# The Economics of Water Project Capacities and Conservation Technologies

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# Motivation

Water projects

- Huge economic, social, and environmental impacts
- Major policy debates

Determination of the capacities: The Cost-Benefit Analysis method

- Symbolized by the *Principles and Guidelines* (1983)

One of the major critiques on the method as practiced in most cases

- Overemphasizing the “hard” engineering solutions
- Overlooking the “soft” management and institutional solutions

The policy debate in response to the recent drought in western US

- Capacities of water projects vs. conservation in water use
- Reductions of the Sierra Nevada snowpacks and threats of climate change

# In this talk . . .

What are the implications of the changes in the institutional, environmental, and technological conditions on optimal water project capacities?

- Water reforms and other improvements in water allocation efficiency
- Warming-caused inflow abundance and other effects of climate change
- Conservation technology adoption

An economic framework for the determination of water project capacities

Potential complementarity between the "hard" and the "soft" solutions

# Position in literature

Models for the determination of water project capacities

- Tsur (1990), Schoengold and Zilberman (2007, p.2943, 2955), Haddad (2011), Pham-Do et al. (2014), . . .
- All enough and good for their purposes
- Little sensitivity analysis, almost deterministic inflows, no conservation

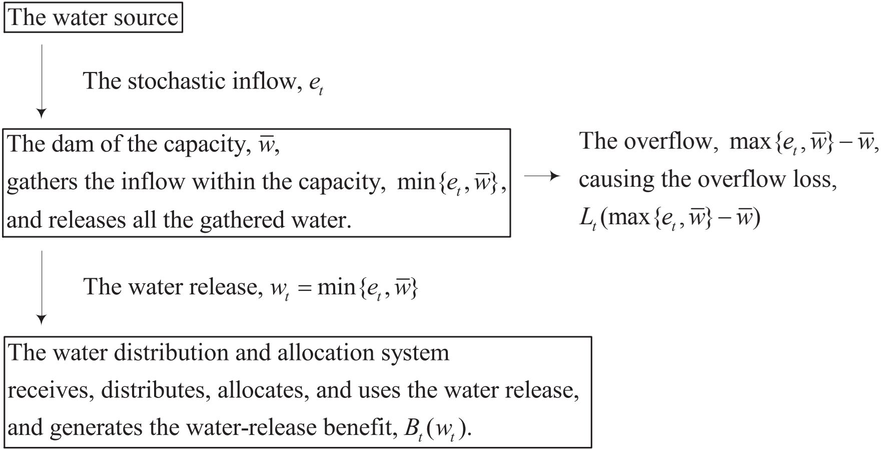
Stochastic, dynamic control of water inventories

- Burt (1964), Tsur and Graham-Tomasi (1991), Troung (2012), . . .
- Difficult to analyze the capacity determination
- Exception: Fisher and Rubio (1997), no conservation

This paper:

- Capacity determination, stochastic inflows, and conservation
- 7 propositions with implications (not all shown here)
- The first with a focus on "capacities $\rightleftharpoons$ conservation"

# A simple model for a water project



The water source

The stochastic inflow, $e_t$

The dam of the capacity, $\overline{w}$,
gathers the inflow within the capacity, $\min\{e_t, \overline{w}\}$,
and releases all the gathered water.

The overflow, $\max\{e_t, \overline{w}\} - \overline{w}$,
causing the overflow loss,
$L_t(\max\{e_t, \overline{w}\} - \overline{w})$

The water release, $w_t = \min\{e_t, \overline{w}\}$

The water distribution and allocation system
receives, distributes, allocates, and uses the water release,
and generates the water-release benefit, $B_t(w_t)$.

See our CUDARE paper for a reservoir model with inventory management.

# The optimal dam capacity

The dam designer's program:

$$\max_{\bar{w}\geq 0} \quad \mathbf{E}_0\left[\sum_{s=0}^{\infty}\rho^s\left(\overset{\text{Water release benefit}}{B_s(\min\{e_s,\bar{w}\})}-\overset{\text{Overflow loss}}{L_s(\max\{e_s,\bar{w}\}-\bar{w})}\right)\right]$$

$$- \overset{\text{Construction and maintenance cost}}{C(\bar{w})} - \overset{\text{Environmental damage}}{D(\bar{w})}$$

Regular assumptions and simplification

- $B_t'(\cdot)\geq 0,\ B_t''(\cdot)<0,\ L_t(0)=0,\ L_t'(\cdot)>0,\ L_t''(\cdot)\geq 0$
- $C'(\cdot)>0,\ C''(\cdot)>0,\ D'(\cdot)>0,\ D''(\cdot)>0$
- $e_t\sim e$, $i.i.d.$ with cdf. $F(\cdot)$ and pdf. $f(\cdot)$, $f(\cdot)=F'(\cdot)$
- $B_t(\cdot)=B(\cdot),\ L_t(\cdot)=L(\cdot)$

