EVALUATING A WATER BUYBACK PROGRAM

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Outline

• Background and motivation
• Theoretical illustration
• Empirical model
  – Data
• Results
Background: Klamath Irrigation Project

- Created under the Reclamation Act (1902) to provide agricultural land for homesteading
- Managed by BOR
- Approx. 220,000 acres of farmland
- 9 major crops:
  - pasture,
  - alfalfa,
  - hay,
  - barley,
  - wheat,
  - oats,
  - potatoes,
  - peppermint,
  - onions
- 1,400 farms and ranches
- Produces $325 million in agricultural commodities (Lucero, 2011)
Background: wildlife

- **Endangered species:**
  - Lost river and shortnose sucker
  - Coho salmon

- **Reasons:** water management, water quality, loss of habitat, overfishing, and other causes (Lewis et al., 2004).
Background: ESA (1973)

- BOR water release subject to Biological Opinions
  - **U.S. Fish and Wildlife Service Biological Opinion**
    - minimum elevation requirement for the Upper Klamath Lake to protect the endangered Lost River and Shortnose suckers
  - **National Marine Fisheries Service Biological Opinion**
    - minimum in-stream flows in the Klamath River to protect the endangered Coho salmon habitat
Background: 2001 shortage

- 2002 die-off 33,000 salmon (Guillen, 2003)
- Project water delivery was between 110,000 AF (OSU/UC, 2002) and 180,000 AF (Klamath Basin Coalition, 2003)
  - Agricultural losses - $27 to $46 million (Jaeger, 2002; 2004)
- Recommendations:
  - simplifying and strengthening water property rights structure (Slaughter and Wiener, 2007),
  - allowing for off-Project water purchases and trades (Jaeger, 2004),
  - water banks (Burke et. al., 2004; Lewis et al., 2004),
  - tradable environmental rights (Tisdall, 2010).
Background: 2010 shortage

- 18,000 acres of bids accepted at a cost of $3.2 million
- Water use decreased by approx. 36,000 - 45,000 AF
- Accepted land idling bids
  - Ranged from $0 to $225 per idled acre
  - The weighted average bid $176 per idled acre
  - Per acre foot cost between $70 and $90
Theoretical illustration

1. Buy water directly

$$\pi^1$$

2. Idle enough land

$$\pi^2$$

$$\pi^1 > \pi^2$$
Empirical model

- Math programming: Demand for water as a Marginal Value of Product (MVP)
  - Tsur (2005), Shumway (1973), Scheierling, Young and Cardon (2004), Yaron and Dinar (1982)

- No Deficit Irrigation
  - Shumway, 1973; Briand, Schuck, and Holland, 2008; Heady et al, 1973
Empirical model

Max: \[ \pi = \sum_{cr, st, it, ws, state} a_{cr, st, it, ws, state} \times \left[ f_{cr, st, it, ws, state} \left( w_{cr, st, it, ws, state} \right) \times P_{cr, state} - \right. \]

\[ \left. \left[ IrrCo_{cr, it, ws, state} \times w_{cr, st, it, ws, state} - Co_{cr} \right] \right] \] (1)

Subject to:

\[ f_{cr, st, it, ws, state} \left( w_{cr, st, it, ws, state} \right) = Yd_{cr, st, state} + \left( Ym_{cr, st, state} - Yd_{cr, st, state} \right) \left[ 1 - 1 - \frac{w_{cr, st, it, ws, state}}{Im_{cr, st, state}} \right] \left( \frac{Im_{cr, st, state}}{ET_{cr} - ET_{cr}} \right) \] (2)

\[ \sum_{cr} a_{cr, st, it, ws, state} \leq Land_{st, it, ws, state} \forall st, it, ws, state \] (3)

\[ \sum_{st, ws, it} a_{cr, st, it, ws, state} = \sum_{y} \lambda_{state, y} \times CropMix_{cr, state, y} \forall cr, state \] (4)

\[ \sum_{y} \lambda_{state, y} = 1 \forall state \] (5)

\[ \sum_{cr, state, st, it} w_{cr, st, it, 'surface', state} \times a_{cr, st, it, 'surface', state} \leq Water_{surface} \] (6)
Model

**Maximum Available Precipitation to be Stored in Root Zone at Planting**
This is the total precipitation for each crop that falls from the beginning of October to the beginning of the growing season for the specific crop.

**Growing Season Precipitation**
This is defined as the total precipitation that falls during the growing season of each crop.

**Crop Yield data per soil type**
Average yields per acre of each crop depending on soil type.

**Observed Maximum Yields**
These are the maximum yields for a well managed crop in the area which does not vary by soil type.

**Irrigation Efficiency**
The amount of water stored in the crop root zone compared to the amount of irrigation water applied.

**Depth of Irrigation Required to Produce Maximum Yield (Im)**
Calculated using the formula Im=ETm/irrigation efficiency.

**Seasonal ETm**
Calculated by summing across daily ETm readings for each crop during the defined growing season on the Agrimet website.

**Available Water Capacity per Soil Type**
This is the quantity of water that the soil is capable of storing at various depths for use by plants.

**Variable Cost per Crop minus Irrigation Costs (VC)**
This is a cost per acre for each crop.

**Price of Crop**
These are the 2007 average prices of the selected crops.

**Constrained Profit Max**
\[ \pi = (P \times Y \times \text{Acres Harvested}) - VC - IC \]

**Production Function**
\[ Y = Yd + (Ym - Yd)(1-(1-I/Im)^{1/B}) \] where \( B = (ETm-ETd)/Im \)

**Dryland Yield of Crop (Yd)**
Calculated using the formula \( Yd = (Ym/ETm) \times (ETd) \).

**Maximum Yield of Fully Irrigated Crop (Ym) per soil type**
Calculated by taking observed max yields and then calibrating those max yields by crop yield data per soil type.

