Technological Change and Climatic Resiliency: Evidence from Irrigation in the United States

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NBER DAE
Summer Institute
July 9, 2019
US Irrigated Agriculture

Irrigated Acres (millions)

- East
- West
Background

- Droughts in the 1890s and 1930s had dramatic agricultural, social, and financial consequences (Hansen and Libecap 2004; Landon-Lane, Rockoff and Steckel 2009; Hornbeck 2012)

- Expanded irrigation and other technological advances increased level of ag production in arid western counties (Hornbeck and Keskin 2014; Edwards and Smith 2018; Olmstead and Rhode 2011)

- Growing literature on temperature shocks, but not drought and irrigation (e.g. Schlenker, Hannemann, and Fisher 2005; Deschenes and Greenstone 2007; Burke and Emerick 2016)

- Limited work on extent and mechanism by which irrigation mitigates shocks (Hornbeck and Keskin 2014; Hansen, Libecap and Lowe 2011)
Motivation

Dalhart, TX (ca. 1938)

Lubbock/Dalhart (ca. 2010s)
Expansion of Irrigation Storage

Groundwater Pumping

Federal Dams
Research Design and Data

- How do counties with potential storage react to drought before/after 1945 relative to those without?
- Create individual county measures of precipitation shock
  - Relative changes versus levels
- Does this change based on type of storage?
  1. Small stream (irrigation but no storage)
  2. Large river (surface storage)
  3. Aquifer
  4. Joint (Large river and aquifer)
- Ag census data 1910-2007 (digitized by Haines, 2010)
  - Crop value
  - Irrigated acres
  - Failed cropland
Measuring Storage Potential
Western Precipitation
Crop Value Pre-1950

The graph illustrates the crop value per acre for different drought bins. The x-axis represents the drought bin, ranging from -2 to 2, while the y-axis shows the crop value per acre, ranging from -0.6 to 0.4. Two lines are depicted: a dashed red line labeled "Small Stream" and a solid green line labeled "Storage." Both lines show a decrease in crop value as the drought bin increases.
Crop Value Post-1950

Post-1950

Crop Value per Acre

Drought Bin

-2 -1 0 1 2

Small Stream

Storage
Crop Value by Storage Type Post-1950

Post-1950

Crop Value per Acre

Drought Bin

Large Stream
Aquifer
Large and Aquifer
Fraction Irrigated by Storage Type Post-1950

Post-1950

Fraction Irrigated

Drought Bin

Large Stream
Aquifer
Large and Aquifer
Summary and Next Steps

- US agriculture has become more resilient to drought, but only partially as a result of adding large dams and groundwater.
- The type of irrigation technology affects how the production process changes: resiliency is interaction between technological and behavior changes.
- Refine and test robustness of measures of drought/temperature:
  - Palmer Drought Severity Index
  - Heat shocks
- Ag census data (1850-1900)
- Data by specific crops (1850-2012)
- Irrigation expansion in the East
Thank you!
Drought Status in 1934
1934 Binned Drought Status

Legend

1934 Drought Status
Precip. Coef. of Var.

- Red: <-1.5
- Orange: -1.5 to -0.5
- Light Orange: -0.5 to 0.5
- Yellow: 0.5 to 1.5
- Green: >1.5
Wettest Year: 1941
Precipitation Bins

![Histogram of Coefficient of Variation (Precip)]
# Regression Results: Storage

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>(1) Pre-1950 Ln(Crop Value)</th>
<th>(2) Post-1950 Ln(Crop Value)</th>
<th>(3) Pre-1950 Pctg Irr.</th>
<th>(4) Post-1950 Pctg Irr.</th>
<th>(5) Pre-1950 Ln(Failure)</th>
<th>(6) Post-1950 Ln(Failure)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bin 1</td>
<td>0.336*** (0.102)</td>
<td>-0.0841 (0.059)</td>
<td>3.94E-05 (0.002)</td>
<td>-0.0109*** (0.002)</td>
<td>-1.692*** (0.082)</td>
<td>0.398** (0.187)</td>
</tr>
<tr>
<td>Bin 2</td>
<td>0.289*** (0.092)</td>
<td>0.00597 (0.037)</td>
<td>-0.00156 (0.003)</td>
<td>-0.00692*** (0.002)</td>
<td>-0.451 (0.322)</td>
<td>-0.146 (0.142)</td>
</tr>
<tr>
<td>Bin 4</td>
<td>-0.394*** (0.090)</td>
<td>-0.0344 (0.045)</td>
<td>0.00131 (0.001)</td>
<td>-0.000265 (0.001)</td>
<td>1.067*** (0.253)</td>
<td>0.504*** (0.126)</td>
</tr>
<tr>
<td>Bin 5</td>
<td>-0.338*** (0.078)</td>
<td>-0.250*** (0.094)</td>
<td>-0.00149 (0.003)</td>
<td>-0.00649** (0.003)</td>
<td>0.371 (0.255)</td>
<td>1.220*** (0.137)</td>
</tr>
<tr>
<td>Storage × Bin 1</td>
<td>-0.358*** (0.126)</td>
<td>0.118* (0.069)</td>
<td>-0.00508* (0.003)</td>
<td>0.00454 (0.004)</td>
<td>2.612*** (0.254)</td>
<td>-0.351* (0.204)</td>
</tr>
<tr>
<td>Storage × Bin 2</td>
<td>-0.256** (0.103)</td>
<td>-0.0419 (0.041)</td>
<td>-0.00285 (0.004)</td>
<td>0.00327 (0.002)</td>
<td>0.496 (0.374)</td>
<td>0.122 (0.154)</td>
</tr>
<tr>
<td>Storage × Bin 4</td>
<td>-0.0811 (0.106)</td>
<td>0.0582 (0.050)</td>
<td>-0.000416 (0.001)</td>
<td>0.000362 (0.002)</td>
<td>-0.02 (0.266)</td>
<td>-0.0695 (0.143)</td>
</tr>
<tr>
<td>Storage × Bin 5</td>
<td>-0.236** (0.092)</td>
<td>0.197** (0.100)</td>
<td>0.00526* (0.003)</td>
<td>0.00153 (0.004)</td>
<td>0.976*** (0.288)</td>
<td>-0.394** (0.163)</td>
</tr>
</tbody>
</table>