# The first order condition and comparative static analysis

$$\overbrace{\underset{\text{Benefit from the marginally more release}}{\frac{1}{1-\rho}\left(1-F(\bar{w})\right)B'(\bar{w})} + \underset{\text{Benefit from the marginally less overflow}}{\frac{1}{1-\rho}\int_{\bar{w}}^{\infty} L'(e-\bar{w})f(e)de}}^{\text{Marginal benefit of dam capacities}}$$

$$= \underbrace{C'(\bar{w}) + D'(\bar{w})}_{\text{Marginal cost of dam capacities}}$$

The marginal benefit and cost intersect at the optimal dam capacity, $\bar{w}^*$.

$$B'(\cdot)\uparrow,\ F(\cdot)\downarrow \implies \text{Marginal benefit of dam capacities} \uparrow$$

$$\implies \bar{w}^* \uparrow$$

# The impact of water allocation efficiency

Improvements in water allocation efficiency could shift up $B'(\cdot)$.

- Transitions from water rights to water markets
  - E.g. the US Central Valley Project Improvement Act of 1992
- Rising energy prices and reallocation of water from irrigation to hydropower or environmental sectors
  - E.g. Quiggin (2006) on the Murray–Darling Basin in Australia
- Optimal centralization of conveyance investments
  - Discussed in Chakravorty et al. (1995)
- Weakening of the market power of monopsony in water generation markets
  - E.g. Chakravorty et al. (2009) on the Water Users Associations

## Implication

*The integrated water reforms that gain extra water release benefit and shift up the marginal water release benefit could require larger water projects.*

# The impact of inflow abundance

A downward shift in $F(\cdot)$ means the inflow is more abundant.

Possible for major water transfer projects

- California State Water Project
  - Mentioned in Schwabe and Connor (2012)
  - The Sierra Nevada snowpacks reduction
  - Lake Oroville and the Thermalito Diversion Dam
- China's South–North Water Transfer Project
- . . .

## Implication

*The climate change that makes the inflows more abundant could require larger water transfer capacities.*

# Dam capacities on conservation technology adoption

The adoption will rotate $B'(\cdot)$ clockwise from $B^{1'}(\cdot)$ to $B^{2'}(\cdot)$.

- Caswell and Zilberman (1986): $B(w) = \mathcal{B}(\alpha w)$
- With small $x$, $EMP \equiv -\frac{x\mathcal{B}''(x)}{\mathcal{B}'(x)} < 1$; with large $x$, $EMP > 1$

Adoption cost: $c_1 = 0$, $c_2 > 0$

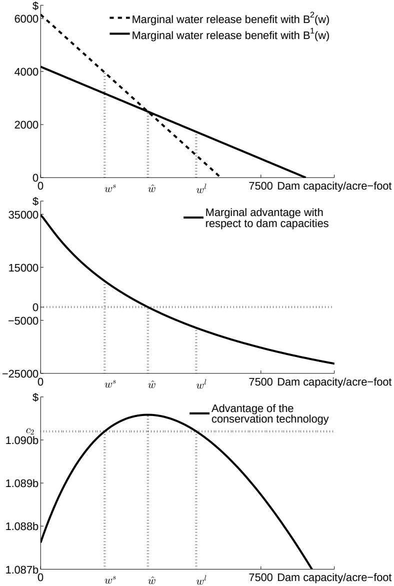
The representative water user's program:

$$\max_{i\in\{1,2\}} \quad \mathbf{E}_0 \left[ \overbrace{\sum_{s=0}^{\infty} \rho^s \, B_s^i(\min\{e_s, \bar{w}\})}^{\text{Water release benefit}} \right] - \overbrace{c_i}^{\text{Adoption cost}}$$

Adopt if and only if

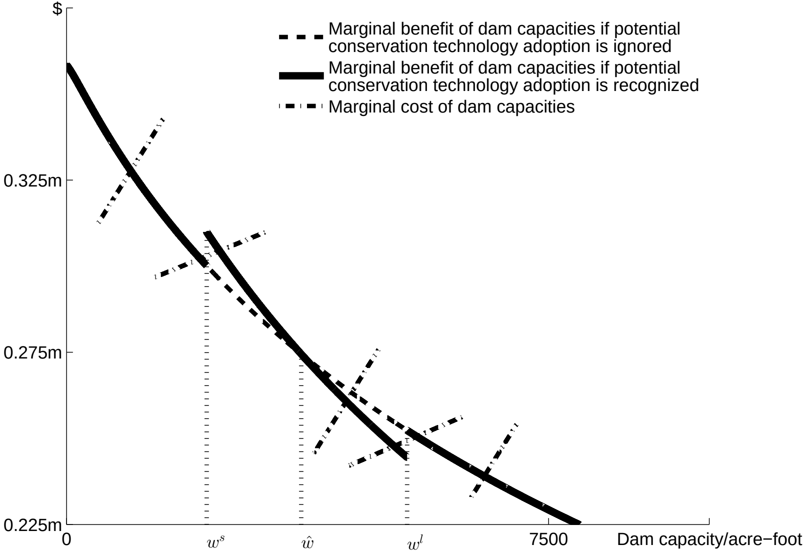
$$\underbrace{\frac{\int_{-\infty}^{\bar{w}} \left(B^2(e) - B^1(e)\right) f(e)de + (1 - F(\bar{w}))\left(B^2(\bar{w}) - B^1(\bar{w})\right)}{1-\rho}}_{\text{Advantage of the conservation technology over the existing technology, } A(\bar{w})} > \underbrace{c_2}_{\text{Adoption cost}}$$

