- Water quantity is not regulated by the federal government – it is controlled by the individual states.
  - Water quality regulation, which started ~1972, is regulated by the federal government.
- The general notion is that the waters of a state belong to the people of the state. What that has meant is that they can abstract the water at no charge.
- The right to use water from a stream or from groundwater is private property in the US.
  - It was private property in Australia until ~1890.
- Water rights are created and enforced by the states individually. The quality of monitoring and enforcement varies greatly among the western states, with Colorado the most diligent and California the least diligent.
- The US does not do river basin management. It does not have river basin management agencies.
  - Individual water user organizations in a river basin are generally like islands of harmony in a turbulent and disorderly sea.
  - The Tennessee Valley Authority has generally deferred to the wishes of (large) water users. Until now, the Colorado River has been managed in deference to the large water users

Market vs administrative allocation of water

- As noted above, the right to use water is private property. Water use is not by a permit or license from the state government which can be revoked or modified.
- As explained in a moment, the property right to use water is not the most common water right being used or transferred in the western US
- Permanent transfers of the property right to use water play a limited role in the allocation of water in the US West.
- Because of water law in the western states, the transfer of a property right to use water is subject to legal/administrative review.
  - That makes the transfer a combination of a market system and an administrative system.
  - It also makes for significant transactions costs.

Complexities of the legal right to use surface water in the US West

- A crucial distinction, widely overlooked, is that between a **property right to use** (extract) water versus a **contract right to receive water**.
- Many -- probably most – water users have a contract right, not a property right to use water.
- The two rights are subject to very different restrictions.

- A contract right is the right to receive water from a water supply organization (wholesale or retail). This is subject to the organization's rules as well as, say, the municipality law or corporate law governing the organization.

- A property right is the right to divert up to a maximum rate of flow of water (NOT a total volume of water), during a specified time period, at a specified location, for a particular type of use at a specified location.
    - Changing any of these details requires approval, subject to some exceptions.

The property right to use water – US West

- Governed by a priority system, not a sharing system.
  - Based on seniority according to date of first diversion.
  - If there is too little streamflow, senior rights take their full maximum, junior rights get nothing.
- It is a right to use – not own – water subject to several key restrictions:
  - The water must be put to use; right is lost if unused for ~5 years.
    - The notion is that the right should be held for use, not for speculation.
  - The use must be "reasonable and beneficial."
    - For decades, this meant nothing in practice. But, it may not come to play a substantive role.
    - In California, there is now judicial recognition that what is reasonable can vary over time as circumstances change.
- Crucially, there are additional restrictions if the right is transferred (or the purpose or place of use is changed without a change in ownership).
- **These render the property right inherently ambiguous and incomplete.**

- Transfers of the property right to use water, and changes in the place or type of use are always subject to challenge on two possible grounds:
    1. Violation of the no-injury rule. There shall be no change in the ownership or use of an existing right that affects flows available to any (downstream) holder of a right to use water, regardless of whether senior or junior to the right being changed.
    2. What is transferred or changed must be a valid right to a valid quantity of water.
        - This is not an issue if water rights have been adjudicated, but that is rare.
            - Water users generally prefer not to take the risk of adjudicating their rights.

  If a challenge arises, the burden of proof is on the party proposing to make the change, not on the challenger.
    - This generates substantial transactions costs.
    - It is the major impediment to the transfer of these water rights.

- Three crucial notions underpin the property right to divert water for use:
  1. Water right is to be held for use, not for speculation.
  2. Water is to be shared whenever streamflow is available
  3. Once established, return flows are to be preserved and not disrupted
- Notions (2) and (3) don't come into play with the same force in the case of a right to store surface water.
  - This makes transfers of stored surface water easier.
  - It puts a premium on storage – but creating storage is expensive.
- The no-injury rule and the requirement of a valid right are often relaxed when water is being leased for a short period (e.g., in California, one year or less).
  - That creates an incentive to avoid long leases or permanent sales.

The contractual right to receive water

- The contractual right is generally NOT subject to the no-injury rule or the to the need to prove one has a valid right to a valid quantity.
- However, it is subject to approval by the water distribution organization.
- The transactions cost of transferring a contract right to water are typically minimal – unlike those of transferring a property right to water.
- A common restriction is that water can be transferred, if at all, only to other members of the organization, and not outside the organization's boundary.

The Colorado –Big Thompson Project (C-BT)

- The most active water market in the US, and the most effective market in transferring water from agricultural to urban use.
  - In 1960, ~85% of the water rights were held by agricultural water users.
  - Today ~30% of the water rights are held by agricultural users – 70% by cities.
- These are contract rights – not property rights.
  - Like most contract rights they can be traded with a low transactions cost.
- What makes C-BT special?
- It has a very large service area.
- It has an extensive delivery system connecting its service area.
- The population living within the service area rose from ~200,000 in 1960 to over 1,000,000 now.
  - This is the truly unusual feature.
  - The service area is located just north of Denver, and includes the Front Range.

The heterogeneity of water rights

- The requirements to avoid the no injury rule and to transfer a valid water right, and the associated transactions cost make each property right to water a distinctive commodity.
  - For agricultural water use, water being sold/bought in advance of the growing season, in the early part of the season, and in the late part of the season are also different commodities.
- Contractual rights to receive water from particular water supply organizations are also differentiated commodities.
- Thus, water being transferred is often a differentiated commodity; these commodities transact in *different* markets.
- It is a mistake to think of a water market as one large market in a homogeneous commodity; it is many markets, often small ones, with separate commodities and separate rules.
- Instead of water marketing being one large reservoir holding water, it is many buckets of water, varying in size.

Distinguish permanent sales of water versus short-run leasing of water

- Short-run leasing provides flexibility for water users. It has a significant economic benefit for buyer and seller.
- But, short-run leasing of water does not bring about a long-run reallocation of the use of water.
  - Unless significant storage is available.
    - With enough storage, it may be possible to engineer long-run reallocation of water through multiple short-run leases of water.
- Short-run leasing of water is not obvious as the solution required to adapt to long-run climate change.

In addition, the way we model demand and supply within a water market is often wrong

- Existing empirical analyses of water markets lump together what are markets in separate commodities.
- They fail to distinguish adequately between short- and long-transfers.
  - Programming models of water marketing generally (i) fail to distinguish between short- and long-run transfers, and (ii) ignore hydrologic variability and short-run uncertainty.
- Where they consider leases and long-run sales, often wrongly impose a requirement that the sale price should equal the discounted value of annual lease prices.
  - That holds for financial assets – but not for water which must be put to use.
    - In the US west, you cannot hold a water right to speculate and not put the water to use.
- They assume implicitly that everyone who owns a water right, or who uses water, is in the market to buy or sell.
  - That is almost certainly false. There is a selection process
    - Many water users want to continue as farmers.
  - In the US, only a subset of water users is in the market to sell, unlike in Australia's Murray-Darling Basin today.
- They assume market equilibrium arises from underlying aggregate supply and demand curves that are continuous rather than, say, step functions.

Evolution of participation in water marketing in Australia's Murray Darling Basin

