Modeling Climate Change Impacts on Farm Households in Zambia

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Outline of presentation

• Modeling impacts of climate change on farm households, and optional adaptation strategies
• Incorporating minimum tillage options in the farm household models (Eastern Province)
• Comparison of farmers’ perceptions of climate change with empirical climate trends
• Findings and conclusions
• Next steps and possible extensions
Objectives of farm household modeling*

• Connect broad-scale climate change analysis and modeling with analysis of smallholder farming systems at a much smaller spatial scale, where adaptation information is most helpful.

• To add an economics dimension to climate and crop modeling, through design and use of models that identify the set of farming activities that optimizes profit or calorie production.

Research questions

1. How will representative farm households in Zambia respond to the effects of climate change on crop yields?

2. To what extent can farmers minimize the negative effects of climate change by changing crops or production technologies?

How the optimization model works

• Choose the set of crops and production technologies that best meets the household’s objectives (profit, calorie production)

• Taking into account:
  • Crop yields
  • Inputs required for each production activity
  • Prices of crop outputs and inputs
  • Availability of land, labor, cash
  • Household calorie consumption needs
  • Desire to maintain soil fertility
The model

Crop budgets

Socio-economic information on households

Farm-household model

Crop yield functions

\[ Y = f(x, \beta) + \epsilon \]

‘Observations’ of future climate

Model output

- Likely cropping patterns & production levels
- Probability distributions of calorie production
- Likely adaptation strategies or constraints to adaptation
Data sources

• Crop Forecast Survey (CFS) 2003 – 2012
• Rural household surveys (SS 2004 & 2008, RALS 12)
• Secondary source (Siegel & Alwang 2005)
• Focus group input
• Zambia Meteorological Department (ZMD)
• IPCC GCM climate predictions
Household types*

Smallholder
- 1.9 hectares
- 2.75 working-age members
- 250 ZMK cash available

Emergent farmer
- 7 hectares
- 3.25 working-age members
- 150,000 ZMK cash available

Female-headed household
- 1.5 hectares
- 2 working-age members
- 225 ZMK cash available

*Rough averages of model values across the three study sites.
### Which crops & management regimes?*

*Based on data from Crop Forecast Survey*

<table>
<thead>
<tr>
<th>Crop</th>
<th>Seed Type</th>
<th>Tillage Method</th>
<th>Fertilizer</th>
<th>Time of tillage</th>
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<td>Early</td>
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</table>

Other crops included: millet, sorghum, sunflower, sweet potato, cotton.

*Examples drawn from a much longer list of regimes included in the models.*
# Labor requirements by site & crop regime

<table>
<thead>
<tr>
<th>SITE 1</th>
<th>MZ10</th>
<th>MZ1</th>
<th>MZ6</th>
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*Unit = 7-hour work day*
<table>
<thead>
<tr>
<th></th>
<th>Small-holder</th>
<th>FHH</th>
<th>Emergent</th>
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<tbody>
<tr>
<td>Budget (cash available, ZMK)</td>
<td>350</td>
<td>325</td>
<td>1,500</td>
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<td>Net revenue (ZMK)</td>
<td>2,119.20</td>
<td>1,916.04</td>
<td>5,099.73</td>
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<td>Returns per AE per day (ZMK)</td>
<td>1.27</td>
<td>1.53</td>
<td>2.57</td>
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<td>Returns to land (ZMK/ha)</td>
<td>1,103.75</td>
<td>1,101.17</td>
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<td>% cash inputs of gross value of production</td>
<td>14.17</td>
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<td>22.73</td>
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<td>Calories per adult equivalent (AE) per day</td>
<td>4,938.24</td>
<td>5,967.49</td>
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<td>Land cultivated (ha)</td>
<td>1.53</td>
<td>1.28</td>
<td>4.72</td>
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<td>Land constraint binding?</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
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<td>Labor constraint binding (months)</td>
<td>Dec</td>
<td>June</td>
<td>Jan, June</td>
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<td>Hectares of crop activity</td>
<td>MZ4</td>
<td>0.29</td>
<td>1.37</td>
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<td>MZ6</td>
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<td>SUN10</td>
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<td>COT12</td>
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<td>COT10</td>
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<td>Fallow</td>
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<td>0.46</td>
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<tr>
<td><strong>VALIDATION TESTS</strong></td>
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<tr>
<td>% difference in model vs actual land use</td>
<td>15.56</td>
<td>20.26</td>
<td>32.16</td>
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<tr>
<td>% difference (gross value of production)</td>
<td>29.03</td>
<td>56.06</td>
<td>0.07</td>
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<tr>
<td>% difference (calories produced – excl. cotton)</td>
<td>4.31</td>
<td>2.92</td>
<td>39.24</td>
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</table>
Baseline crop choices, Eastern Province

