

Agricultural Impacts of Climate Change: Adaptation and Mitigation

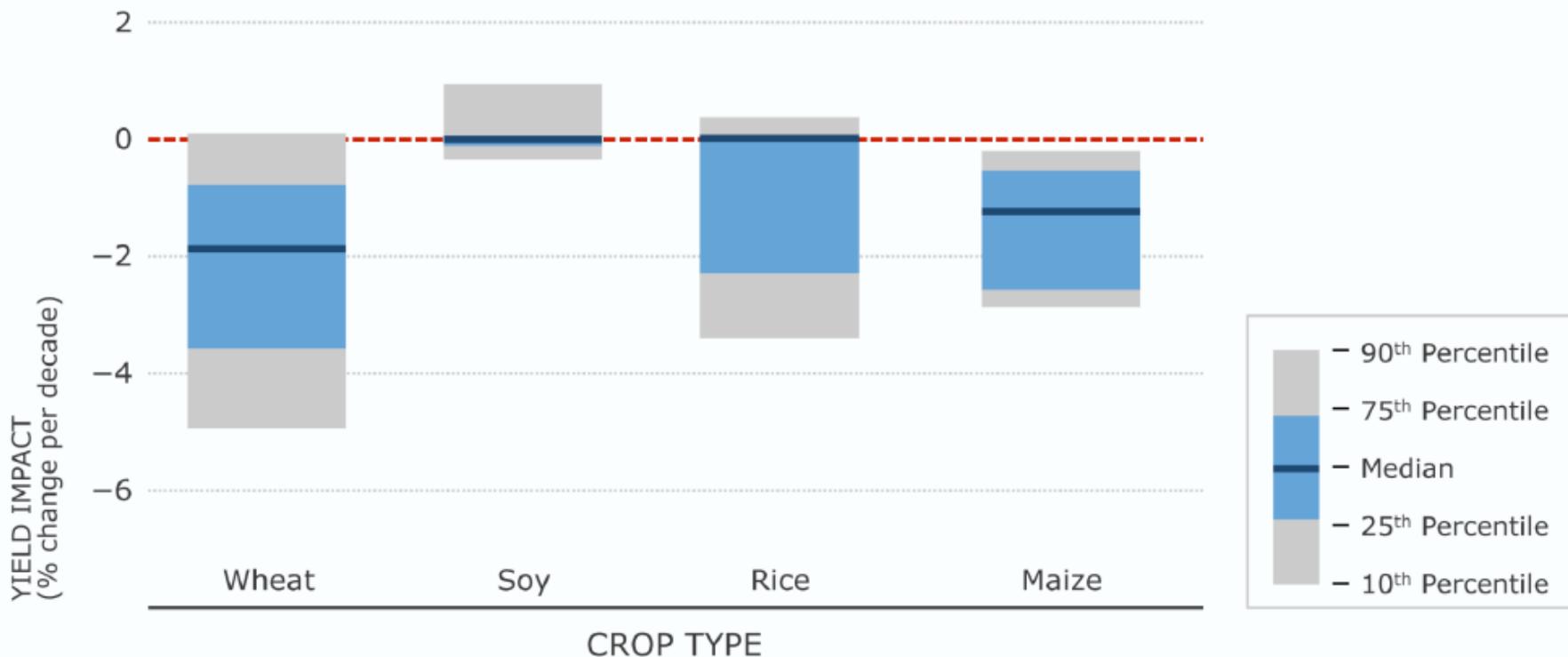
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¹ Presentation to the Snowmass Meeting on Integrated Impacts of Climate Change, July 28, 2015

Outline of the talk

- **Brief review of what is known about climate impacts on agriculture**
- **Interactions between adaptation and mitigation in agriculture**
- **A focus on R&D-led adaptation**