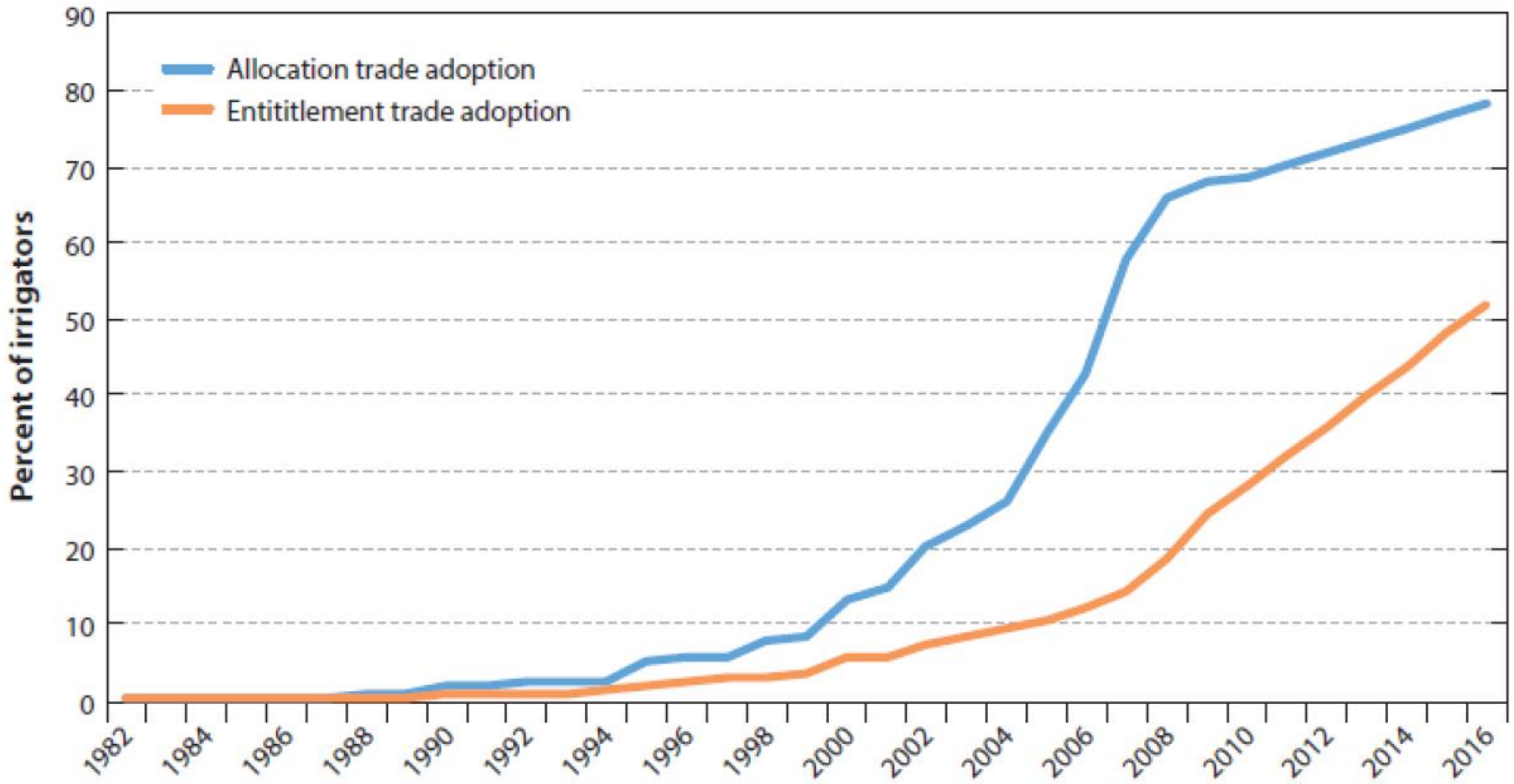
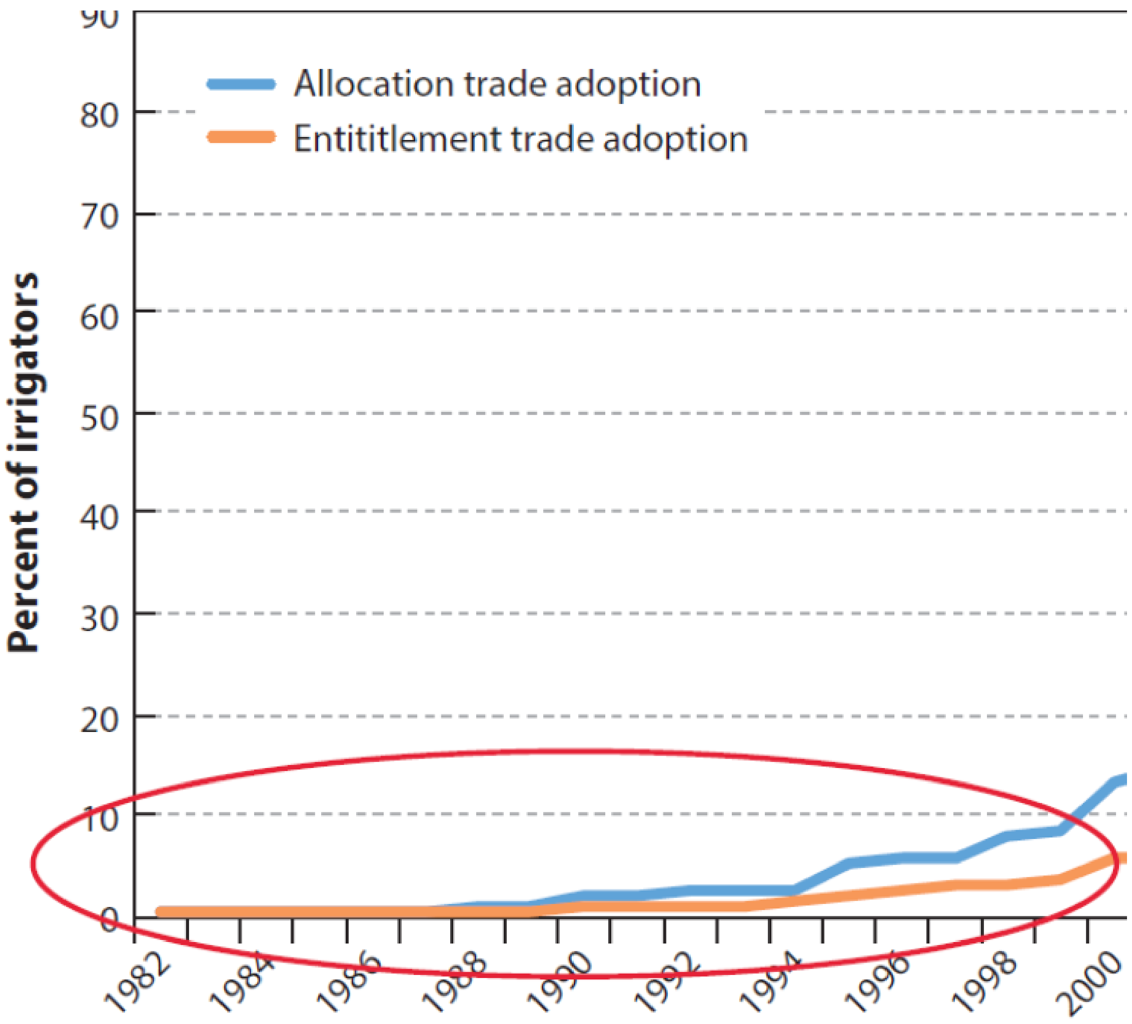


Figure 3

Percent of irrigators in the southern Murray-Darling Basin, Australia, that have used the water allocation and water entitlement markets at least once by 2015–2016. Figure created using current and historical University of Adelaide irrigator survey data.

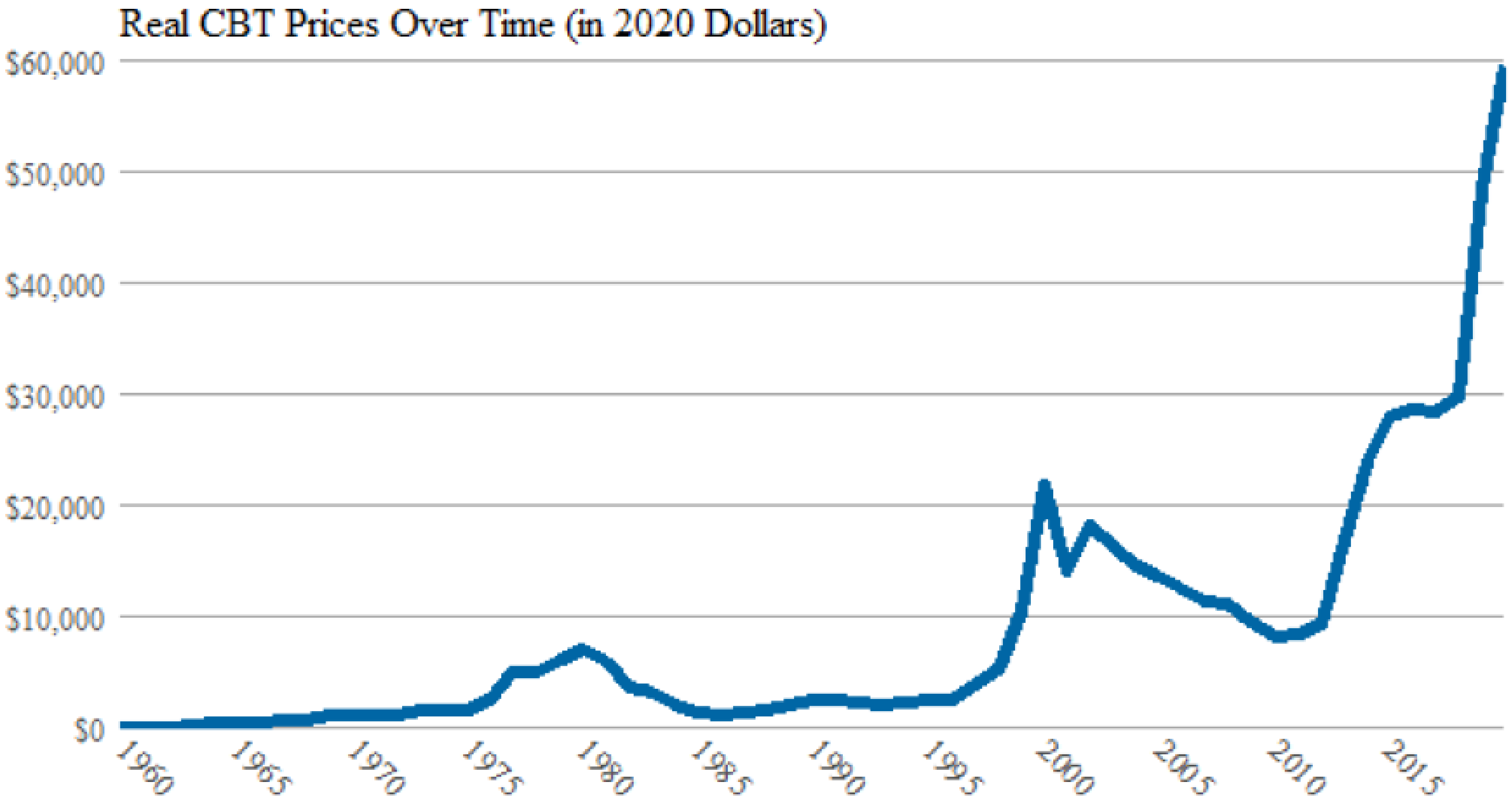
- My hunch is that the surface water market in California looks like this