Emergent farmer
- MZ4 (Hybrid maize, hand-hoe, fertilizer, late planting)
- MZ6 (Local maize, plough, no fertilizer, late planting)
- SUN10 (Improved sunflower, plough, late planting)
- COT12 (Cotton, hand-hoe, late planting)
- COT10 (Cotton, plough, late planting)
- Fallow

Female-headed household

Smallholder

Hectares
Statistical crop yield models

• Yield (kg/ha) a function of:
  ➢ **Rainfall** (amount and intra-season variability)
  ➢ **Temperature** (average across growing season)

• Data: (1) ZMD weather records from nearby met stations, and (2) CFS field-level data (9 years) aggregated to district

• Stepwise variable selection procedure:
  \[
  \ln(\text{Mean yield}_{dcsf}) = f(rain, rain^2, avg.\ temp, temp^2, CV_{rain, districts})
  \]
  where d = district, c = crop, s = seed type, f = fertilizer use
Climate change scenarios

• The Hadley (HadCM3) model (relatively “dry”)
  – Declines in rainfall
  – Somewhat higher intra-season variability in rainfall than CCSM
  – Increases in temperature

• The CCSM model (relatively “wet”)
  – Increases in rainfall
  – Somewhat less drastic increases in temperature than Hadley
Future climate scenarios used to predict yields in 2050

Hadley: ↓ 10 mm (-1%); ↑ 2.29 °C (+11%)
CCSM: ↑ 71 mm (+7%); ↑ 2.08 °C (+10%)

Hadley: ↓ 76 mm (-8%); ↑ 2.41 °C (+10%)
CCSM: ↑ 38 mm (+4%); ↑ 2.17 °C (+9%)

Hadley: ↓ 50 mm (-7%); ↑ 2.31 °C (+10%)
CCSM: ↑ 28 mm (+4%); ↑ 2.31 °C (+10%)
Future yield predictions for Eastern Province based on statistical yield analysis

Proportion change in expected yield

- MZ1, MZ4, MZ9, MZ6, GR1, GR2, GR12, GR6, SUN10, SUN2, SP12, SP2, COT16, COT10

Legend:
- Hadley
- CCSM
Future yield predictions for Eastern Province based on statistical yield analysis

Hybrid maize with fertilizer

Sunflower

Cotton

Proportion change in expected yield

MZ1 MZ4 MZ9 MZ6 GR1 GR2 GR12 GR6 SUN10 SUN2 SP12 SP2 COT16 COT10

Hadley

CCSM
Effects of adaptation in Eastern Province

Site 2

- **Emergent farmer - Hadley**
- **Emergent farmer - Baseline**
- **FHH - Hadley**
- **FHH - Baseline**
- **Smallholder - Hadley**
- **Smallholder - Baseline**

**Effects of adaptation in Eastern Province**

**Smallholder**
- Baseline: 4,938 cal/AE/day
- No adaptation: 4,584
- With adaptation: 4,829 (+4.97%)

**Female-headed household**
- Baseline: 5,967 cal/AE/day
- No adaptation: 5,614
- With adaptation: 5,827 (+3.57%)

**Emergent farmer**
- Baseline: 10,995 cal/AE/day
- No adaptation: 10,082
- With adaptation: 10,326 (+2.22%)
Effects of adaptation in Southern Province

