Agricultural Decision Making Under Climate Uncertainty

Risk & Decision Analysis Applied to Climate Adaptation

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Key Points:

• Agriculture is risky business, especially due to markets and climate

• Risk pervades the whole structure of agriculture, from the producer to the trader, and is often addressed by government policy which plays a big role in ag worldwide.
  – Price supports
  – Marketing assistance
  – Insurance
  – Disaster aid

• Systems to manage risk within ag are well-developed:
  – Adaptive, flexible production methods often with intelligence gathering
  – Farm finance management (e.g., from family savings to alternative income)
  – Marketing strategies (on-farm storage; forward contracts, etc.)
Formal risk and decision analysis has been applied to agriculture for a long time:

Different from traditional ag-economic approaches, but generally compatible
Attend to: Risk, uncertainty, decision making, and decision support
Some aspects of ag risk

• Large uncertainty, but very adaptable system, mostly short-term, repetitive “bets” with lots of learning

• Some long-term investments (e.g., irrigation), so some dimensions of long-term risk do matter

• Risk aversion vs. regret aversion (mini-max, maxi-min, etc.)

• Deal with full statistical distribution, and explicitly with extreme events and catastrophic loss

• RDA should lead to decision support (RDA does not yield decisions but can provide decision support)

• Incremental vs. transformational responses (adaptation)
Enterprise Decision Structuring

• What’s the goal of the DM’er? What outcomes matter (utilities), what options, sequences, range of outcomes, etc.
  – What to plant, when to plant, manage for pest, manage fertility, when to harvest, how to market, how to hedge

• What utility function?
  – risk aversion posture (e.g., maximum yield, maximized expected utility, avoid complete loss; trade-off with average gain, etc.).
Risk analysis and risk management and decision-support emerging as important planning tools
Risk

\[ R = p \cdot c \]

**Expected utility of a decision**

\[
EU(d_i) = \sum_{j=1}^{N} P(s_j) \cdot U(d_i, s_j)
\]

\( d_i \) = alternative decisions \( i = 1, 2 \ldots \)
\( N \) = number of possible future states \( (s_j) \)
\( P(s_j) \) = probability of state \( j \)

**Risk and regret aversion**

If \( S \) is a state, and \( P \) a policy choice, let \( P^*(S) \) be the best policy choice conditional on \( S \) being the state, and \( V(S, P) \) the value of choosing policy \( P \) if the outcome is \( S \). Then the goal is:

\[
\min_p \max_S [V(S, P^*(S)) - V(S, P)]
\]
**FISHERMAN'S CHOICE**

### A. EXPECTED UTILITY: COMPLETE UNCERTAINTY

<table>
<thead>
<tr>
<th>ALTERNATIVE ACTIONS</th>
<th>STATES OF NATURE</th>
<th>Expected utility</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>E₁ Hurricane</td>
<td>E₂ No. hurricane</td>
</tr>
<tr>
<td>A₁ Evacuate</td>
<td>Equipment intact Pay for evacuation (+1)</td>
<td>Equipment intact Pay for evacuation (+1)</td>
</tr>
<tr>
<td>A₂ Remain</td>
<td>Lose equipment (0)</td>
<td>Equipment intact (+2)</td>
</tr>
</tbody>
</table>

### B. EXPECTED UTILITY: KNOWN PROBABILITY

<table>
<thead>
<tr>
<th>ALTERNATIVE ACTIONS</th>
<th>STATES OF NATURE</th>
<th>Expected utility</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>E₁ Hurricane</td>
<td>E₂ No. hurricane</td>
</tr>
<tr>
<td></td>
<td>Equipment intact Pay for evacuation (.4(+1) = .4)</td>
<td>Equipment intact Pay for evacuation (.6(+1) = .6)</td>
</tr>
<tr>
<td>A₁ Evacuate</td>
<td>.4(0) = 0</td>
<td>Equipment intact (+2)</td>
</tr>
<tr>
<td>A₂ Remain</td>
<td>Lose equipment</td>
<td>Equipment intact (+2)</td>
</tr>
</tbody>
</table>

### C. EXPECTED UTILITY: SUBJECTIVE PROBABILITIES

<table>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>E₁ Hurricane</td>
<td>E₂ No. hurricane</td>
</tr>
<tr>
<td>A₁ Evacuate</td>
<td>Equipment intact Pay for evacuation (.9(+2) = 1.8)</td>
<td>Equipment intact Pay for evacuation (.1(+2) = .2)</td>
</tr>
<tr>
<td>A₂ Remain</td>
<td>Lose equipment (.9(0) = 0)</td>
<td>Equipment intact (.1(+4) = .4)</td>
</tr>
</tbody>
</table>

### D. EXPECTED UTILITY: MINIMIZE REGRET

<table>
<thead>
<tr>
<th>ALTERNATIVE ACTIONS</th>
<th>STATES OF NATURE</th>
<th>Expected utility</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>E₁ Hurricane</td>
<td>E₂ No. hurricane</td>
</tr>
<tr>
<td>A₁ Evacuate</td>
<td>Equipment intact Pay for evacuation 1-1</td>
<td>Equipment intact 0</td>
</tr>
<tr>
<td>A₂ Remain</td>
<td>Lose equipment</td>
<td>Equipment intact</td>
</tr>
</tbody>
</table>