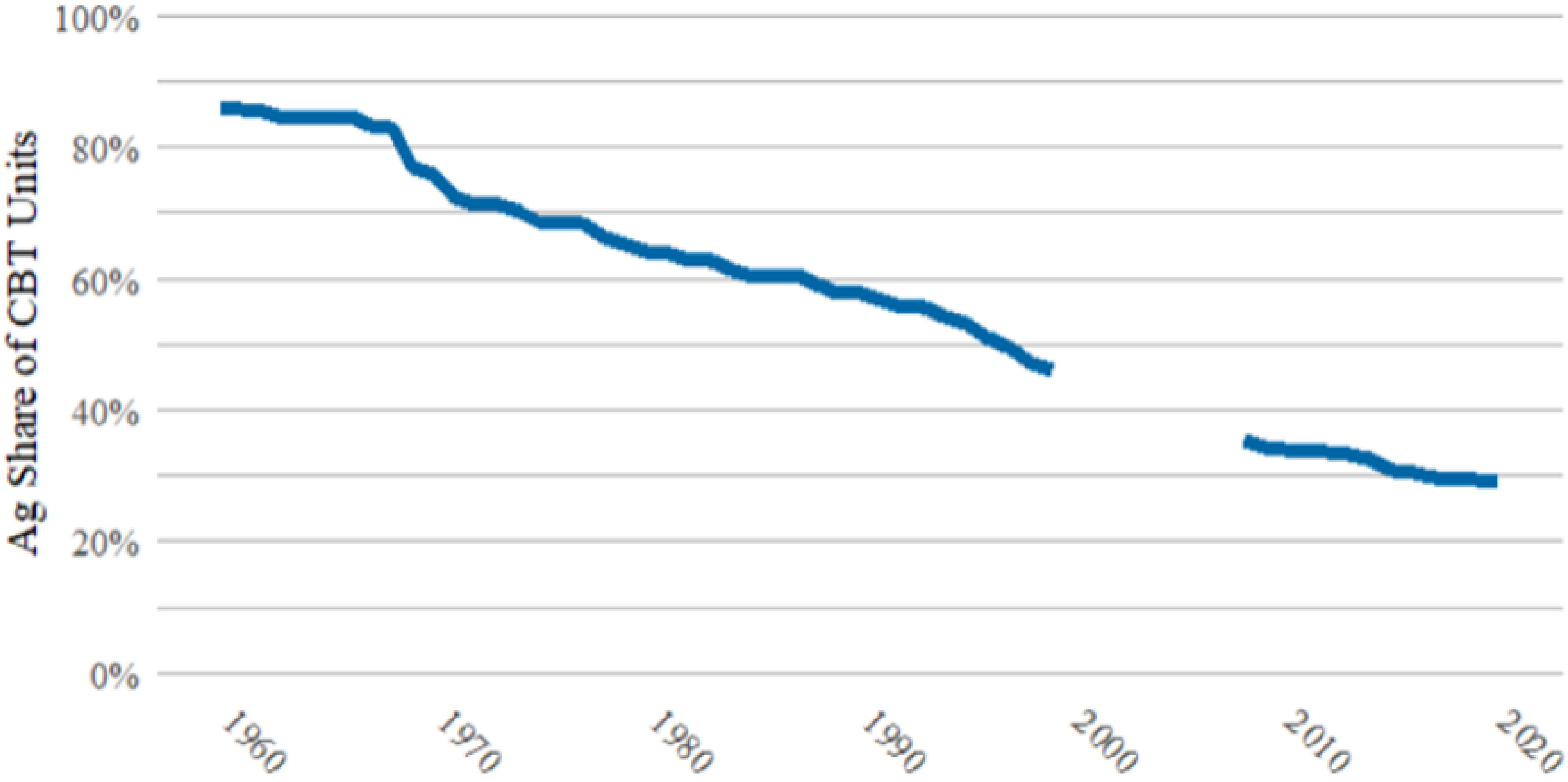
Questions that need to be investigated

- Who chooses to participate as a seller?
- How does that evolve over time?
- What factors (other than price) explain who is willing to become a seller and when?
- How does the aggregate supply curve arise? As the price offered rises, do more sellers exhibit a willingness to sell, or does the amount of water that a given seller offers for sale increase, or both?

- These questions are now being investigated using micro-data from the C-BT market.


Real CBT Prices Over Time (in 2020 Dollars)
$60,000
$50,000
$40,000
$30,000
$20,000
$10,000
$0
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015

Percent of CBT Units in Agriculture Since 1960

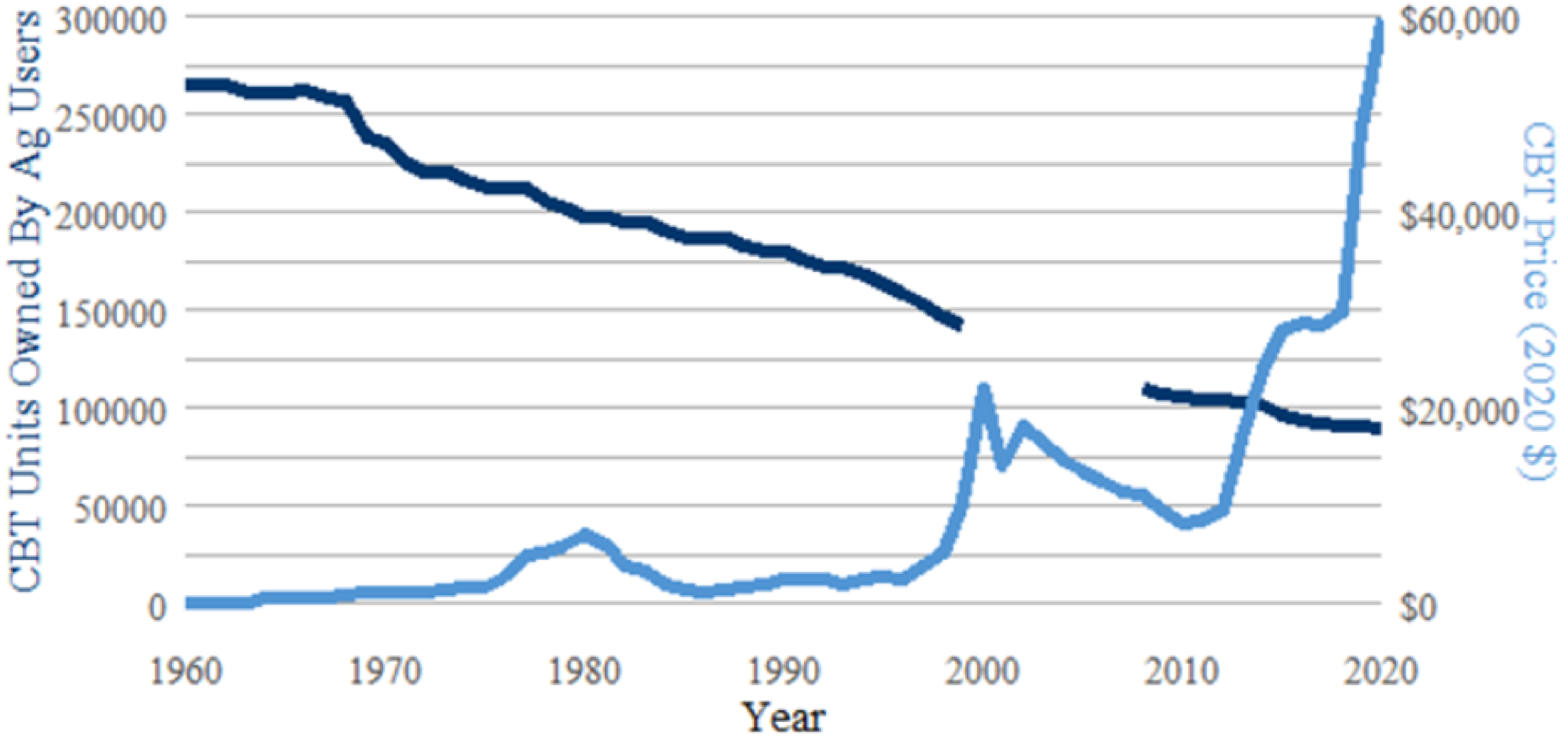


What this suggests is that:

1) There is a steady drift out of agriculture as farmers retire.

2) Water market price is not a major determinant of the sale of agricultural water.

3) The rise in price reflects competition among urban buyers who will pay whatever it takes to buy a water right.



- Economists tend to assume that a water market is rather like the stock market.
  - If the price of IBM shares rises from 150 to 155, somebody who would not sell at 150 now chooses to sell at 155. Water users are more likely to sell in discrete chunks. They also are likely to sell when on the way to retirement.
    - This comes out from a very detailed analysis of C-BT transactions.
- I think that a water market is often more like a furniture warehouse. Customers don’t come in every hour. They drop in once a week or once every few weeks. One time, the customer is looking for a sofa; another time, for a chair.
- This calls for a different approach to statistical modeling of market equilibrium.

Where water market transactions do and don't occur

- Transactions costs are lowest for (1) transfers of contractual rights to receive water within a given water supply organization, and for (2) short-term leases of property rights to water.
  - The latter because the rules that normally apply to transfers of a property right to water have often been waived for short-term leases of these property rights.
- These types of exchange constitute the overwhelming majority of water transfers that occur in the US West.
  - Sales of contract rights to water are sometimes an effective adaptation for economic growth & climate change, as in C-BT, but not most of the time.
- Short-run leases of property rights to water are not obviously the best tool to manage population growth and economic development, or the best adaptive shield to deal with climate change.

In order to broaden the scope of water markets

To broaden the scope of water marketing it would be necessary (1) to allow the transfer of contract rights to water outside the service area of the water supply organizations, and (2) to soften the constraints imposed by the no-injury rule on property rights to water, and (3) to adjudicate property rights to water to eliminate questions about the validity of existing property rights to water.

- None of these changes is easy.
  - Such changes face heavy political opposition, which is what has prevented them from being made during the last 100+ years.
- None of these changes is likely to occur within the next 20-40 years.
- Changing water rights is the key to changing the role of water markets. This is a political challenge. It requires a political strategy as well as an economic one.
  - A successful political strategy most likely will involve some form of compensation.
  - There is a requirement for an actual Pareto improvement – not a potential Pareto improvement.
    - The distributional impacts matter!!!

Modeling water as bargaining, not optimization

- Economists tend to approach water via an optimization analysis, as though there were a supreme planner controlling things.
- That is a delusion. Because of the political, ethical, and emotional concerns aroused by water, the power to make and implement decisions is, at best, both dispersed and shared.
- Hence a bargaining analysis is often more meaningful and relevant.
- That approach highlights the importance of conciliation and compensation (monetary or otherwise) in securing majority agreement, if not total consensus.