Site 1

- Emergent farmer - Hadley
- Emergent farmer - Baseline
- FHH - Hadley
- FHH - Baseline
- Smallholder - Hadley
- Smallholder - Baseline

Hectares

- MZ10 (Hybrid maize, plough, no fertilizer, late planting)
- MZ1 (Local maize, hand-hoe, no fertilizer, early planting)
- MZ8 (Hybrid maize, plough, fertilizer, late planting)
- SUN6 (Local sunflower, plough, late planting)
- SUN10 (Improved sunflower, plough, late planting)
- SP6 (Local sweet potato, plough, late planting)
- COT10 (Cotton, plough, late planting)
- COT12 (Cotton, hand-hoe, late planting)
- Fallow

Baseline
No adaptation
With adaptation

Smallholder
3,227 cal/AE/day
↓
3,154
↓ +7.39%
3,392
Female-headed household
3,581
↓
3,915
↓ +0%
3,915
Emergent farmer
8,124
↓
7,418
↓ +10.14%
8,241
Vulnerability analysis: Monte Carlo simulations

Emergent farmer, Eastern Province

Smallholder, Northern Province

Baseline=blue (right curve); CCSM=green (middle curve); Hadley=red (left curve)

Probability of falling below 3,000 calories/AE/day, given optimum farm plan (North Prov):

At baseline: 6.6%

15.9% under CCSM scenario

20.3% under Hadley scenario
Main findings and conclusions

• Crops have different levels of sensitivity to climate change → implications for agricultural policy.
• Farmers will choose different crops (cotton, sunflower) and technologies (less fertilizer) under climate change.
• This on-farm adaptation is likely to mitigate (but not necessarily offset) the negative effects of climate change.
• The household types modeled are expected to meet consumption requirements even under climate change, but smallholder farmers are most vulnerable to consumption shortfalls in a bad production year.
• Larger-scale adaptation measures are needed (e.g. heat-tolerant seed varieties, and agricultural investments and policies to reduce risk for small farmers).
Analysis of minimum tillage*

• Motivation:
  – Conservation agriculture (CA) is promoted as an effective adaptation to climate variability.
  – Minimum tillage (MT) is the most commonly adopted component of CA.
  – Dis-adoption rates of MT are high while overall use of MT remains low. Why?
  – Math programming models can capture the trade-offs farmers make when allocating resources.

Expanding the model

• 3 new maize regimes added to the household models for Eastern Province

  - Local seed – *Basins* – Early tillage – No fertilizer
  - Hybrid seed – *Basins* – Early tillage – Fertilizer
  - Hybrid seed – *Ripping* – Early tillage – Fertilizer

• Yields and labor requirements taken from CFS. Yields *increase* and labor requirements *decrease* over time.

• Crop budgets alternately assume:
  - Free equipment + subsidized inputs
  - Equipment purchases + commercially priced inputs

• Sometimes assistance is removed after two years.
## Labor requirements for conventional and MT maize regimes

<table>
<thead>
<tr>
<th>Land preparation</th>
<th>Planting</th>
<th>Weeding</th>
<th>Fertilizer application</th>
<th>Guarding</th>
<th>Harvest</th>
<th>Post-Harvest activities</th>
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</thead>
<tbody>
<tr>
<td>MZ1: Local maize, hand-hoe, no fertilizer, early planting</td>
<td>29.63</td>
<td>11.43</td>
<td>44.44</td>
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<td>21.87</td>
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<td>MZ4: Hybrid maize, hand-hoe, fertilizer, late planting</td>
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<td>11.29</td>
<td>33.86</td>
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<td>MZ6: Local maize, plough, No fertilizer, late planting</td>
<td>14.81</td>
<td>12.18</td>
<td>44.44</td>
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<td>10.00</td>
<td>23.28</td>
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<tr>
<td>MZ-BAS1: Local maize, planting basins, no fertilizer, early planting</td>
<td>45.34</td>
<td>53.79</td>
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<td>5.78</td>
<td>10.00</td>
<td>27.33</td>
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<td>MZ-BAS2: Hybrid maize, basins, fertilizer, early planting</td>
<td>46.29</td>
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<td>8.58</td>
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<td>35.33</td>
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<td>MZ-RIP2: Hybrid maize, ripping, fertilizer, early planting</td>
<td>9.13</td>
<td>48.43</td>
<td>48.43</td>
<td>15.15</td>
<td>15.15</td>
<td>23.81</td>
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Unit = 7-hour workday  
*Source: Requirements estimated from CFS 2010 and 2011*
Results: Emergent farmer maximizing profit

