Table 2. Summary of agriculture impacts of the 2015 California drought

<table>
<thead>
<tr>
<th>Description</th>
<th>Base year</th>
<th>Drought change</th>
<th>% change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface water supply</td>
<td>22.2</td>
<td>10.7 loss</td>
<td>-48%</td>
</tr>
<tr>
<td>Groundwater use</td>
<td>10.4</td>
<td>8.0 increase</td>
<td>72%</td>
</tr>
<tr>
<td>Net water use</td>
<td>32.6</td>
<td>3.3 reduction</td>
<td>-10%</td>
</tr>
<tr>
<td>Drought-related idle land (ha)</td>
<td>500,000a</td>
<td>225,000 more</td>
<td>45%</td>
</tr>
<tr>
<td>Crop revenue ($</td>
<td>$35 billion</td>
<td>$900 million loss</td>
<td>-2.6%</td>
</tr>
<tr>
<td>Dairy and livestock revenue ($)</td>
<td>$12.4 billion</td>
<td>$350 million loss</td>
<td>-2.8%</td>
</tr>
<tr>
<td>Groundwater pumping cost ($)</td>
<td>$780 million</td>
<td>$590 million rise</td>
<td>75.5%</td>
</tr>
<tr>
<td>Direct costs ($)</td>
<td>N/A</td>
<td>$1.8 billion loss</td>
<td>N/A</td>
</tr>
<tr>
<td>Total economic impact ($)</td>
<td>N/A</td>
<td>$2.7 billion loss</td>
<td>N/A</td>
</tr>
<tr>
<td>Direct farm jobs</td>
<td>200,000b</td>
<td>10,100 loss</td>
<td>5.1%</td>
</tr>
<tr>
<td>Total job losses</td>
<td>N/A</td>
<td>21,000 loss</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Source: Data from Howitt et al. (2015b).

Table 5. Historical droughts in California, their impacts, innovations, and leading innovators

<table>
<thead>
<tr>
<th>Drought</th>
<th>Impacts</th>
<th>Innovations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1800s</td>
<td>Herds and crops devastated</td>
<td>Local irrigation, 1873 Federal Central Valley study</td>
</tr>
<tr>
<td>1924</td>
<td>Crop devastation</td>
<td>Local reservoir projects, major regional/state water project plans</td>
</tr>
<tr>
<td>1928–1932</td>
<td>Delta salinity, crop losses</td>
<td>Major statewide dam and canal plans and projects (CVP, SWP)</td>
</tr>
<tr>
<td>1976–1977</td>
<td>Major urban and agricultural shortages</td>
<td>Urban conservation; early markets</td>
</tr>
<tr>
<td>1988–1992</td>
<td>Urban and agricultural shortages; endangered fish</td>
<td>Interties, conjunctive use; water markets; conservation; new storage</td>
</tr>
<tr>
<td>2007–2009</td>
<td>Water shortages for agriculture and fish</td>
<td>New water use reporting requirements, Delta planning institutions, and urban water conservation mandates</td>
</tr>
<tr>
<td>2012–2016</td>
<td>Warm drought, little Delta water, major agricultural shortages, damage to fish and forests</td>
<td>Groundwater sustainability legislation; Delta barrier; state urban conservation mandates; more water use reporting; local responsiveness</td>
</tr>
</tbody>
</table>

Source: Data from Lund (2014a).
Conceptual Models for Extreme Weather Events and Health

- **Model 1**
  - Random variation in Extreme Weather Events Across Year/Month and Zip Code
  - Economic Consequences: e.g., job and income loss
  - Stress Consequences: Biological Systems Stressed beyond Capacity to Cope
  - Health Consequences: Lower Birth Weight, Fetal Death, Higher Psychological Distress, Low self-rated health