- How should the conflict be conceptualized?
- For subnational water conflicts, since the parties can, and do, sign binding contracts among themselves, this calls for an application of cooperative game theory.
  - It is not appropriate to non-cooperative game theory (e.g., Prisoners' Dilemma)
- Co-operative game theory can shed light on why divergent outcomes have emerged for the conflicts in the two basins.
  - Emergence of harmony in the Colorado River after ~2000
  - No such development yet in California

Solution to a cooperative (bargaining) game

- The conflicts are zero-sum games.
  - To be sure there is space for some win-win solutions.
  - But, in the end, there is only so much water to be allocated.
  - And the needed infrastructure involves joint costs which must somehow be allocated among the parties.
  - These two features make the conflict, at bottom, a zero-sum game.
- A solution to the game is likely to lie in the core.
  - The core is the set of outcomes with the property that no coalition of players, acting as an independent group, can achieve more for itself than what it would obtain from outcomes in the core. The core is thus the set of bargaining outcomes that cannot be improved on by any coalition acting alone.
- A theorem states that, when the game is zero-sum, no core exists.
  - In such a game, any equilibrium leaves at least one group in the position that it can do better for itself by dropping out and going it alone.
  - Hence, any bargaining equilibrium is not stable and cannot be sustained.
  - The long history of litigation on the Colorado and in CA exemplifies the result predicted by the theorem.

When can a bargaining solution arise?

- A key factor for each party in a bargaining game is his Best Alternative to a Negotiated Agreement (BATNA).
  - This is the outcome for him if no agreement can be reached.
- If a party's BATNA changes for the worse, he is more likely to prefer having an agreement.
- An outside, higher-level actor could alter the BATNA's
  - Offering reward for joining the agreement
  - Threatening punishments if no agreement is reached.
- Therefore, by manipulating the BATNA's and outside party can intervene – if he so chooses – to increase the likelihood of agreement.

My hypothesis

- When and how does subnational water conflict get resolved?

- Answer: When a higher-level authority intervenes to change the BATNA, inducing a sufficiently powerful set of coalitions to be formed that a bargaining solution comes about.

- I will argue that what happened in the Colorado River (bargaining solution emerges after 2000) and in California (no solution has yet emerged) support this hypothesis.

Economic instruments

- Economic instruments will not come into play unless:

1. There exist some agency possessing the legal authority to price water.
2. That agency has the political will and ability to exercise its pricing authority effectively.

- These are generally lacking in the United States.

3. The pricing of water is likely to be an effective tool for steering water users' decisions in the short run.

- This is generally not the case for either urban or agricultural water users.
  - Political constraints will come into force to prevent high prices that might change water use significantly.
  - Quantity controls are used and are likely to be far more effective.
  - The challenge is to design the right quantity controls.

Use of economic instruments in US water

- Overwhelmingly, water is priced based on cost, not scarcity.
    - The notion of setting a price to send a signal of scarcity is massively rejected.
- It is priced looking backwards to historical cost, not forwards to replacement cost.
- There is virtually no economic regulation of water pricing or use.
    - Urban water supply is ~85% municipal or public, and not subject to any economic regulation; only 15% is by for-profit companies, which are regulated, but by the states individually.
    - Agricultural water supply is even less by for-profit and regulated companies.
    - The US has no regulatory agency with authority over the economic efficiency of water use and water pricing like Australia’s Competition and Consumer Commission.
- Urban water prices are set 1-3 years in advance, through a review process that is primarily political, and motivated by the desire to keep water rates low
    - Hoping to use pricing to send a signal of scarcity is a losing proposition.

It is a fallacy to assume that, for urban water users, water market purchases could generate a price signal of scarcity – they don’t.

- Most of the cost of urban water supply is fixed costs. For the major wholesale organizations that supply urban water, fixed costs are 75-85% of their total annual cost. Variable costs are 15-25%.
- The water they deliver that comes from water market purchases is a small fraction of the water they deliver.
- The cost of water purchased in new water market transactions is going to be a fraction of that 15-25% of their total annual cost.
- Thus, water market purchases are not going to generate a discernable price signal for urban water users.

Economic modeling of agricultural water use

- We commonly employ two approaches to modeling agricultural water use:
- 1. Optimization – setting up and solving a (representative farmer’s) optimization decision to derive the farmer’s input demand for water.
  - Profit maximization
  - Some other version of maximization.
- 2. Econometric estimation using ordinary least squares or some variant with the object of estimating the expected value of the farmer’s input demand function for water.
- In my experience, both of those approaches fail to deliver an accurate or even realistic representation of how much water is applied, and of when a farmer might be open to leasing or selling his water right.
  - Reality involves far more idiosyncratic variation in farm level water use than these approaches allow for.

Evidence of idiosyncratic variation in irrigation water use

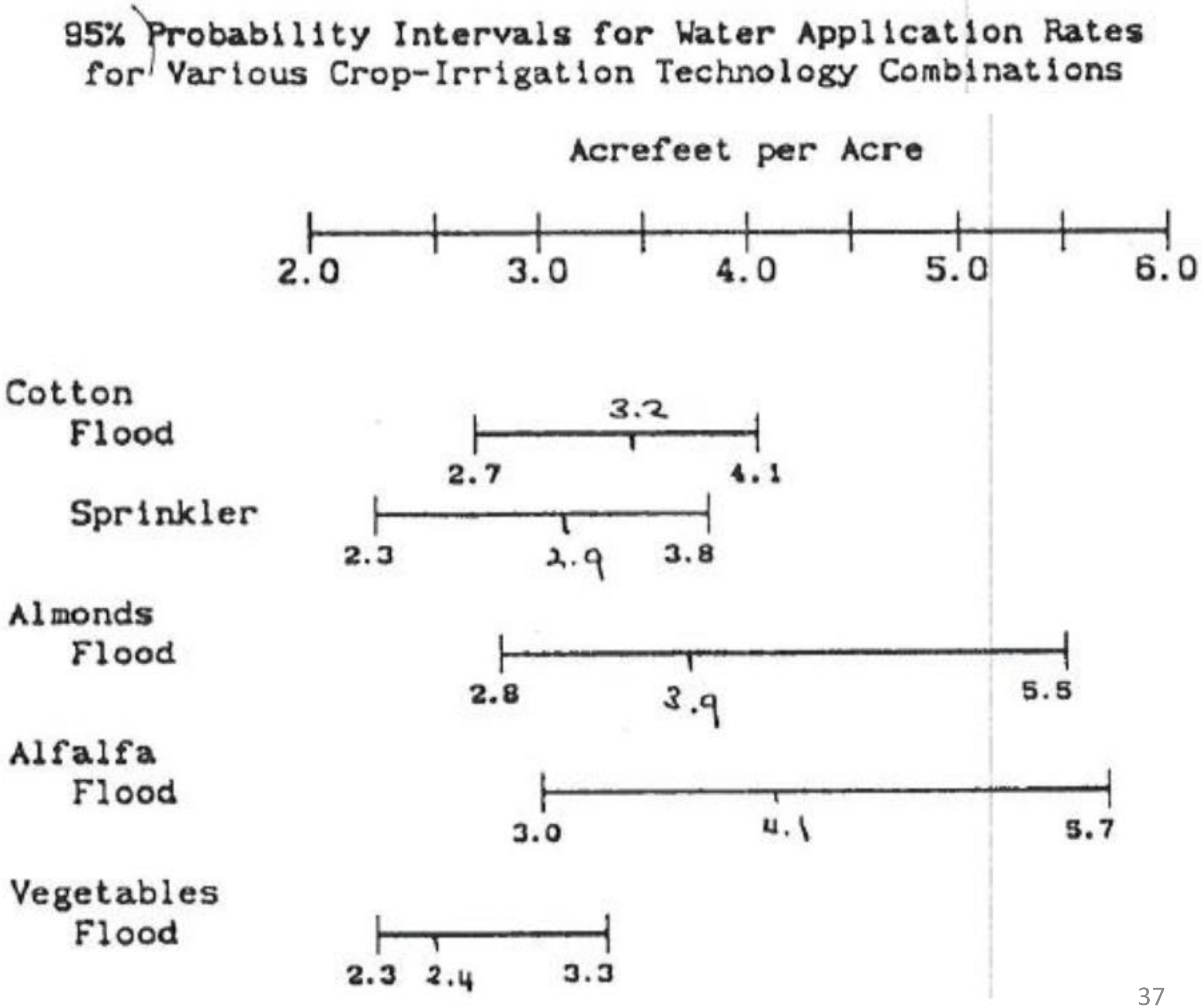
Whenever empirical data are available at the farm, they show that different farmers growing the same crop on the same type of soil with the same irrigation technology, and facing the same prices, nevertheless use very different quantities of key inputs.

Instead of a single input quantity, as predicted by programming models and conventional econometric models, there is a *probability distribution* of input quantities with a heavy right-hand tail.

The existence of a distribution of input use instead of a single quantity suggests that conventional approaches are missing something.

