Assessing How Agronomic and Economic Adaptations Affect Vulnerability to Climate Change

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Transitioning Cereal Systems to Adapt to Climate Change

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Themes

- AgMIP & REACCH projects
- The AgMIP RIA Method
- Adaptation: methodological challenges
- Linking agronomic & economic models for adaptation analysis
- The way forward: CGRA
AgMIP Regional Climate Change Impact Assessment Teams

5-year project, DFID funded
8 regional teams, 18 countries, ≈ 200 scientists
Data, models, scenarios designed & implemented by multi-disciplinary teams & stakeholders

Small-scale, mixed crop and crop-livestock systems; principal crops vary by region (maize, millet/peanut, rice, wheat) typical of “semi-subsistence agriculture”
For the AgMIP story (agmip.org):
REACCH - Regional Approaches to Climate Change in Pacific Northwest Agriculture

5-year project funded by USDA-NIFA
University of Idaho
Oregon State University
Washington State University
USDA-ARS
+ 100 scientists & students

Large-scale wheat-fallow and annual cropped systems typical of “industrial commodity agriculture”
Stakeholders: the climate is changing, what to do?
What will African, US ag be in 2030, 2050?
How can they be improved in the face of climate, technological & many other changes?
Adaptation Concepts and Challenges

• Natural, autonomous, planned
• Agronomic
• Behavioral
• Economic & Social
• Institutional
• Within-system (short-run)
• Between system (long-run)

⇒ Need an analytical framework to evaluate **benefits of adaptation distinct from climate impact**
Integrated Assessment Framework: system adaptations evaluated in context of climate and other system changes
Looking Forward: Pathways and Scenarios

Impact, Adaptation & Vulnerability of Ag Systems: AgMIP Regional IA Methods (http://www.agmip.org/regional-integrated-assessments-handbook/#)

Vulnerability = risk of loss

Prices more important than other elements of RAPs and CC!
REACCH Project: Magnitude of vulnerability (loss) without adaptation

Prices more important than other elements of RAPs and CC!

RAP3 Dysfunctional World
Low Prices

RAP2 Business-as-Usual
Low Prices

RAP1 Sustainable World
Low Prices

RAP3 Dysfunctional World
HIGH Prices

RAPs 1&2 HIGH Prices

Prices more important than other elements of RAPs and CC!
Experimental design: impact vs adaptation

- Must quantify well-defined **treatment effects** to distinguish environmental change, policy, and other drivers of change
  - Impact indicator: $V[\text{technology, climate, state of world}]$
  - $H =$ historical or current conditions, $F =$ future conditions

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Treatment effects relevant to science & policy stakeholders

- Reduced-form statistical/econometric models only represent climate impact + adaptation in current (historical) world
- “Hybrid (semi-)structural models” that satisfy “Marshak’s Maxim” can estimate all relevant treatment effects

1. What is the sensitivity of current agricultural production systems to climate change?
2. What are the benefits of adaptation in current agricultural systems?
3. What is the impact of climate change on future agricultural production systems?
4. What are the benefits of climate change adaptations?
Need to adapt to positive climate changes too ...
Linking Crop Models to Economic Models: Relative Yields

Agronomic and economic concepts of production function

\[ y = b(m, g, s, w, \tau) \]

\[ y = \text{yield (kg/ha)} \]
\[ m = \text{management variables (unit/ha)} \]
\[ g = \text{genetic characteristics of the crop} \]
\[ s = \text{soil variables} \]
\[ w = \text{weather variables} \]
\[ \tau = \text{parameters} \]

Technological change = shift in production function
= change in m, g and \( \tau \)

(note: can add other biotic factors: pests & diseases)
Climate adaptation

• All technologies are designed to perform in relation to a particular climate (distribution of weather $= \gamma$)

• Without climate change, technological change ($m, g$ and $\tau$) improves performance of system at compound rate $\Gamma$
  
  o $\Gamma$ estimated independently using SSPs, RAPs (independent of crop or livestock models)

  o Future (expected) yield without climate change: $y_F = \Gamma y_H$

• Climate adaptations = changes in $m, g$ and $\tau$ distinct from those included in a no-climate scenario

  o Example: PNW cropping system: crops & rotations
Linking Crop Models to Economic Models: Relative Yields

• We use crop or livestock simulation models to estimate the effects of climate or technology adaptation on productivity, *holding all else constant*.

• Crop or livestock models are used to isolate the effects of climate change, or the effects of a change in technology, consistent with the experimental design described above.