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<th>Costs:</th>
<th>Free equipment + subsidized inputs</th>
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<tr>
<td>Season:</td>
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<tr>
<td>Net revenue (ZMK)</td>
<td>5,440.86  5,424.20  5,605.63  5,772.60  5,939.54</td>
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<tr>
<td>Returns/ AE/ day (ZMK)</td>
<td>2.75  2.74  2.83  2.91  3.00</td>
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<td>Cash spent on inputs</td>
<td>1,159.52  1,174.71  927.79  975.23  1,022.60</td>
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<td>Calories/ AE/ day</td>
<td>10,903.13  10,111.35  10,412.33  10,757.06  11,101.68</td>
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<td>Land cultivated (ha)</td>
<td>3.61  3.73  3.78  3.80  3.82</td>
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<td>Total labor days</td>
<td>301.51  294.26  296.28  297.45  298.62</td>
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<td>Labor binding?</td>
<td>May, June</td>
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<td><strong>Hectares</strong></td>
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<td>MZ-RIP2</td>
<td>0.19  0.42  0.42  0.42  0.42</td>
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<td>MZ4</td>
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<tr>
<td>GR1</td>
<td>0.00  0.00  0.00  0.00  0.00</td>
</tr>
<tr>
<td>SUN10</td>
<td>1.09  1.65  1.70  1.70  1.69</td>
</tr>
<tr>
<td>SUN2</td>
<td>0.00  0.00  0.00  0.00  0.00</td>
</tr>
<tr>
<td>COT10</td>
<td>1.61  1.65  1.65  1.64  1.62</td>
</tr>
<tr>
<td>Fallow</td>
<td>2.87  2.75  2.70  2.68  2.66</td>
</tr>
</tbody>
</table>
Emergent farmer, maximizing calories, free/subsidized inputs

- Multi-season 4
  - MZ-BAS2: Hybrid maize, basins, fertilizer, early planting
  - MZ-RIP2: Hybrid maize, ripping, fertilizer, early planting
  - MZ4: Hybrid maize, hand-hoe, fertilizer, late planting
  - SUN10: Improved sunflower, plough, late planting
  - COT10: Cotton, hand-hoe, late planting
  - Fallow

- Multi-season 3
  - MZ-BAS2: Hybrid maize, basins, fertilizer, early planting
  - MZ-RIP2: Hybrid maize, ripping, fertilizer, early planting
  - MZ4: Hybrid maize, hand-hoe, fertilizer, late planting
  - SUN10: Improved sunflower, plough, late planting
  - COT10: Cotton, hand-hoe, late planting
  - Fallow

- Multi-season 2
  - MZ-BAS2: Hybrid maize, basins, fertilizer, early planting
  - MZ-RIP2: Hybrid maize, ripping, fertilizer, early planting
  - MZ4: Hybrid maize, hand-hoe, fertilizer, late planting
  - SUN10: Improved sunflower, plough, late planting
  - COT10: Cotton, hand-hoe, late planting
  - Fallow

- Multi-season 1
  - MZ-BAS2: Hybrid maize, basins, fertilizer, early planting
  - MZ-RIP2: Hybrid maize, ripping, fertilizer, early planting
  - MZ4: Hybrid maize, hand-hoe, fertilizer, late planting
  - SUN10: Improved sunflower, plough, late planting
  - COT10: Cotton, hand-hoe, late planting
  - Fallow