Observations: 1,914 6,617 1,914 6,688 954 3,285
R-squared: 0.335 0.355 0.094 0.151 0.315 0.719
Number of stcounty: 479 479 479 479 478 474

Robust standard errors in parentheses

∗∗∗p < 0.01, ∗∗p < 0.05, ∗p < 0.1
Irrigated Acreage Pre-1950
Irrigated Acreage Post-1950

Post-1950

Fraction Irrigated

Drought Bin

-2 -1 0 1 2

Small Stream

Storage
Crop Failure Pre-1950

The graph shows the relationship between failed crops and drought bins for the period Pre-1950. The graph includes two lines:
- The green line represents 'Storage' with markers indicating failed crops.
- The red dashed line represents 'Small Stream' with markers indicating failed crops.

The x-axis represents the Drought Bin, ranging from -2 to 2, and the y-axis represents Failed Crops, ranging from -2 to 2.
## Regression Results: Storage Types

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>(1) Pre-1950 Ln(Crop Value)</th>
<th>(2) Post-1950 Ln(Crop Value)</th>
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<th>(4) Post-1950 Pctg Irr.</th>
<th>(5) Pre-1950 Ln(Failure)</th>
<th>(6) Post-1950 Ln(Failure)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bin 1</td>
<td>0.337***</td>
<td>-0.084</td>
<td>5.03E-05</td>
<td>-0.0109***</td>
<td>-1.714***</td>
<td>0.399**</td>
</tr>
<tr>
<td></td>
<td>(0.102)</td>
<td>(0.059)</td>
<td>(0.002)</td>
<td>(0.002)</td>
<td>(0.083)</td>
<td>(0.188)</td>
</tr>
<tr>
<td>Bin 2</td>
<td>0.291***</td>
<td>0.00595</td>
<td>-0.00154</td>
<td>-0.00691***</td>
<td>-0.456</td>
<td>-0.145</td>
</tr>
<tr>
<td></td>
<td>(0.092)</td>
<td>(0.037)</td>
<td>(0.003)</td>
<td>(0.002)</td>
<td>(0.324)</td>
<td>(0.142)</td>
</tr>
<tr>
<td>Bin 4</td>
<td>-0.393***</td>
<td>-0.0346</td>
<td>0.00137</td>
<td>-0.000284</td>
<td>1.081***</td>
<td>0.504***</td>
</tr>
<tr>
<td></td>
<td>(0.090)</td>
<td>(0.045)</td>
<td>(0.001)</td>
<td>(0.001)</td>
<td>(0.254)</td>
<td>(0.127)</td>
</tr>
<tr>
<td>Bin 5</td>
<td>-0.337***</td>
<td>-0.250***</td>
<td>-0.00138</td>
<td>-0.00657**</td>
<td>0.386</td>
<td>1.219***</td>
</tr>
<tr>
<td></td>
<td>(0.078)</td>
<td>(0.094)</td>
<td>(0.003)</td>
<td>(0.003)</td>
<td>(0.256)</td>
<td>(0.137)</td>
</tr>
<tr>
<td>Aquifer x Bin 1</td>
<td>-0.467***</td>
<td>0.188**</td>
<td>-0.00602*</td>
<td>0.00245</td>
<td>2.831***</td>
<td>-0.323</td>
</tr>
<tr>
<td></td>
<td>(0.152)</td>
<td>(0.077)</td>
<td>(0.003)</td>
<td>(0.006)</td>
<td>(0.266)</td>
<td>(0.221)</td>
</tr>
<tr>
<td>Aquifer x Bin 2</td>
<td>-0.305***</td>
<td>-0.0193</td>
<td>-0.00187</td>
<td>0.00459*</td>
<td>0.791*</td>
<td>0.126</td>
</tr>
<tr>
<td></td>
<td>(0.117)</td>
<td>(0.045)</td>
<td>(0.004)</td>
<td>(0.003)</td>
<td>(0.414)</td>
<td>(0.166)</td>
</tr>
<tr>
<td>Aquifer x Bin 4</td>
<td>-0.0973</td>
<td>0.0754</td>
<td>-0.000474</td>
<td>0.0042</td>
<td>0.141</td>
<td>0.0128</td>
</tr>
<tr>
<td></td>
<td>(0.127)</td>
<td>(0.053)</td>
<td>(0.001)</td>
<td>(0.003)</td>
<td>(0.276)</td>
<td>(0.152)</td>
</tr>
<tr>
<td>Aquifer x Bin 5</td>
<td>-0.243**</td>
<td>0.198*</td>
<td>0.00476</td>
<td>-0.00131</td>
<td>1.186***</td>
<td>-0.440**</td>
</tr>
<tr>
<td></td>
<td>(0.114)</td>
<td>(0.106)</td>
<td>(0.004)</td>
<td>(0.005)</td>
<td>(0.322)</td>
<td>(0.190)</td>
</tr>
</tbody>
</table>
### Regression Results: Storage Types