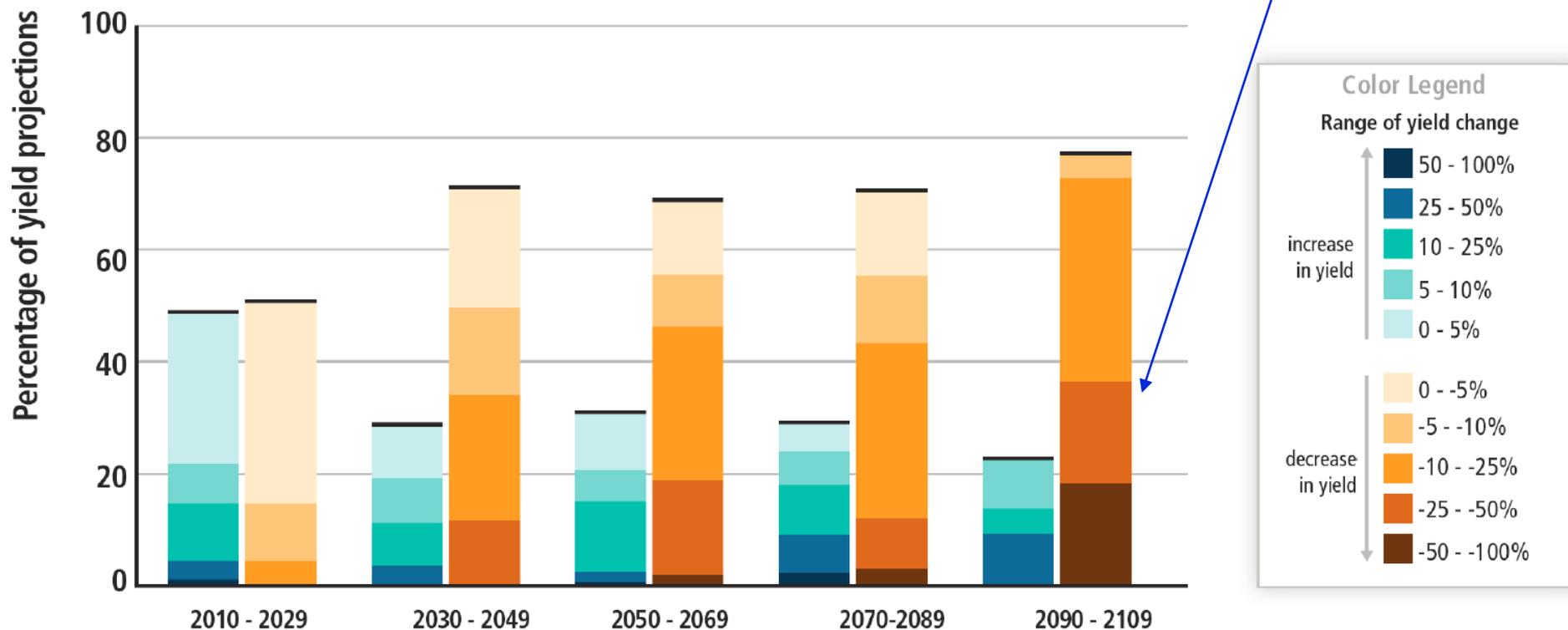
Climate change is already reducing yields of some crops



Source: AR5, as presented by CSIRO/Mark Howden for the IPCC Food Security Summit, Dublin, May 2015