- 1-season with MT
  - MZ-BAS2: Hybrid maize, basins, fertilizer, early planting
  - MZ-RIP2: Hybrid maize, ripping, fertilizer, early planting
  - MZ4: Hybrid maize, hand-hoe, fertilizer, late planting
  - SUN10: Improved sunflower, plough, late planting
  - COT10: Cotton, hand-hoe, late planting
  - Fallow

- No MT options
  - MZ-BAS2: Hybrid maize, basins, fertilizer, early planting
  - MZ-RIP2: Hybrid maize, ripping, fertilizer, early planting
  - MZ4: Hybrid maize, hand-hoe, fertilizer, late planting
  - SUN10: Improved sunflower, plough, late planting
  - COT10: Cotton, hand-hoe, late planting
  - Fallow

Emergent farmer, maximizing calories, commercial prices

- Multi-season 4
  - MZ-BAS2: Hybrid maize, basins, fertilizer, early planting
  - MZ-RIP2: Hybrid maize, ripping, fertilizer, early planting
  - MZ4: Hybrid maize, hand-hoe, fertilizer, late planting
  - SUN10: Improved sunflower, plough, late planting
  - COT10: Cotton, hand-hoe, late planting
  - Fallow

- Multi-season 3
  - MZ-BAS2: Hybrid maize, basins, fertilizer, early planting
  - MZ-RIP2: Hybrid maize, ripping, fertilizer, early planting
  - MZ4: Hybrid maize, hand-hoe, fertilizer, late planting
  - SUN10: Improved sunflower, plough, late planting
  - COT10: Cotton, hand-hoe, late planting
  - Fallow

- Multi-season 2
  - MZ-BAS2: Hybrid maize, basins, fertilizer, early planting
  - MZ-RIP2: Hybrid maize, ripping, fertilizer, early planting
  - MZ4: Hybrid maize, hand-hoe, fertilizer, late planting
  - SUN10: Improved sunflower, plough, late planting
  - COT10: Cotton, hand-hoe, late planting
  - Fallow

- Multi-season 1
  - MZ-BAS2: Hybrid maize, basins, fertilizer, early planting
  - MZ-RIP2: Hybrid maize, ripping, fertilizer, early planting
  - MZ4: Hybrid maize, hand-hoe, fertilizer, late planting
  - SUN10: Improved sunflower, plough, late planting
  - COT10: Cotton, hand-hoe, late planting
  - Fallow

- 1-season with MT
  - MZ-BAS2: Hybrid maize, basins, fertilizer, early planting
  - MZ-RIP2: Hybrid maize, ripping, fertilizer, early planting
  - MZ4: Hybrid maize, hand-hoe, fertilizer, late planting
  - SUN10: Improved sunflower, plough, late planting
  - COT10: Cotton, hand-hoe, late planting
  - Fallow

- No MT options
  - MZ-BAS2: Hybrid maize, basins, fertilizer, early planting
  - MZ-RIP2: Hybrid maize, ripping, fertilizer, early planting
  - MZ4: Hybrid maize, hand-hoe, fertilizer, late planting
  - SUN10: Improved sunflower, plough, late planting
  - COT10: Cotton, hand-hoe, late planting
  - Fallow
Small-scale farmer, maximizing calories, free/subsidized inputs

- Multi-season 4
- Multi-season 3
- Multi-season 2
- Multi-season 1
- 1-season with MT
- No MT options

- MZ-BAS1: Local maize, planting basins, no fertilizer, early planting
- MZ-RIP2: Hybrid maize, ripping, fertilizer, early planting
- MZ4: Hybrid maize, hand-hoe, fertilizer, late planting
- MZ6: Local maize, plough. No fertilizer, late planting
- COT12: Cotton, hand-hoe, late planting
- Fallow

Small-scale farmer, maximizing calories, commercial prices

- Multi-season 4
- Multi-season 3
- Multi-season 2
- Multi-season 1
- 1-season with MT

- MZ-BAS1: Local maize, planting basins, no fertilizer, early planting
- MZ-RIP2: Hybrid maize, ripping, fertilizer, early planting
- MZ4: Hybrid maize, hand-hoe, fertilizer, late planting
- MZ6: Local maize, plough. No fertilizer, late planting
- COT12: Cotton, hand-hoe, late planting
- COT10: Cotton, hand-hoe, late planting
- Fallow
Conclusions on min. tillage analysis

• MT requires more labor for planting and weeding, but less than expected, hence may not a big constraint to MT adoption.