# Too Large and too small dams discourage adoption

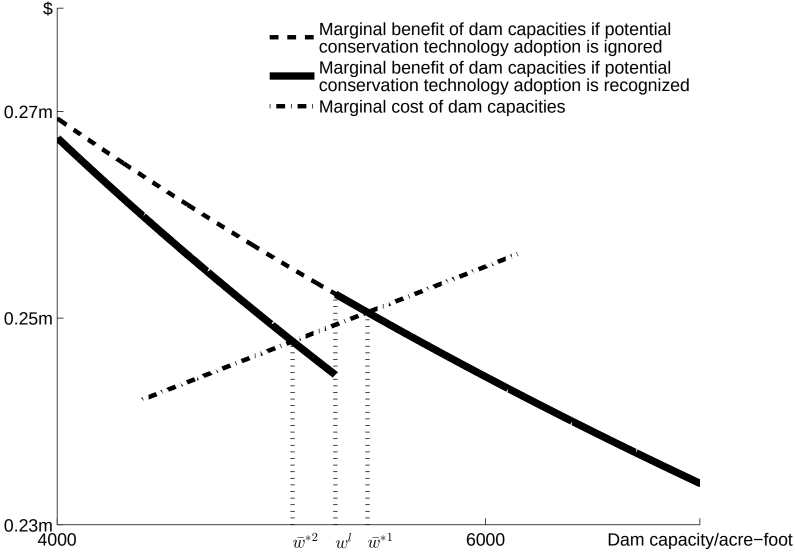


- $B^{1'}(\cdot)$ is rotated clockwise to $B^{2'}(\cdot)$.
- $A'(\bar{w})$ crosses zero from above.
- $A(\bar{w})$ is non-monotonic in $\bar{w}$.

# Optimal dam capacities with potential adoption



# Ignoring potential conservation explains oversized dams



# Conclusion

Potential complementarity between the “hard” and the “soft” solutions

- Integrated water reforms $\Longrightarrow$ larger optimal capacities
- Too small dams could discourage conservation technology adoption.

Implications of the environmental and technological changes

- Warming-caused inflow abundance $\Longrightarrow$ larger optimal capacities
- Overlooking potential conservation could explain oversized dams.

The design of water projects shouldn’t be divorced from the institutional, environmental, and technological conditions.

# Acknowledgement

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Thank you very much!

# The impact of overflow loss

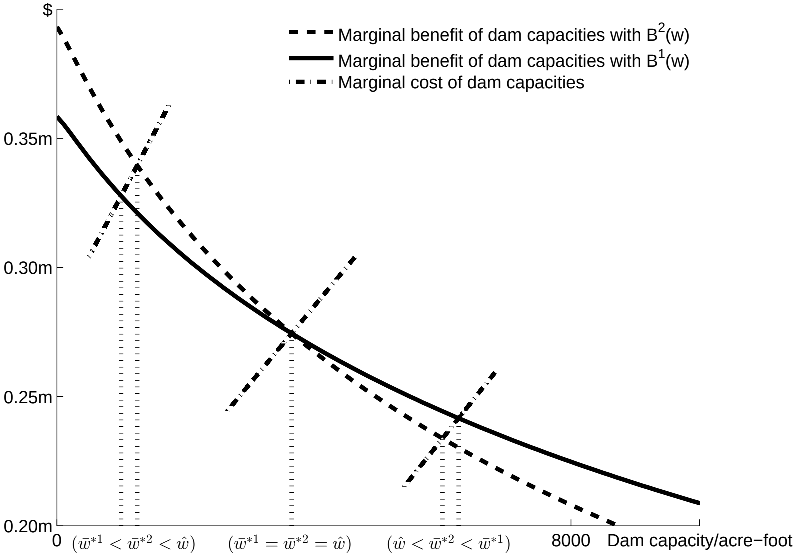
Heavier concern about food security could shift up $L'(\cdot)$.

- Flooding and waterlogging could seriously interrupt agricultural production.

## Implication

*If the marginal overflow loss is more seriously concerned in the age emphasizing food security, the emphasis could require larger water projects.*

# Conservation technology adoption on dam capacities



# Capacities vs conservation in literature

Models for the determination of water project capacities

- The first to consider the impact of conservation

Factors affecting conservation technology adoption

- The first to consider the impact of water project capacities

Capacities or resource abundance vs. conservation technologies

- Intuitively, substitutes . . .
- Non-monotonic: E.g. Caswell and Zilberman (1986)
- This paper: Non-monotonic, for diversion dams and water transfer projects
- Xie and Zilberman (2014): Possibly complementary, for storage dams