- **Model 2**
  - Random variation in Extreme Weather Events Across Year/Month and Zip Code
  - Economic Consequences: e.g., job and income loss
  - Stress Consequences: Biological Systems Stressed beyond Capacity to Cope
  - Water Policy (e.g., reliability, water markets, access to water banks, groundwater)
  - Health Consequences: Lower Birth Weight, Fetal Death, Higher Psychological Distress, Low self-rated health
Health Data

- **Office of Statewide Health Planning and Development (OSHPD)**
  - Infant vital statistics database; holds a record of every birth, newborn hospitalization, maternal antepartum and postpartum hospital visit between 1991 and 2011
  - **Main outcome:** birth weight (N = 11 million)
  - Other outcomes: fetal death, 28-day mortality

- **California Health Interview Surveys (CHIS)**
  - Representative sample of 18+ pop. (N = 350,000 adults)
  - **Main outcome:** psychological distress (Kessler 6)

Climate and Weather Data

- **NOAA’s Global Historical Climatology Network**
  - 800 network stations within California; period of interest: 1990–2015
  - Daily maximum and minimum temperatures, daily precipitation totals, monthly PDSI

Water Policy Data

- Central Valley Project Operations Office and the State Water Project
  - Annual water allocations to water districts (short and long-run variances)
  - Portfolio data (access to groundwater, water banks and trades)

**Empirical Strategy: Fixed Effects Ordinary Least Squares**

Assume: intertemporal variation in temperature / drought at any ZIP code is essentially random

Compare changes in health as different ZIP codes move in and out of periods of extreme weather
Measuring Extreme Weather Events

- **Extreme weather events:**
  - **Extreme heat** = days with mean temperature greater than 90 degrees Fahrenheit
  - **Daytime heat wave** = a spell of at least three successive warm days
  - **Nighttime heat wave** = a spell of at least three successive warm nights
  - Warm day (warm night) = one where the daily high (daily low) exceeds the 90th percentile of that location’s maximum (minimum) temperatures for that time of the year
  - **Daytime cold wave** = 3 or more consecutive cool days
  - **Nighttime cold wave** = 3 or more consecutive cool nights
  - Cool day (night) analogous to warm day (night); based on 20th percentile of max (min) temperature
  - High overnight temperatures particularly dangerous since cooling opportunities are reduced

CHIS: respondent exposure is unique to their location and recall period (30 days prior to interview)

OSHPD: in utero exposure is determined by the mother’s ZIP code and duration of pregnancy
Impacts on Psychological Distress

- Nighttime heat waves increase distress
  - Both frequency and duration matter
  - Marginal nighttime heat wave event increases the average adult’s distress by 1 percent
  - Marginal hot night increased distress by 0.4 percent
  - No seasonal difference detected
  - Differential impacts not detected for women or elderly

- Daytime heat waves do not appear to affect distress levels

- Poor adults were esp. vulnerable to extreme heat, e.g. *days with mean temperature > 90°F*

- No effect in the pooled sample
Impacts on Birth Weight: Second and Third Trimesters

- Extreme heat has several detrimental effects on newborns
- Hot days (mean temperature > 90°F) reduce birth weight
- Hot days shorten gestation
  - The impact on birth weight comes through gestation
- Extreme heat depresses birth weights more in rural ZIP codes than in cities
- Hot weather reduces birth weight if it occurs *unseasonably*
  - Compared to infants born in the summer/autumn, the third trimesters of infants born in the winter/spring coincide with cold months
  - Hot days in the cold time of the year dramatically reduce birth weight but hot days in the warm months seem to not!
Impacts on Birth Weight: Second and Third Trimesters

- Below 30F: 1.06
- 30 - 40F: -0.14
- 40 - 50F: -0.08
- 60 - 70F: -0.22
- 70 - 80F: -0.32
- 80 - 90F: -0.42
- Over 90F: -0.19

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- Below 30F: 0.24
- 30 - 40F: 0.12
- 40 - 50F: -0.09
- 60 - 70F: -0.08
- 70 - 80F: -0.17
- 80 - 90F: -0.26
- Over 90F: 0.03