• Models with four-year time frame include partial adoption of MT, but less so for models with one-year time frame (where long-run benefits aren’t fully incorporated).

• Question then about whether farmers are willing and able to take a long-term perspective on investing in minimum tillage.

• Important to incorporate risk into this analysis and to compare MT with other climate risk-reducing options.
Farmer perceptions vs empirical climate records*

- Generally, farmer accounts are consistent with met. data on rising temperature.
- Farmer perceptions of rainfall diverge from empirical records.
- Rainfall records indicate a mixed picture, with a recent uptick in rainfall levels in Eastern Province and a shorter rainy season in Northern Province.
- Farmers in all study areas perceive the rainfall season to be growing shorter, highly variable, and with declining seasonal rainfall amounts.
- Empirical records on the other hand show relatively less variability in rainfall amounts, and no significant change in rainfall onset and cessation dates.

Possible explanations for the divergence

- Our analysis may be too coarse—use of dekad (10-day) instead of daily rainfall records
- Farmer recollections may be incorrect
- Farmers may focus on climate-related parameters that are salient in their lives but difficult to document with only meteorological data.
- Farmers may fail to differentiate yield impacts of weather from yield impacts of changes in farming systems, and other confounding factors such as soil degradation.
Adaptation measures used by farmers

- Use of conservation agriculture practices, mainly minimum tillage—in Eastern and Southern Provinces
- Staggered planting—planting in phases to deal with uncertainty of the onset of the rains
- Diversification into other crops (e.g., cotton, sorghum), off-farm wage income, trading, and migration
Summary on farmer perceptions

• Our comparison suggests that the study of climate change should incorporate farmer perceptions and not be left to expert judgment or scientific observation alone.

• A lack of correlation between farmers’ perceptions and observed weather does not imply that farmers’ perceptions are invalid.

• Local systems of knowledge contribute different parameters and offer a more contextual interpretation of these climate parameters.

• Farmer knowledge should be considered complementary rather than contradictory.
Overall next steps and possible extensions

• Next steps:
  – Complete the report on sensitivity of field crops to climate shocks
  – Finalize and disseminate/publish other reports

• Possible extensions:
  – Improved analysis of risk and vulnerability
  – Improved analysis of minimum tillage; dependent on better estimates of input/output coefficients
  – Analysis of government crop promotion policies, considering which crops are apparently sensitive to climate change or not
Reports available

• Mulenga and Wineman, “Climate Trends and Farmers’ Perceptions of Climate Change in Zambia.”
• Mulenga, “Climate Change Impact on Agricultural Production and Adaptation Strategies: Farmers’ Perceptions and Experiences.”
• Wineman, “Maize Production in the Future.”
• Wineman, “Multidimensional Household Food Security Measurement in Rural Zambia.”
• Wineman, “Sensitivity of Field Crops to Climate Shocks in Zambia” (Draft available soon)
Questions?
Extra slides
Mathematical structure of model

\[ \text{max calories} = \sum_{j=1}^{n} K_j X_j \]

Where \( K_j \) = calories per ha and \( X_j \) = ha, for activity j

Subject to:

- Input requirements for each crop activity
- Resource constraints: \( \sum_{j=1}^{m} a_{ij} X_j \leq b_i \)
  \( \rightarrow \) For land and biweekly labor
- Budget constraint: \( \sum_{j=1}^{n} C_{ij} X_j \leq \omega \)
- Household calorie requirement: \( K_j X_j \geq \theta \)
- Non-negativity constraint: \( X_j \geq 0 \)
- Flexibility constraints (sometimes): \( K_j X_j \geq \varphi \)
Crop budgets by site & crop regime