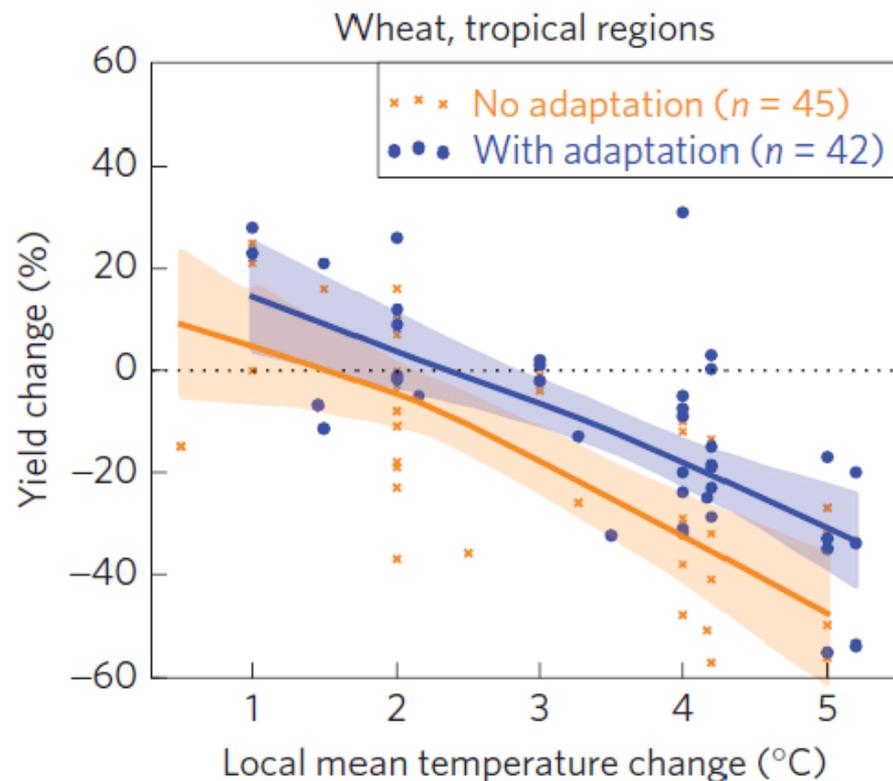
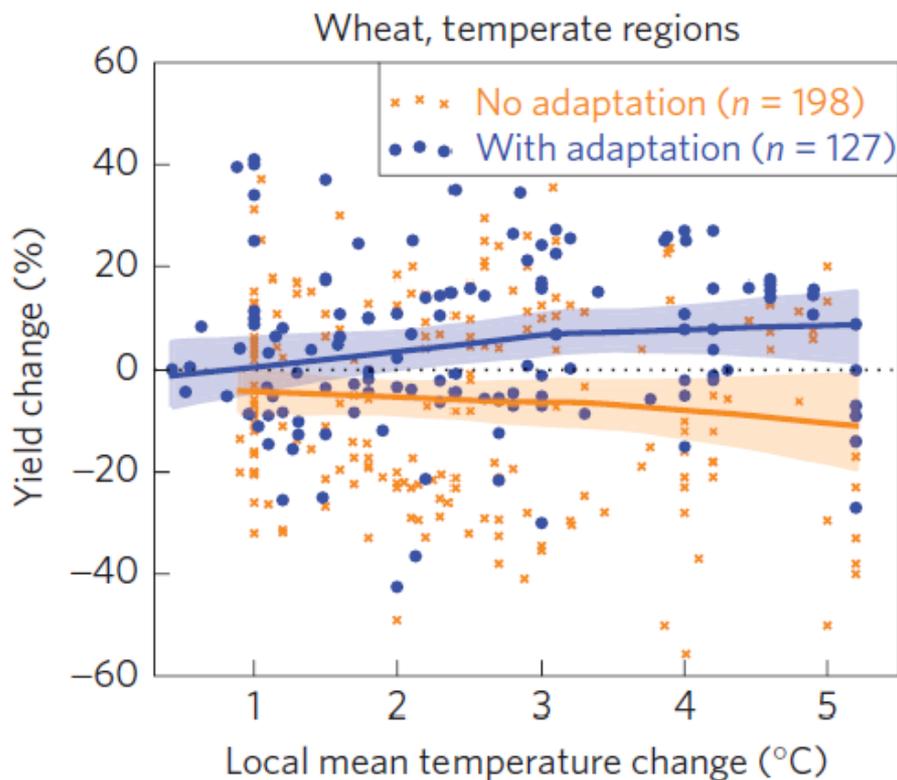
Note: most of underlying studies do not include effects of elevated CO₂ which tends to boost yields

Impacts vary greatly (some initially mix of +/-) by emissions scenario, crop, location and adaptation actions, but become predominantly negative by 2100



Source: AR5, Fig. SPM.7

Tropics will be hit hardest, agronomic adaptation could play an important role



Source: AR5-WGII, Fig. 7-4. Dots show CO₂ effects included; X's ignore this effect. Shaded area represents 95% CI from non-parametric regressions. Adaptation = solely agronomic adaptation