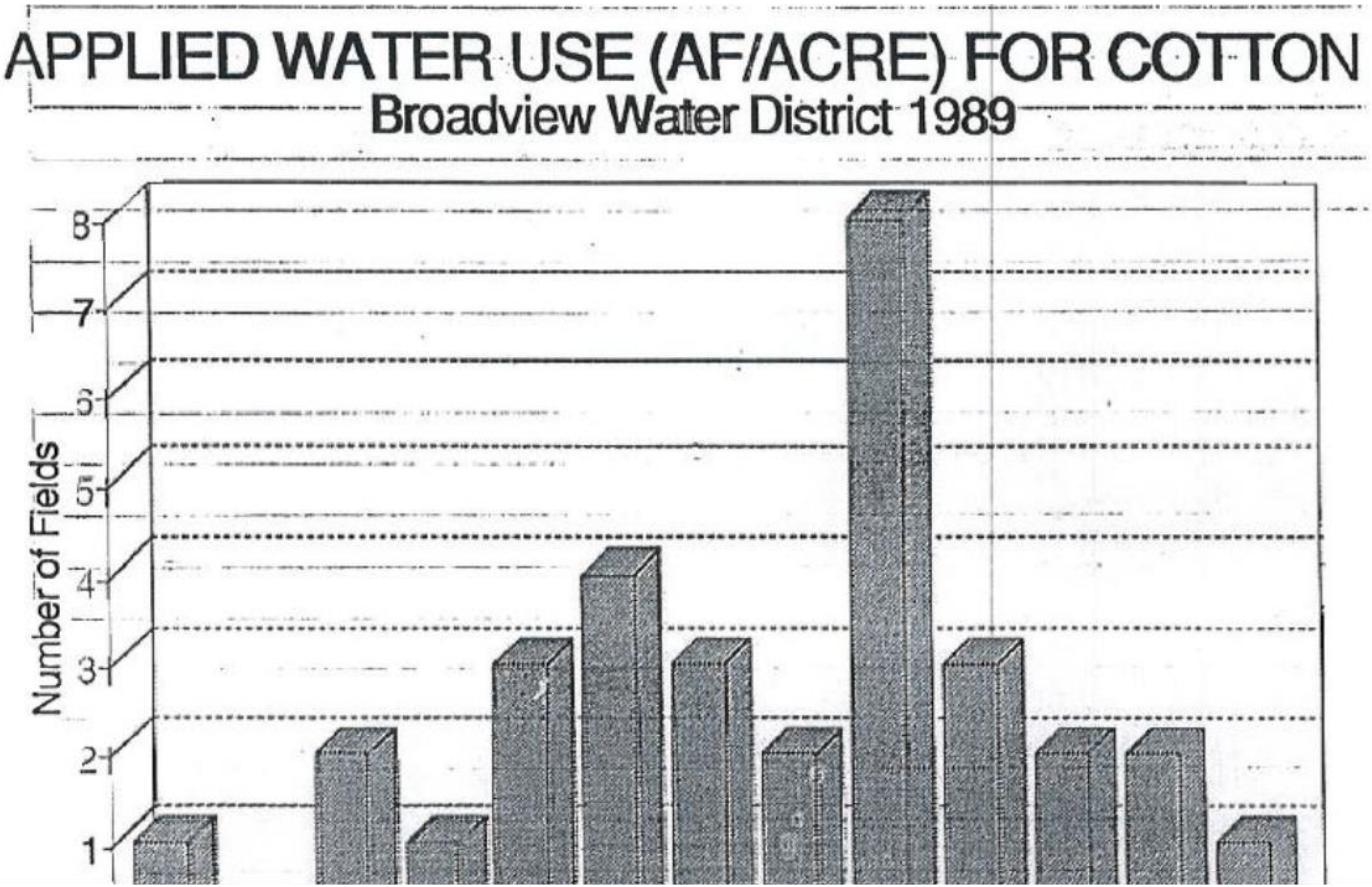
Irrigation application in Kern County CA : X-inefficiency?

- They all face the same input/output prices, so there should be no variation in the amount of water applied for a given crop and irrigation technology
- There is evidence of X-inefficiency

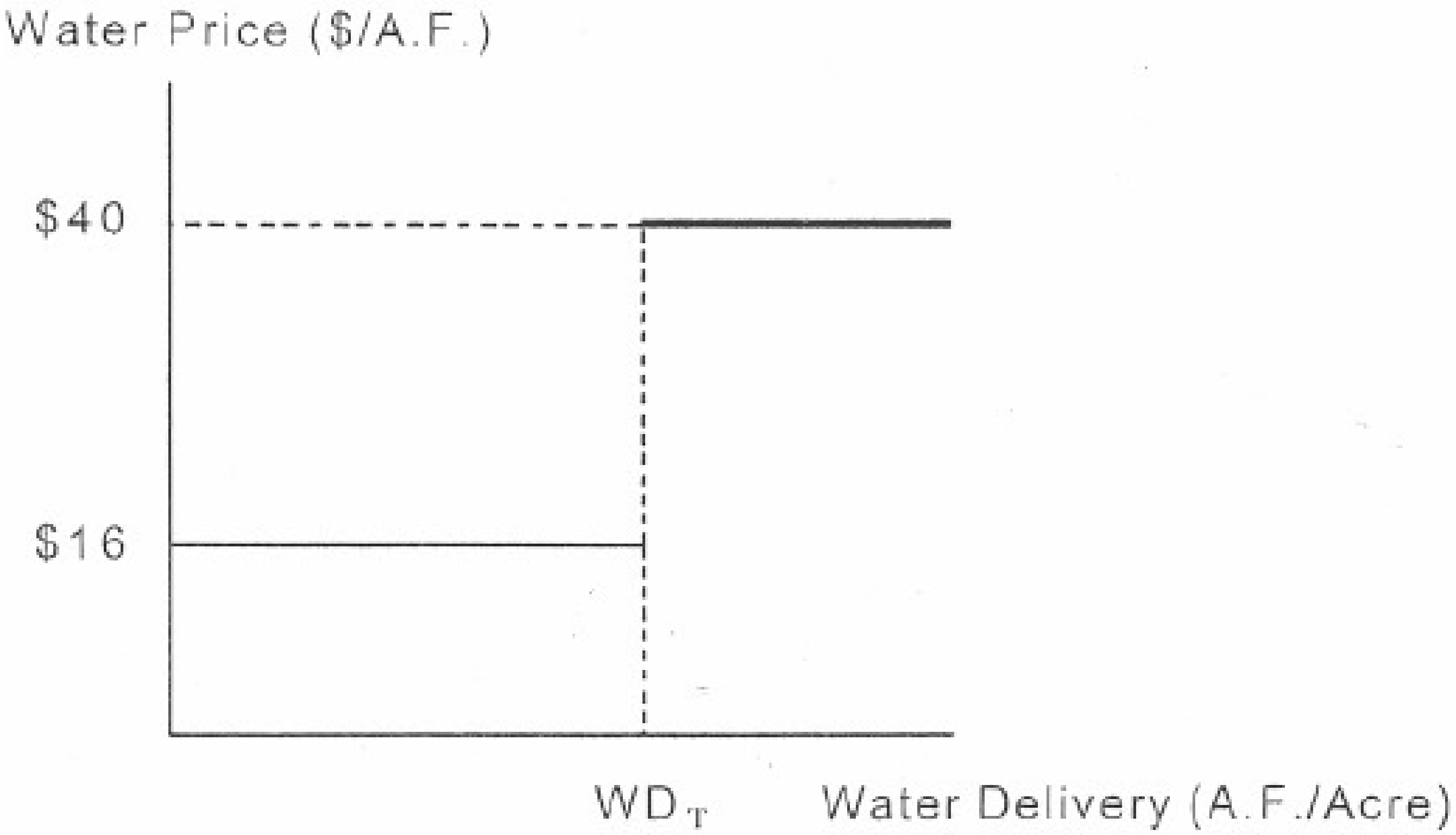


Broadview Irrigation District is a very small district of about 9,000 acres just north of Westlands water District. It has about a dozen farmers farming an average of about 2 fields each.

Broadview was under pressure to reduce the amount of irrigation water that its farmers applied,, because their excessive water use was causing contaminated drainage water to run off their fields; the contaminated drainage was actually causing a significant pollution problem. It was determined that if irrigation use fell by about 10% percent, the problem would be solved.


APPLIED WATER USE (AF/ACRE) FOR COTTON
Broadview Water District 1989
Number of Fields
8
7
6
5
4
3
2
1

- The District was under pressure to do something about this – or otherwise be compelled to capture and decontaminate its runoff water,
- The district took action in 1989 by adopting a simple increasing block rate schedule.



What happened

- The left column shows water use before the price change.
- The right column shows what happened when the pricing change occurred.
- Two years later, almost nobody was using water in the second rate tier.
- The right tail of the water use distribution had disappeared.
- At the same time, there was no evidence of any loss of crop yield or loss of profit.

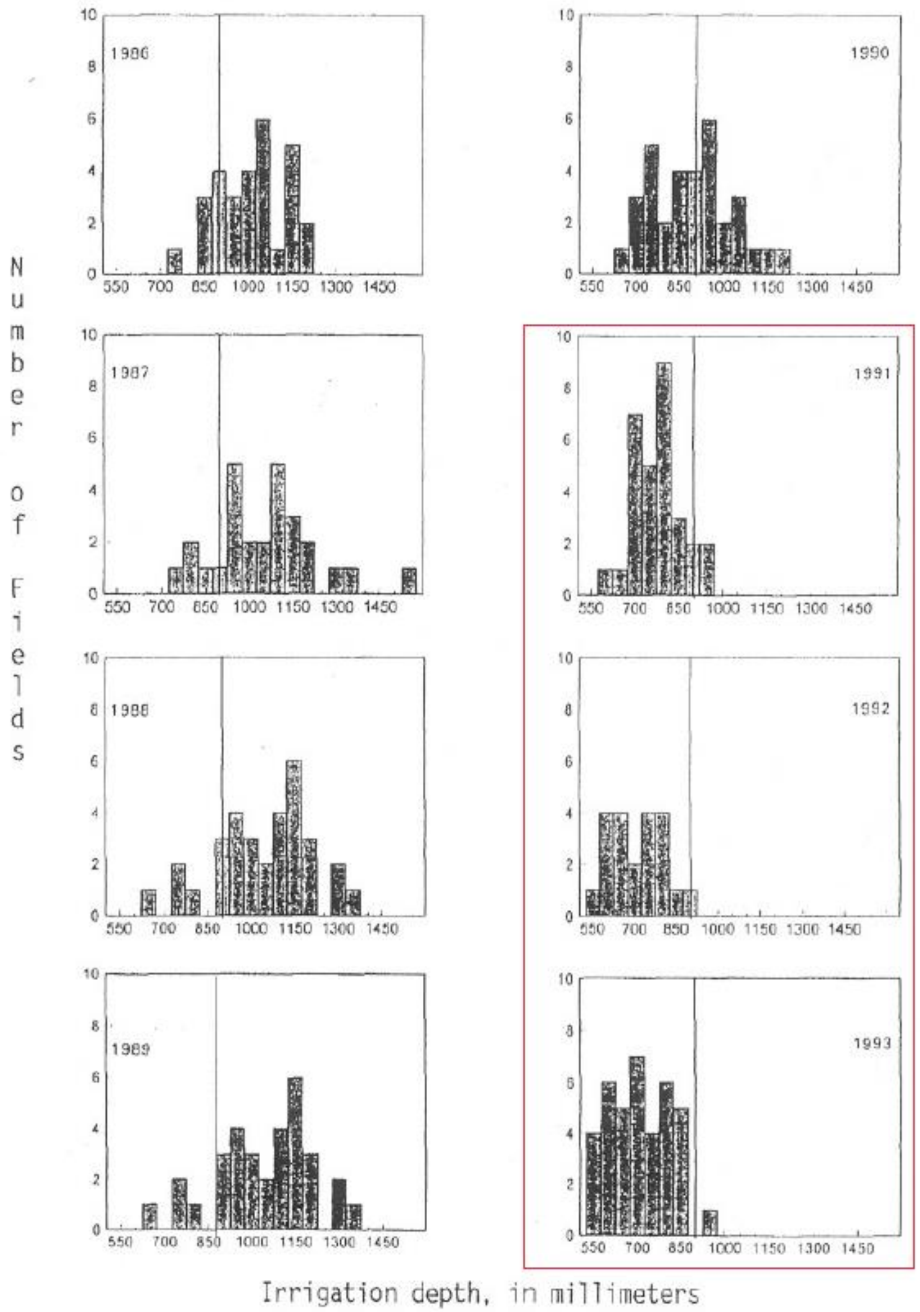


Fig. 2. Shift of frequency distributions for cotton irrigations in the Broadview Water District, 1986–1993.