**FIGURE 2.8—PAY-OFF MATRICES FOR EQUIPMENT EVACUATION ON TROPICAL CYCLONE WARNING**

In trying to decide whether to evacuate the boat with his equipment or to "sit it out" in the face of a tropical cyclone warning, a "rational" fisherman might analyze his choices in many ways depending on his knowledge, beliefs, and values.
<table>
<thead>
<tr>
<th>Chance of Hurricane = 20%</th>
<th>Hurricane</th>
<th>No Hurricane</th>
<th>EU=(.2*-1)+(.8*-1)=-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evacuate</td>
<td>-1</td>
<td>-1</td>
<td>EU=(.2*-1)+(.8*-1)=-1</td>
</tr>
<tr>
<td>Remain</td>
<td>-3</td>
<td>0</td>
<td>EU=(.2*-3)+(.8*0)=-0.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>30% chance</th>
<th>Hurricane</th>
<th>No Hurricane</th>
<th>EU=(.3*-1)+(.7*-1)=-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evacuate</td>
<td>-1</td>
<td>-1</td>
<td>EU=(.3*-1)+(.7*-1)=-1</td>
</tr>
<tr>
<td>Remain</td>
<td>-3</td>
<td>0</td>
<td>EU=(.3*-3)+(.7*0)=-0.9</td>
</tr>
<tr>
<td></td>
<td>Hurricane</td>
<td>No Hurricane</td>
<td></td>
</tr>
<tr>
<td>----------------</td>
<td>-----------</td>
<td>--------------</td>
<td>------</td>
</tr>
<tr>
<td>Evacuate</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Remain</td>
<td>0</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Hurricane</th>
<th>No Hurricane</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Evacuate</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Remain</td>
<td>0</td>
<td>2</td>
<td>0.8</td>
</tr>
</tbody>
</table>
Problem 5.8 - Excel Solution
Making Hard Decisions with DecisionTools, 3rd ed., Clemens & Reilly

<table>
<thead>
<tr>
<th>Cost of Burners</th>
<th>Damage using Burners</th>
<th>Cost of Sprinklers</th>
<th>Damage using Sprinklers</th>
<th>Value of Crop</th>
<th>Probability of Freeze</th>
</tr>
</thead>
<tbody>
<tr>
<td>$7,000</td>
<td>Low</td>
<td>$20,000</td>
<td>High</td>
<td>$50,000</td>
<td>50%</td>
</tr>
<tr>
<td></td>
<td>Best Guess</td>
<td>$17,500</td>
<td>Low</td>
<td>$25,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Best Guess</td>
<td>$27,500</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>High</td>
<td>$30,000</td>
<td></td>
</tr>
</tbody>
</table>

Results found by varying losses in the tree and determining the expected loss:
Alternative            | Min Expected Crop Value | Max Expected Crop Value |
------------------------|-------------------------|-------------------------|
Do nothing              | $25,000                 | $25,000                 |
Set burners             | $35,000                 | $37,500                 |
Use sprinklers           | $35,000                 | $35,000                 |

Spider Graph of Decision Tree 'Problem 5.8'
Expected Value of Entire Model

- Damage using Burners (B7)
- Damage using Sprinklers (D7)
Less work yet on when and how to adapt to climate change.
Farmers and other decision-makers face real conundrums:

• Adapt to what trend?
• When to adapt?
• What adaptation?

Ouch!
FarmAdap: Great Plains Dryland Wheat Farm Model
When to Adapt?

Adaptations under rapid change
Adaptations under gradual change

Gradual change w/ extreme drought

Begin adaptation w/ extreme drought

Begin adaptation w/o extreme drought

- Non-Adaptive (Continuous Spring Wheat)
- Adaptive Fallow without extreme drought
- Adaptive Fallow with extreme drought

Year

Net income (1,000 $)
https://www.AnalyticaCloud.com/acp/Client/AcpClient.aspx?inviteId=19&inviteCode=322716&subName=william%2Etravis%40colorado%2Eedu
Much work to do in ag risk and climate:

- Extremes and complete loss
- Alternative risk transfer instruments
- Game theory: how to choose when choice by others affects your utility.
- Value (+/-) of additional information (e.g., seasonal to decadal forecasts)
Farmers in central North Dakota are growing more Winter Wheat as winters warm and cold-hardy varieties become available. But watch out for those cold extremes! Is it time to switch yet?

- Adapt to what trend?
- When to adapt?
- What adaptation?

Ouch!
North Dakota base
North Dakota Step 2

[Map of North Dakota with regions highlighted in red, blue, and yellow.]
Insurance Instruments

• Yield deficiency
• Income protection
• Index insurance (often rainfall, but maybe range condition, even NVDI)
  – Is insurance adaptive?
  – Can insurance schemes keep up with climate and technological change?
  – Might it incentivize risky behaviors and non-adaptation (worries from the flood insurance program in the US)?
Herd management after first year of drought

- Hold on (Normal Cull)
  - 2nd year Drought
  - No Drought
    - Normal income; Range Fair-Good

- Moderate Cull
  - No Drought
    - High Payoff; Range Good
    - Low Payoff; Range Fair
  - Continued Drought
    - High Payoff; Range Good
    - Low Payoff; Range Good

- Sell Off
  - No Drought
    - High Payoff; Range Good
    - Low Payoff; Range Good
  - Continued Drought
    - High Payoff; Range Good
    - Low Payoff; Range Good

Sale Decision

2nd yr drought?

Market

Income & Range Outcome
Ranching drought decision-making model

60% chance of drought in second year:
- Cull to forage available
- Cull 10%
- No cull

Sell the herd or hold on?