IAMs rely on crop models which remain relatively immature for climate analysis

- **Most biophysical crop models were developed for other purposes – *not focused on impacts of extreme temps***
- **White et al. (2011) review 221 studies using 70 crop models to assess climate impacts and found at that time - *only a handful considered*:**
 - **Effects of elevated CO₂ on canopy temperature**
 - **Direct heat effects on key stages of crop development**
- **Only a subset of relevant processes are included in any one model; *often the omitted processes are*:**
 - **those that become *more damaging with climate change***
 - **empirically *more important in context of tropical systems* (e.g. VPD, heat stress on crop development and pests and disease)**
- **AgMIP is fostering harmonization of data and improvements in modeling, however huge uncertainties remain.....**

Statistical work has been promising, where high quality data are available

- Schlenker & Roberts set the pace by identifying key temperature thresholds

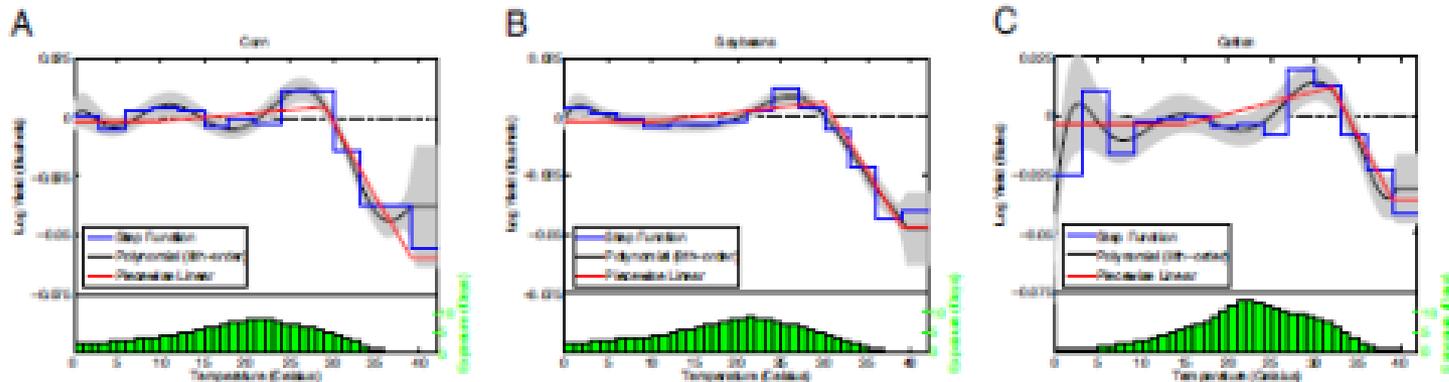
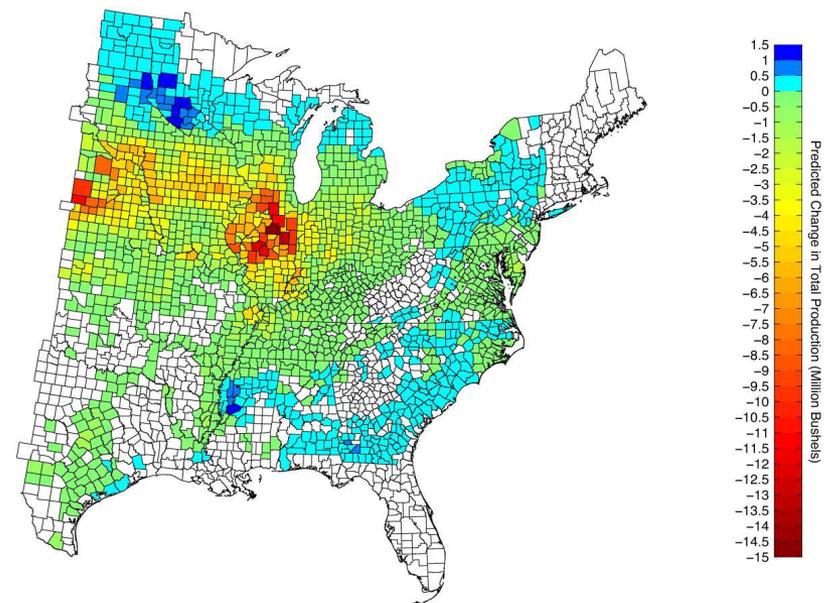
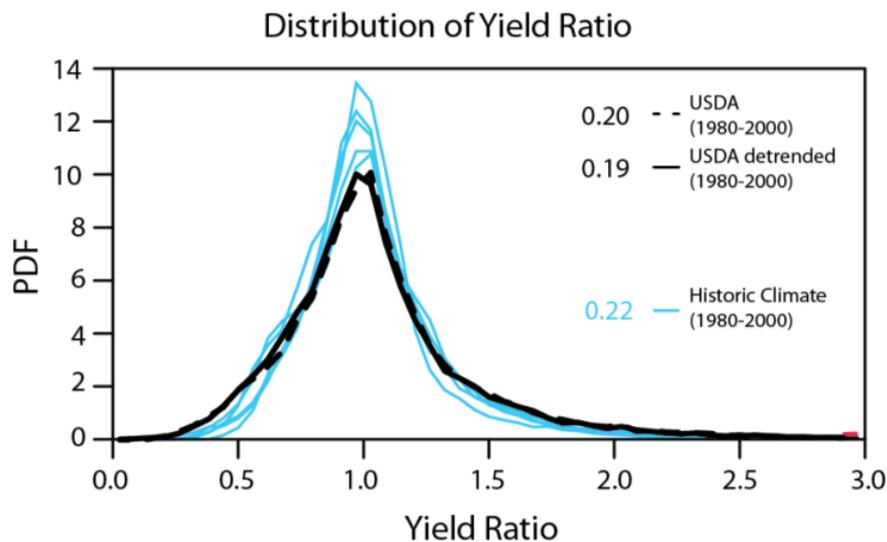