• Climate $\gamma = \text{distribution of weather } w$

• $b \left( m_t, g_t, s_t, \gamma_t, \tau_t \right) = \text{average simulated yield (note } \gamma \text{ replaces } w \text{ in prod fn)}$

• Define a relative yield due to climate change:

$$r(m_t, g_t, s_t, \gamma_F, \gamma_H, \tau_t) \equiv \frac{b \left( m_t, g_t, s_t, \gamma_F, \tau_t \right)}{b \left( m_t, g_t, s_t, \gamma_H, \tau_t \right)}$$

Or $$r(T_t, \gamma_F, \gamma_H) \equiv \frac{b \left( T_t, \gamma_F \right)}{b \left( T_t, \gamma_H \right)}, \quad T_t = (m_t, g_t, \tau_t)$$
Core Question 1: Climate Sensitivity in Current System

- Definition of relative yield

\[ r(T_t, \gamma_F, \gamma_H) \equiv b(T_t, \gamma_F)/b(T_t, \gamma_H) \]

Implies (H = current, F = future):

\[ b(T_H, \gamma_F) = r(T_H, \gamma_F, \gamma_H) b(T_H, \gamma_H) \]

Replace \( b(T_H, \gamma_H) \) with observed yield \( y_H \)

- Then projected yield \( \mu \) with changed climate is:

\[ \mu_H(y_H, T_H, \gamma_F, \gamma_H) = r(T_H, \gamma_F, \gamma_H) y_H \]
Core Question 2: Adaptation in Current Climate & World

- Definition of relative yield for adaptation analysis:

\[ r(T_H^a, T_H, \gamma_H) = \frac{b(T_H^a, \gamma_H)}{b(T_H, \gamma_H)}. \]

Note: here we assess management and technology change for a given climate.

Projected yield with adaptation in current climate:

\[ \mu_H(y_H, T_H^a, T_H^a, \gamma_H) = r(T_H^a, T_H, \gamma_H) y_H \]
Core Question 3: Climate Impact in Future Climate & World

- Recall definition:

\[ r(T_t, \gamma_F, \gamma_H) \equiv b(T_t, \gamma_F)/b(T_t, \gamma_H) \]

In future world, this implies:

\[ \mu_F(y_F, T_F, \gamma_F, \gamma_H) = r(T_F, \gamma_F, \gamma_H) y_F \]

Also recall \( y_F = \Gamma y_H \) so:

\[ \mu_F(\Gamma, y_H, T_F, \gamma_F, \gamma_H) = r(T_F, \gamma_F, \gamma_H) \Gamma y_H \]

Note: no “double-counting” of technological change \( \Gamma \) and effect of climate change \((\gamma_F, \gamma_H)\)
Core Question 4: Climate Adaptation in Future World

Recall from Question 2:

\[ \mu_H(y_H, T_H^a, T_H, \gamma_H) = r(T_H^a, T_H, \gamma_H) y_H \]

In future world this becomes:

\[ \mu_F(y_F, T_F^a, T_F, \gamma_F) = r(T_F^a, T_F, \gamma_F) y_F \]

Thus

\[ \mu_F(\Gamma, y_H, T_F^a, T_F, \gamma_F) = r(T_F^a, T_F, \gamma_F) \Gamma y_H \]

Note: distinct effects of tech change (\( \Gamma \)), effect of climate (\( \gamma_F \)) and climate adaptation (\( T_F^a \) and \( T_F \))

Note:
relative yield with CC + adaption
\[ = (\text{relative yield with CC}) \times (\text{relative yield with adaptation}) \]
Relative yield distributions in dryland wheat region of PNW

Source: Author and collaborators, REACCH-PNA Project
Application: system choice in PNW low-rainfall zone using CropSyst and TOA-MD models

Economic model: expected net returns = f(prices, cost, relative yield)

Predicted adoption of annual cropping in wheat-fallow area = 20%
actual adoption rate = 23%

Antle and Stöckle, 2015 REEP (in review)
The way forward: AgMIP Coordinated Global and Regional Assessments (CGRA)

- Goal: results ready for AR6
- Key features:
  - New food security and nutrition indicators
  - Focus on risk and resilience to extremes, and long-term CC impact and adaptation
- Core project for global scenario design and model simulations
- Regional/national assessments with common protocols
- 1st year:
  - pilot projects for protocol development
  - Food security and nutrition indicator development
Thank you!

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