Major reduction in agricultural water use without any noticeable loss of profit

- The same thing has happened in last ten years at one location in Colorado and in two places in Kansas where water use per acre was reduced by 20-25% in response to a threat of regulatory intervention.
- Water use was reduced without any obvious reduction in profit.

Implication: farmers are not choosing the exact profit-maximizing quantity of irrigation water

- Setting up and solving a farmer's profit maximization problem is not going to give us the correct formula for his irrigation demand function..
- Reducing the use of water for irrigation use may be more than just getting the price right.
- It may involve grabbing farmers' attention.
- And it may involve the use – or threat – of interventions to impose quantity controls on the amount of water used for irrigation.
  - This was how reductions in irrigation use actually came about in Kansas & Colorado.
  - In those cases, farmers reduced water use by ~20%, *with no evident loss in profit*.
- It also provides a rationale for pricing irrigation water via a block tariff structure.

The missing piece of the puzzle may be that (some) farmers are being inefficient in varying degrees

- At least in how much water they apply.
- After all, water is crucial – if you end up applying to little you compromise the yield obtained.
- Water is applied intermittently throughout the growing season. At any point in the season, you can't be sure about the crop ET and available water supply in the remainder of the season.
- While a crucial input, water may be a relatively small share of the total production cost.
- If you are risk averse, err on the side of over- rather than under-irrigation.

There is some slack in the use of irrigation water

- Does that mean there will always be slack in this water use?

NOT NECESSARILY

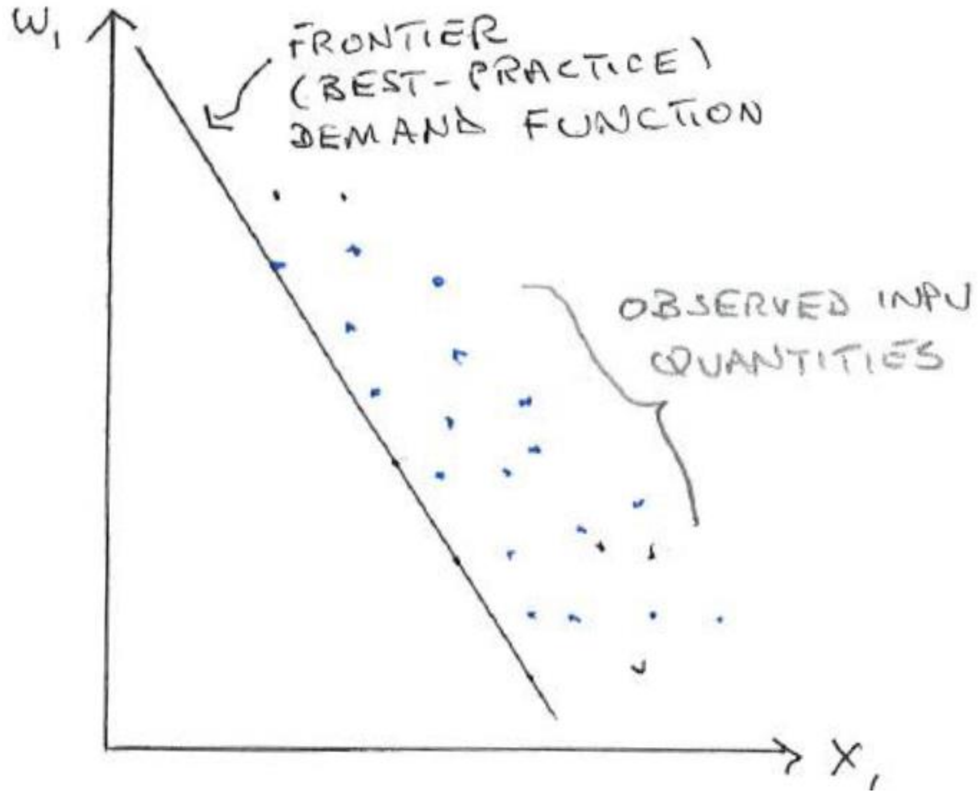
- Rather, the implication is that we should apply a form of econometric modeling that both permits the existence of slack and also measures the extent of slack.

That modeling is the estimation of a **frontier demand** function.

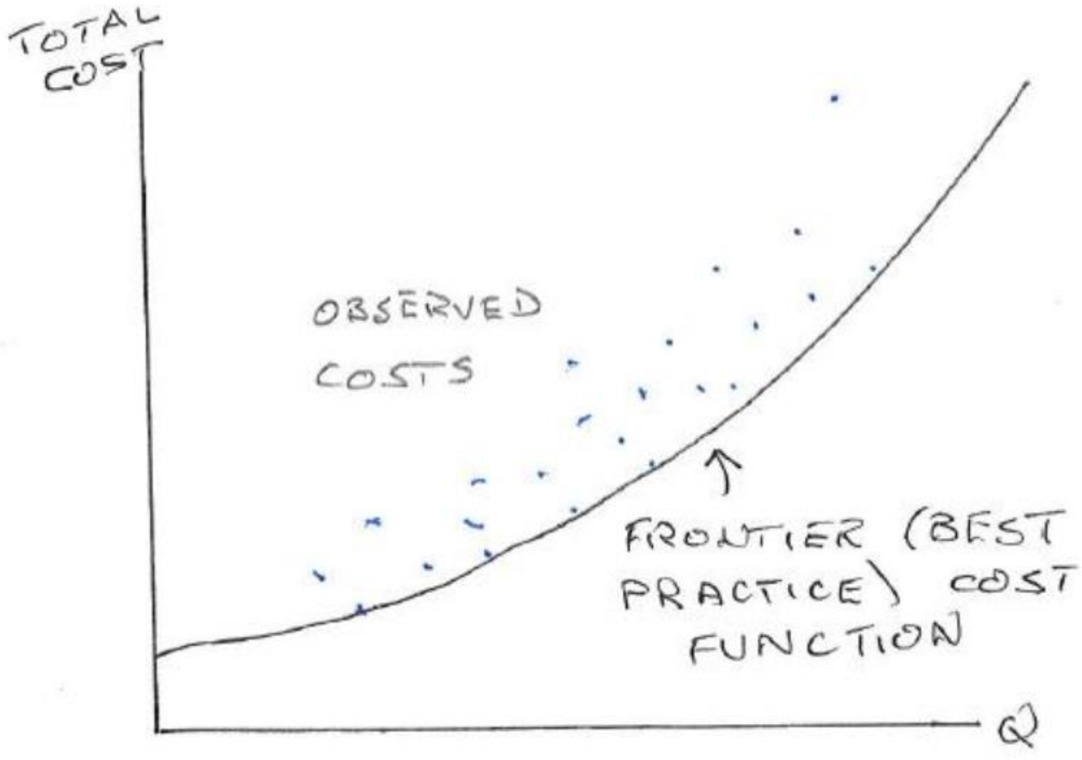
How should we think of this? We should estimate frontier water demand/production cost functions

Cost inefficiency (frontier demand/cost functions)

Input demand function



Cost function

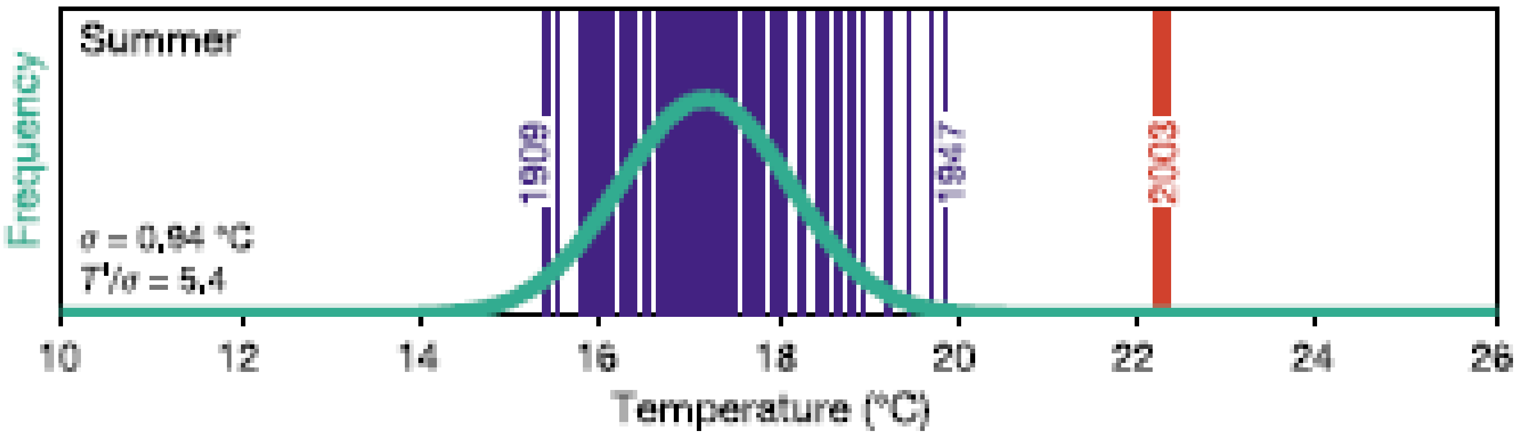


THE CHALLENGES OF CLIMATE CHANGE

- For next few decades, the main economic impact will arise from local extreme events.
  - Local in spatial dimension; local in temporal dimension.
  - Successful representation/projection of these requires fine spatial and temporal scales of modeling – downscaling becomes essential.