Fig. 1. Nonlinear relation between temperature and yields. Graphs at the top of each frame display changes in log yield if the crop is exposed for one day to a particular 1° C temperature interval where we sum the fraction of a day during which temperatures fall within each interval. The 95% confidence band, after adjusting for spatial correlation, is added as gray area for the polynomial regression. Curves are centered so that the exposure-weighted impact is zero. Histograms at the bottom of each frame display the average temperature exposure among all counties in the data.

- And this work has proved useful in historical validation as well as forecasting.....

Statistical work allows for valid predictions where data are good

- SR yield function reproduces year-on-year variation in US maize yields
- Performed well in predicting impacts of 2012 drought in US



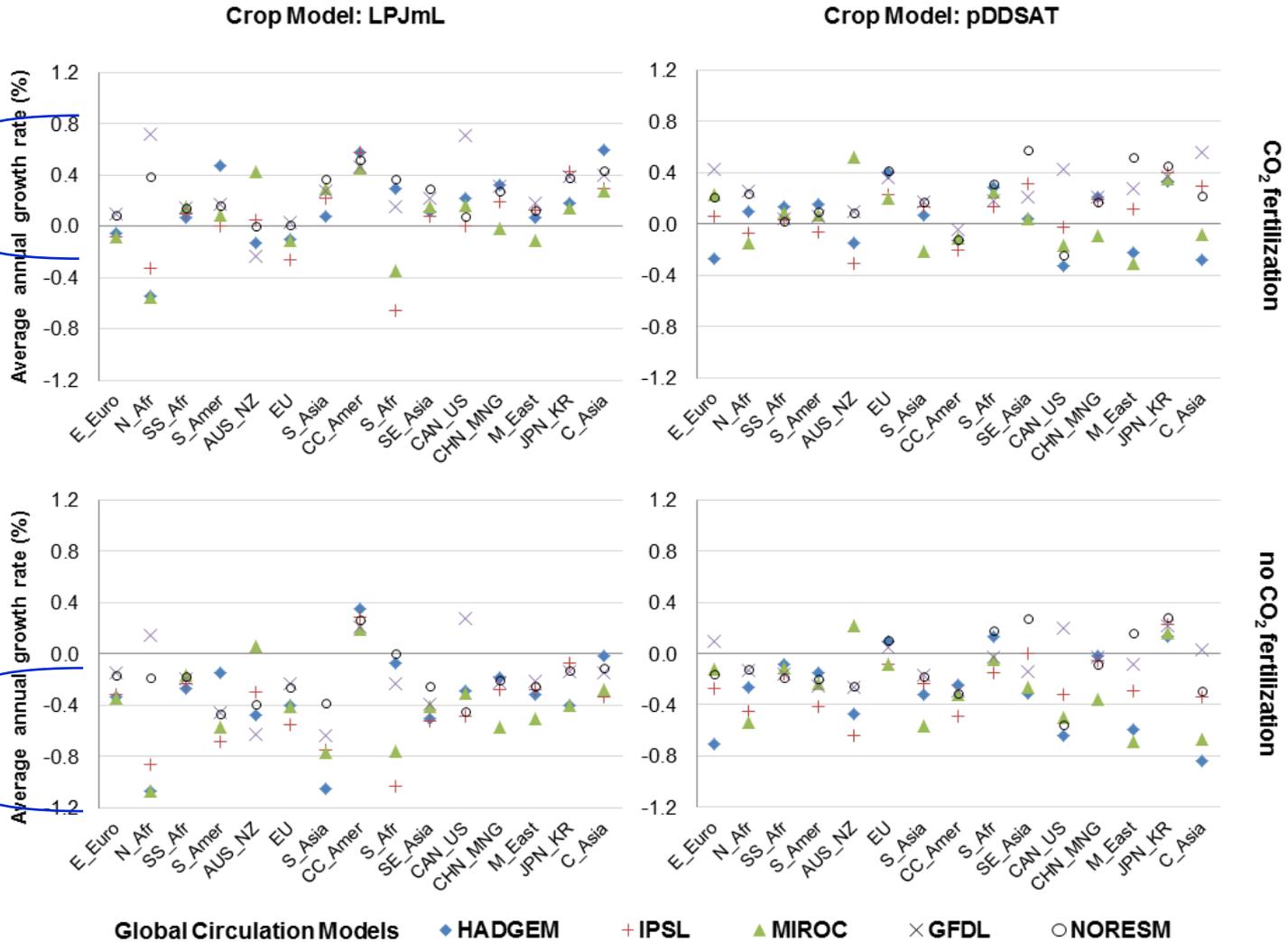
However, most severely affected regions (e.g., Africa) have very poor time series data, this has made statistical work difficult and error-prone (e.g., Tanzania)

This takes us back to the crop models as engines for driving global GCMs. AgMIP is playing a key coordinating role here.....

AgMIP global yield impacts due to climate change in 2050 for staple grains & oilseeds vary widely by region, crop model & CO2 fertilization on/off

Global avg. crop impacts are still *positive under CO2 fert @ mid-century mark*

Temp and precip changes shift most impacts into *negative territory @ mid-century, in absence of CO2 fertilization*