**Root Zone Depth**
Maximum depth each crops' roots extend into the soil.

**Precipitation Stored in Root Zone at Planting**
Precipitation stored in root zone at planting is calculated using maximum available precipitation data as well as the root zone depth of the particular crop.

**Seasonal ETd**
Calculated using the formula: \([\text{precipitation stored in root zone at planting} + (\text{growing season precip} \times .75)]\). ETd is calculated for each crop and soil type.

**Historical Crop Mixes**
These are the acres harvested of each crop in Gooding and Jerome counties from 1998 to 2007.
Data

- NRCS
  - Soil types and characteristics
  - Yields
  - Water capacity per soil type
  - Root zone depth

- Oregon State extension publications
  - Variable costs of production
  - Irrigation costs
  - Maximum yields

- Bureau of Reclamation
  - Agrimet Website
    - Seasonal ETm
    - Growing Season precipitation
  - Klamath project historical crop mix
Results

• MVP values are calculated under two scenarios
  – Deficit irrigation:
    • Choice variables: acreage and per acre applied water
  – No Deficit Irrigation:
    • Choice variables: Acreage

• Historic Klamath Project Operation Plans: average irrigation water use 390,000 acre feet. Max 500,000.

• Reducing irrigation by 45,000 AF
  – From 200,000 AF
  – From 390,000 AF
  – From 500,000 AF
**Results**

<table>
<thead>
<tr>
<th>With Deficit</th>
<th>Irrigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\theta$</td>
<td>0.082</td>
</tr>
<tr>
<td><em>St. Err.</em></td>
<td>(0.0173)</td>
</tr>
<tr>
<td><em>Z</em>-value</td>
<td>4.74</td>
</tr>
<tr>
<td><em>P</em>-value</td>
<td>0</td>
</tr>
<tr>
<td>$\beta_1$</td>
<td>-9.84E-06</td>
</tr>
<tr>
<td>$\chi^2(1)$</td>
<td>830.492</td>
</tr>
<tr>
<td><em>P</em>-value</td>
<td>0</td>
</tr>
<tr>
<td>$\beta_0$</td>
<td>7.904</td>
</tr>
</tbody>
</table>

$$y = (\theta \beta_0 + \theta \beta_1 x + 1)^{1/\theta}$$
Results

With No Deficit Irrigation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\theta$</td>
<td>0.663</td>
</tr>
<tr>
<td>St. Err.</td>
<td>(0.0455)</td>
</tr>
<tr>
<td>Z-value</td>
<td>14.57</td>
</tr>
<tr>
<td>P-value</td>
<td>0</td>
</tr>
<tr>
<td>$\beta_1$</td>
<td>-0.00012</td>
</tr>
<tr>
<td>$\chi^2(1)$</td>
<td>474.753</td>
</tr>
<tr>
<td>P-value</td>
<td>0</td>
</tr>
<tr>
<td>$\beta_0$</td>
<td>77.92</td>
</tr>
</tbody>
</table>

$$y = (\theta \beta_0 + \theta \beta_1 x + 1)^{1/\theta}$$

Demand with No Deficit Irrigation

- Shadow prices
- Fitted Curve
## Results

<table>
<thead>
<tr>
<th>Value of idled irrigation water</th>
<th>With Deficit Irrigation</th>
<th>With No Deficit Irrigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$MVP_{x^*}^{low=200K}$</td>
<td>6,601,133</td>
<td>11,300,000</td>
</tr>
<tr>
<td>Std. Err</td>
<td>(1246787)</td>
<td>(3139579)</td>
</tr>
<tr>
<td>P-value</td>
<td>0.013</td>
<td>0.037</td>
</tr>
<tr>
<td>$MVP_{x^*}^{med=390K}$</td>
<td>1,782,845</td>
<td>5,512,179</td>
</tr>
<tr>
<td>Std. Err</td>
<td>(189715)</td>
<td>(1272237)</td>
</tr>
<tr>
<td>P-value</td>
<td>0.003</td>
<td>0.023</td>
</tr>
<tr>
<td>$MVP_{x^*}^{high=500K}$</td>
<td>779,404</td>
<td>2,866,820</td>
</tr>
<tr>
<td>Std. Err</td>
<td>(51003)</td>
<td>(540234)</td>
</tr>
<tr>
<td>P-value</td>
<td>0.01</td>
<td>0.013</td>
</tr>
</tbody>
</table>

### Buy back program

- $3,2$ million.
- $18,312$ acres of idled land
- $45,000$ acre feet

\[
MVP_{x^*} = \int_{x'}^{x^*} (\theta \beta_0 + \theta \beta_1 x + 1)\bar{\theta} \, dx
\]
Conclusions

• Average per AF values - $17, $40, and $64
  – $22 to $79 per acre foot (Adams and Cho, 1998)
  – $9 to $105 per acre foot (Boehlert and Jaeger, 2010)
  – $75 (Burke et al., 2004)

• Difference between estimated and actual
  – Discontinuity of buy-back program
  – “Participation factor” (Burke, Adams, and Wallender (2004)
  – Multi-year contracts
Thank you!
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