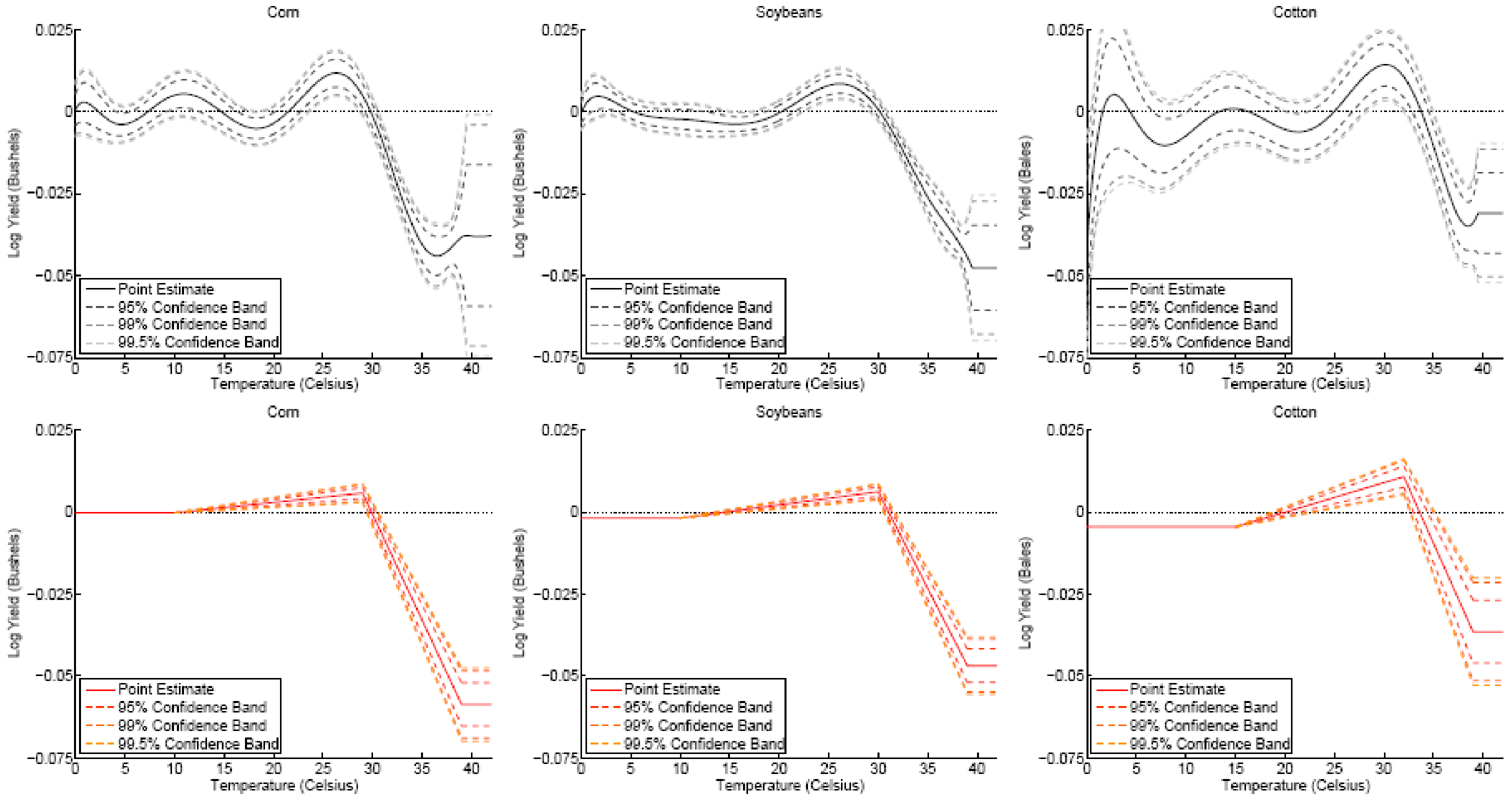
The importance of local extreme events

- I am drawing a distinction between catastrophic climate events with global-scale impacts and local extreme events with significant impacts on a local scale (e.g. the 2003 heat wave in Paris with 15,000 deaths).
  - Extreme precipitation
  - Heat waves
  - Drought



Asymmetric Relation of Temperature and Crop Yield Schlenker & Roberts (2006, 2008, 2009)

- **Relationship is distinctly asymmetric, fairly flat at first and then sharply declining beyond an upper threshold.**
- **It is *not* symmetric as assumed by Mendelsohn, Nordhaus & Shaw.**



Notes: Graphs display changes in log yield if the crop is exposed for one day to a particular 1°C temperature interval where we sum the fraction of a day temperatures fall within each interval. The 95%, 99%, and 99.5% confidence bands, after adjusting for spatial correlation, are added. Curves are centered so the exposure-weighted impact is zero.

Importance of extreme temperature, especially near-term (Schlenker et al., 2006)

	Proportion of net economic loss to US agriculture due to change in:	
	Precipitation & degree days 8-32C	Degree days over 34C
2020-2049 both emission scenarios 2070-2099 B1 scenario	10-20%	80-90%
2070-2099 A1Fi scenario	40%	60%

Local extreme events

- This evidence suggests that most of the damages from climate change are associated with extreme climate events.
  - This evidence is for crop yields, but I think it applies also to most other dimensions of impact.
- My hunch: change in average temperature & precipitation is essentially of minor importance, compared to change in incidence of local extremes.
- But, most of existing damage literature (until last couple of years) has focused on changes in average conditions.

The political challenge – lack of willingness to adapt *in advance* of disaster

- In my experience, the major challenge is going to be the political unwillingness to do something right now, triggered by a tendency to procrastination combined with wishful thinking – it will occur later in the century, we are busy right now working on legacy problems, and maybe a solution will found if we wait a while.

The curse of procrastination and wishful thinking

- St. Augustine famously said that, as a teenager he prayed to god: “Let me be chaste and celibate, O Lord, but just not yet.”

- Winston Churchill is said to have recalled after World War II: “You can always count on the Americans to do the right thing. But, only after they have exhausted every other alternative.”

- Trying to escape hard choices in the hope that they will ultimately not be needed is a dangerous combination of wishful thinking and procrastination.

The Colorado River crisis starting in 2021 as a prime example of the tendency to procrastinate