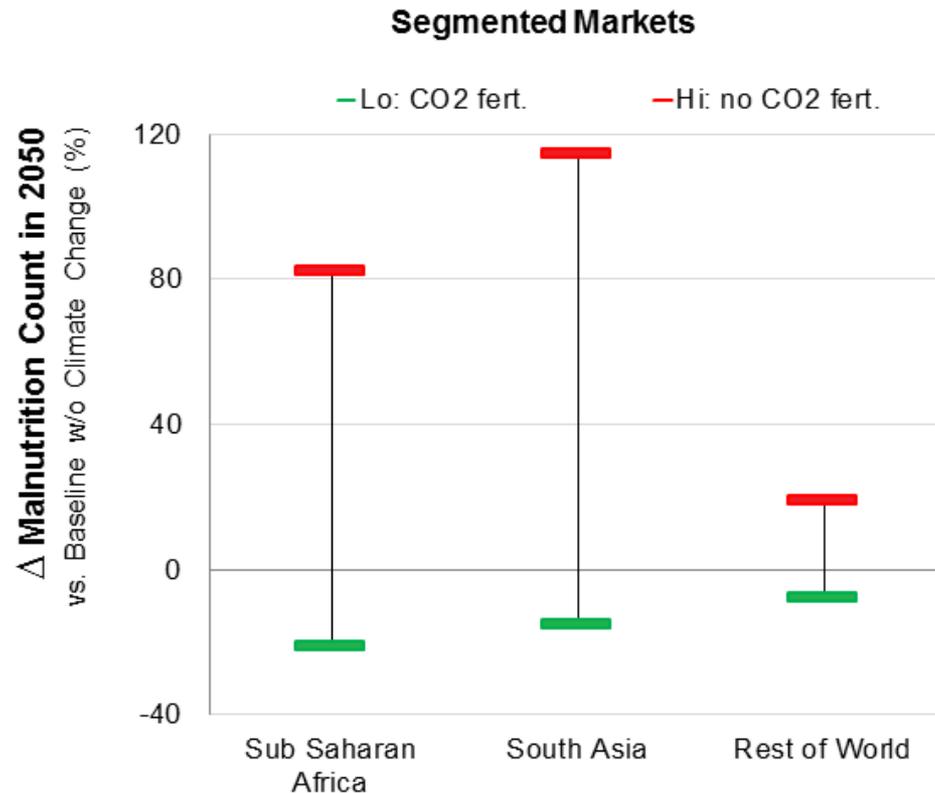
CO₂ fertilization

no CO₂ fertilization

Global Circulation Models ◆ HADGEM + IPSL ▲ MIROC × GFDL ○ NORESM

And these differences translate into very different food security outcomes