<table>
<thead>
<tr>
<th></th>
<th>Joint x Bin 1</th>
<th>Joint x Bin 2</th>
<th>Joint x Bin 4</th>
<th>Joint x Bin 5</th>
<th>Large Stream x Bin 1</th>
<th>Large Stream x Bin 2</th>
<th>Large Stream x Bin 4</th>
<th>Large Stream x Bin 5</th>
<th>Observations</th>
<th>R-squared</th>
<th>Number of stcounty</th>
<th>Fixed Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-0.147 (0.120)</td>
<td>-0.264** (0.121)</td>
<td>-0.0719 (0.114)</td>
<td>-0.244** (0.113)</td>
<td>-0.238 (0.182)</td>
<td>-0.0418 (0.140)</td>
<td>-0.00778 (0.135)</td>
<td>-0.162 (0.117)</td>
<td>1,914</td>
<td>0.338</td>
<td>479</td>
<td>Year, Cty</td>
</tr>
<tr>
<td></td>
<td>0.0132 (0.088)</td>
<td>-0.0814* (0.049)</td>
<td>0.052 (0.055)</td>
<td>0.152 (0.108)</td>
<td>0.0858 (0.106)</td>
<td>-0.0452 (0.055)</td>
<td>0.0182 (0.063)</td>
<td>0.290** (0.116)</td>
<td>6,617</td>
<td>0.356</td>
<td>479</td>
<td>Year, Cty</td>
</tr>
<tr>
<td></td>
<td>-0.00448 (0.004)</td>
<td>-0.00601 (0.006)</td>
<td>0.000169 (0.002)</td>
<td>0.00905* (0.005)</td>
<td>-0.00405 (0.004)</td>
<td>0.00213 (0.004)</td>
<td>-0.00111 (0.001)</td>
<td>0.000272 (0.003)</td>
<td>1,914</td>
<td>0.101</td>
<td>479</td>
<td>Year, Cty</td>
</tr>
<tr>
<td></td>
<td>0.00827 (0.009)</td>
<td>-0.000584 (0.004)</td>
<td>-0.00686* (0.004)</td>
<td>-0.00326 (0.006)</td>
<td>0.00465 (0.003)</td>
<td>0.00558*** (0.002)</td>
<td>-0.000345 (0.002)</td>
<td>0.0144*** (0.004)</td>
<td>6,688</td>
<td>0.143</td>
<td>479</td>
<td>Year, Cty</td>
</tr>
<tr>
<td></td>
<td>-0.406* (0.237)</td>
<td>0.760* (0.184)</td>
<td>-0.164 -0.135</td>
<td>1.002*** (0.185)</td>
<td>-0.346</td>
<td>-0.835 (0.207)</td>
<td>-0.469 (0.191)</td>
<td>-0.442* (0.251)</td>
<td>954</td>
<td>0.331</td>
<td>478</td>
<td>Year, Cty</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3,285</td>
<td>0.719</td>
<td>474</td>
<td>Year, Cty</td>
</tr>
</tbody>
</table>

Robust standard errors in parentheses

* **p < 0.01, **p < 0.05, *p < 0.1
Crop Value by Storage Type Pre-1950

Pre-1950

Crop Value per Acre

Drought Bin

Large Stream
Aquifer
Large and Aquifer
Fraction Irrigated by Storage Type Pre-1950

Pre-1950

Drought Bin

Fraction Irrigated

Large Stream
Aquifer
Large and Aquifer
Fraction Irrigated by Storage Type Post-1950
Crop Failure by Storage Type Pre-1950

Drought Bin

Failed Crops

-2 -1.5 -1 -0.5 0 0.5 1 1.5 2

Pre-1950

Large Stream Aquifer Large and Aquifer
Crop Failure by Storage Type Post-1950

Post-1950

Failed Crops

Drought Bin

-2 -1.5 -1 -0.5 0 0.5 1 1.5 2

-2 -1.5 -1 -0.5 0 0.5 1 1.5 2

Large Stream

Aquifer

Large and Aquifer