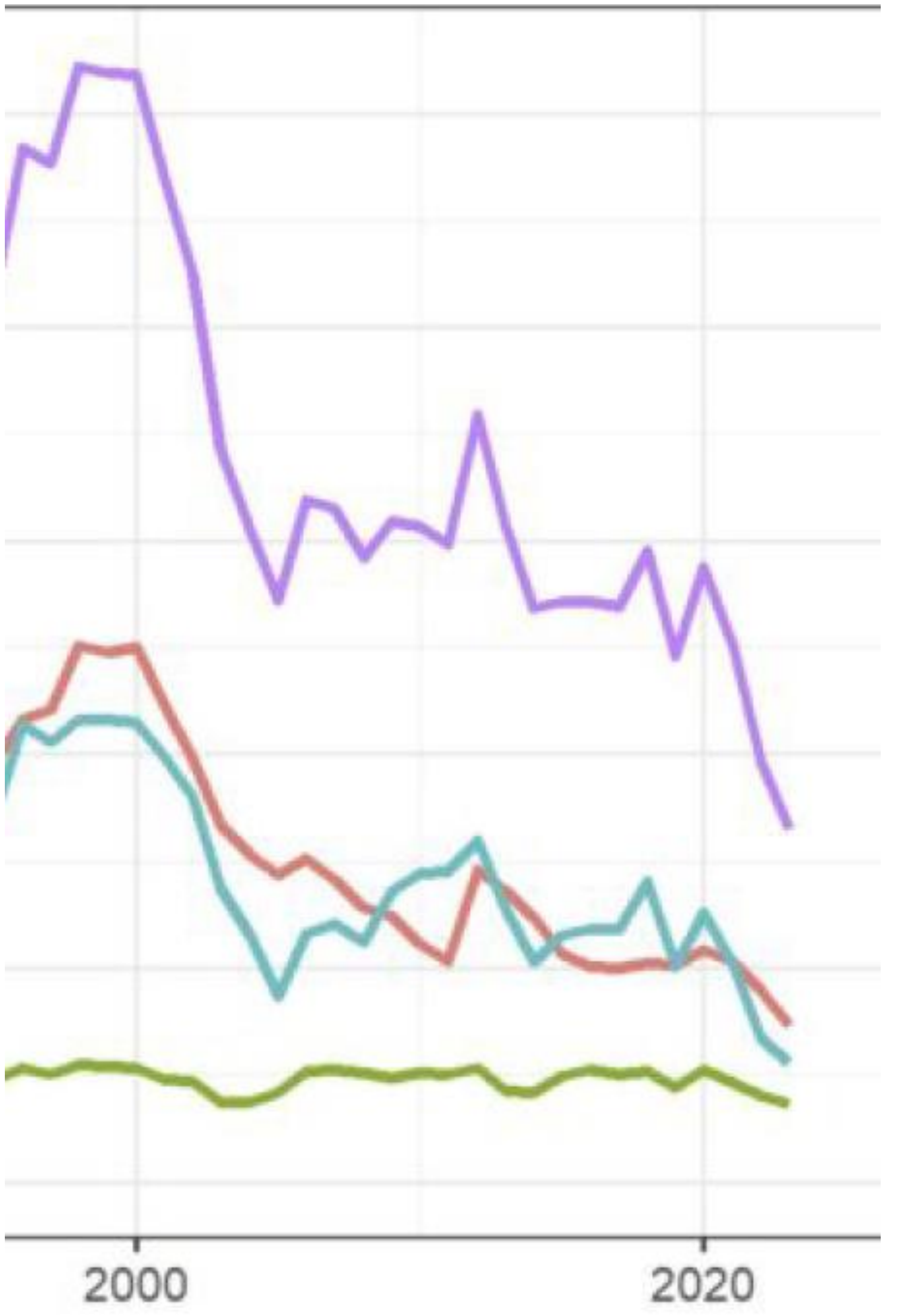
Colorado River history

- First large diversion, the Grand Ditch in CO, delivers 17,00 AF/yr 16 miles away, across the Continental Divide.
- Mid-1890s, first proposal to dam river near Grand Canyon and irrigate as far as a Phoenix.
- 1901, California Development Company starts delivering Colorado River water to Imperial Valley in CA. Becomes Imperial Irrigation District (IID)
- By 1903, >100,000 acres being irrigated (perhaps 5 – 10 AF per acre).
- By 1909, 160,000 acres irrigated.
- 1917 The 7 states form the League of the Southwest to lobby for development of the resources of the Colorado River.
- Emerging conflict: invest in All-American Canal vs flood control and storage.
- 1918 Growing concern/opposition from Upper Basin states and Mexico.

- 7 states negotiate Colorado River Compact, 1922
  - Assumes a streamflow of ~18 MAF (better data at the time suggested 15-16MAF).
  - Allocates 7.5 MAF to upper basin states and 7.5 MAF to lower basin states.
  - Ignores evaporation now ~1.5 MAF; ignores Indian reservations along the river.
- 1944 treaty allocates 1.5 MAF to Mexico
- 1963 Supreme Court ruling in Arizona vs California; allots 4.4 MAF to California, 2.8 MAF to Arizona and 0.3 to Nevada.
- 1970s-1990: Upper Basin states using far less than 7.5 MAF. California, allotted actually using 5.2 or more. Arizona using less than entitlement.
- 1984 First paper published projecting reduction in streamflow due to climate change
- 1988. Central Arizona Project comes online – Arizona starts taking its full 2.8MAF.
- 2003 California forced to reduce its use to 4.4

- Last 20 years
  - Major drought on the Colorado River
  - Water use averages 15.3 MAF
  - Actual streamflow since 2000 has averaged more like 12.5 MAF
  - Reservoir storage depleted.
- Crisis warnings August 2021, prompting cutback in deliveries starting Jan 2022.
- Situation continues to deteriorate. August 2022, Federal government announces that a further reduction of 2-4 MAF will be required starting January 2023.
  - States given to January 31 2023 to propose a plan.
  - Six states submit one plan; California submits its own plan.
  - Federal government must make a decision by this summer.

- Reservoirs were full in 2000
- Drought throughout most of this period except 2012
- Diversions continued unchanged throughout this period.
- Reservoirs now approaching dead pool.



Different strategies for dealing with the crisis

- 6 states propose large cuts starting right away. Take account of evaporation.
- California proposes smaller cut, with larger cuts to come much later. Disregards evaporation (which affects California most because it is the largest user of Colorado River water in the lower basin).

Risk management

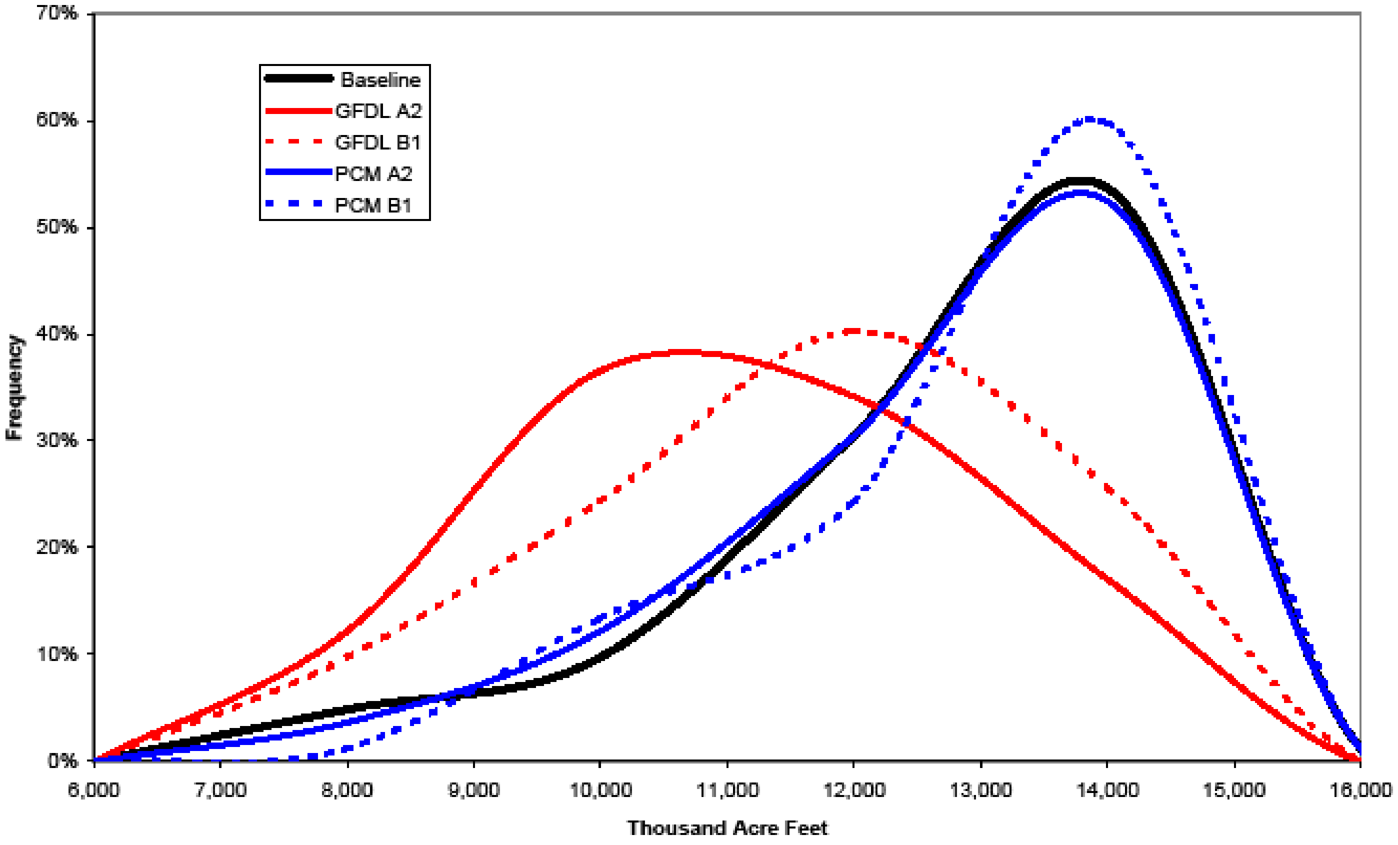
- Climate change is about risk and risk management.
- Economics and finance have a well developed body of concepts and theory for managing risk.
- Two key economic ideas about risk:
  - (1) Diversification and risk pooling;
  - (2) Downside risk aversion and the economic value of insurance.
- Climate change is the least diversifiable risk imaginable.
  - Unless we can relocate to another planet.

Downside risk aversion

- The standard concept of risk aversion is less relevant than the concept of downside risk aversion.
  - Conventional risk aversion guards against extreme outcomes of *both a positive and negative* nature: it weights both types equally.
- Downside risks is based on the notion that there is an asymmetry – downside risks matter more (are weighted more heavily) than upside risks.
- The concept was first applied in the financial literature in the 1970s – going broke is viewed differently than making a surprisingly large profit.
- It is likely to apply to many physical outcomes of climate change – e.g., asymmetry between a water manager having too little water versus having too much water.

Downside risk in annual deliveries to Central Valley agriculture, 2085
(Hanemann et al. 2015)

- Under the downscaled projections from the GDFL model (a medium-sensitivity GCM), but not the PCM model (a low-sensitivity GCM), there is a significant increase in downside risk with respect to water deliveries for agriculture in California's Central Valley.



Downside risk-adjusted impact

CENTRAL VALLEY AGRICULTURE ANNUAL NET REVENUE 2085 ($ million)			
	MEAN	DOWNSIDE RISK FACTOR	ADJUSTED VALUE
BASELINE	$415	$132	$283
GFDL A2	$314	$178	$136
GFDL B1	$349	$163	$186
PCM A2	$397	$130	$267
PCM B1	$413	$126	$287
	LOSS COMPARED TO BASELINE		
GFDL A2	$101	$46	$147
GFDL B1	$66	$31	$97
PCM A2	$18	-$2	$16
PCM B1	$2	-$6	-$4

In terms of conventional risk aversion, there is almost no risk premium.

With downside risk there may be a significant risk premium.

For GFDL, the downside risk premium increases the estimate of loss by about 50%.

For PCM, the downside risk premium reduces the estimate of loss.

Some conclusions

- Climate change is about risk management.
- Risk management requires foresight – and the ability to act on that foresight.
- The insurance industry can play an important role in promoting private adaptation to deal with local climate risks, by using individualized calculations of climate risks.
- Collective adaptation involves physical investments for infrastructure, which represent a physical form of insurance that we need to undertake.
- If our current situation is not well adapted to the problems we face (and have faced for some time), why should we expect to have success in dealing with climate change?
- The highest priority in preparing for climate change is getting our house in order now to deal well with the circumstances we face now.
- In that sense, this is not just about climate change: it is about doing a better job now.