<table>
<thead>
<tr>
<th>Site</th>
<th>Basal Fert</th>
<th>Top Fert</th>
<th>Seed/planting material</th>
<th>Plough</th>
<th>Basal Fert</th>
<th>Top Fert</th>
<th>Seed/planting material</th>
<th>Plough</th>
<th>Total Variable Costs</th>
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<tr>
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<td>1.07</td>
<td>30.00</td>
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<td>1.07</td>
<td>30.00</td>
<td></td>
<td></td>
<td>30.00</td>
</tr>
<tr>
<td>MZ4</td>
<td>123.46</td>
<td>133.33</td>
<td>28.64</td>
<td></td>
<td>2.67</td>
<td>2.82</td>
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<td>929.29</td>
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<td>133.33</td>
<td>23.11</td>
<td></td>
<td>2.67</td>
<td>2.82</td>
<td>1.07</td>
<td></td>
<td>756.45</td>
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<td>MZ6</td>
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<td></td>
<td>1.07</td>
<td>40.00</td>
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<td>39.01</td>
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<td>3.16</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>163.46</td>
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</tbody>
</table>
Effect of adaptation in Northern Province

**Site 3**

- **Emergent farmer - Hadley**
- **Emergent farmer - Baseline**
- **FHH - Hadley**
- **FHH - Baseline**
- **Smallholder - Hadley**
- **Smallholder - Baseline**

- MZ2 (Local maize, hand-hoe, no fertilizer, late planting)
- MZ3 (Hybrid maize, hand-hoe, fertilizer, early planting)
- MZ1 (Local maize, hand-hoe, no fertilizer, early planting)
- MZ4 (Hybrid maize, hand-hoe, fertilizer, late planting)
- GR1 (Local groundnuts, hand-hoe, early planting)
- GR2 (Local groundnuts, hand-hoe, late planting)
- GR6 (Local groundnuts, plough, late planting)
- CAS1 (Local cassava)
- CAS2 (Improved cassava)
- MIL1 (Local millet, hand-hoe, early planting)
- MIL2 (Local millet, hand-hoe, late planting)
- SP2 (Improved sweet potato, plough, early planting)
- MB1 (Local mixed beans, hand-hoe, late planting)
- MB2 (Local mixed beans, hand-hoe, early planting)
- PR1 (Local paddy rice, hand-hoe, early planting)
- Fallow
Effect of adaptation in Northern Province, cont.

**Hadley**

<table>
<thead>
<tr>
<th>Category</th>
<th>Baseline</th>
<th>No adaptation</th>
<th>With adaptation</th>
<th>Effect of adaptation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smallholder</td>
<td>3,869 cal/AE/day</td>
<td>3,154</td>
<td>3,344</td>
<td>+4.92%</td>
</tr>
<tr>
<td>Female-headed household</td>
<td>4,477</td>
<td>3,905</td>
<td>4,004</td>
<td>+2.21%</td>
</tr>
<tr>
<td>Emergent farmer</td>
<td>9,740</td>
<td>8,024</td>
<td>8,046</td>
<td>+0.23%</td>
</tr>
</tbody>
</table>

**CCSM**

<table>
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<tr>
<th>Category</th>
<th>Baseline</th>
<th>No adaptation</th>
<th>With adaptation</th>
<th>Effect of adaptation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smallholder</td>
<td>3,869 cal/AE/day</td>
<td>3,301</td>
<td>3,458</td>
<td>+4.07%</td>
</tr>
<tr>
<td>Female-headed household</td>
<td>4,477</td>
<td>4,050</td>
<td>4,117</td>
<td>+1.51%</td>
</tr>
<tr>
<td>Emergent farmer</td>
<td>9,740</td>
<td>8,466</td>
<td>8,478</td>
<td>+0.12%</td>
</tr>
</tbody>
</table>
Fitted distributions of rainfall at study sites

Average temperature