Crop Model: LPJmL Global Circulation Model: HADGEM



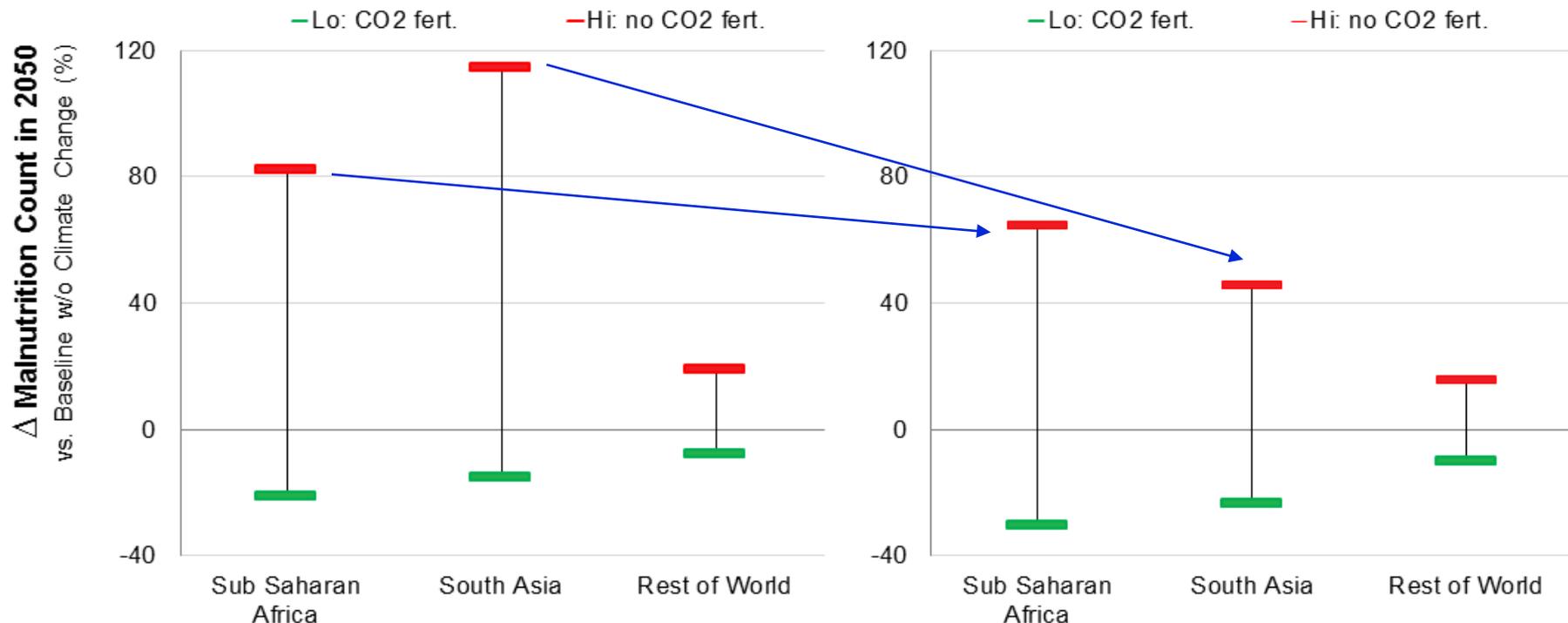
Impact of climate change on malnutrition depends critically on CO2 fertilization

Although better use of global trade could mitigate food security risks of climate change

Crop Model: LPJmL Global Circulation Model: HADGEM

Segmented Markets

Integrated Markets



Impact of climate change on malnutrition depends critically on CO2 fertilization; if ignore this, impacts could be severe, but moderated by integrated global markets

This raises the broader question of interplay between impacts, adaptation and mitigation (follow-on to Karen's presentation)

- **Focus on global croplands**
- **Mitigation typically involves *removing land from agriculture* (avoided deforestation, afforestation) or *slowing yield growth* by insisting on more environmentally friendly production methods**
- **Adaptation *offsets adverse climate impacts* through investments and area expansion**
- **All of this places additional pressure on the world's land resources with implications for GHGs and biodiversity**
- **Introduce a 'sustainability equation' to clarify**

A sustainability equation focusing on global cropland use

This is the long run growth in cropland



$$q_L^* = \left[\underbrace{(\Delta_A^D + \Delta_L^S - \Delta_L^D)}_{\text{drivers}} / \left(1 + \underbrace{\eta_A^{S,I} / \eta_A^{S,E} + \eta_A^D / \eta_A^{S,E}}_{\text{economic responses}} \right) \right] - \Delta_L^S$$

These are the drivers of global change

These are the economic responses to scarcity which buffer the change in global land use

Drivers of global change

Growth in global food demand: population, income, biofuels

$$q_L^* = [(\Delta_A^D + \Delta_L^S - \Delta_L^D) / (1 + \eta_A^{S,I} / \eta_A^{S,E} + \eta_A^D / \eta_A^{S,E})] - \Delta_L^S$$

Trend growth in yields: R&D; climate
Impacts also include here

Backward shift in land supply to agriculture,
e.g., due to REDD+ policies, climate change impacts,
urbanization, competition for water

Economic adaptations buffer cropland area expansion

Crop supply response at intensive margin (yield response to price) Crop supply response at extensive margin (area response to price)

$$q_L^* = [(\Delta_A^D + \Delta_L^S - \Delta_L^D) / (1 + \eta_A^{S,I} / \eta_A^{S,E} + \eta_A^D / \eta_A^{S,E})] - \Delta_L^S$$

Price elasticity of demand for food

Note that these adaptations are present, even in the absence of climate change: Private adaptations (Bill Nordhaus' point)

Autonomous (economic) adaptations

buffer cropland area expansion

Crop supply response at intensive margin (yield response to price) Crop supply response at extensive margin (area response to price)

$$q_L^* = [(\Delta_A^D + \Delta_L^S - \Delta_L^D) / (1 + \eta_A^{S,I} / \eta_A^{S,E} + \eta_A^D / \eta_A^{S,E})] - \Delta_L^S$$

Farmers increase yields in response to scarcity and dampens area expansion

Food consumption shrinks in response to scarcity and dampens area expansion

Both economic buffers *depend on the responsiveness of the intensive margin of supply and consumer demand, relative to the extensive margin of supply ... think of this as autonomous adaptation*

Mitigation and global land use in absence of autonomous adaptation

$$q_L^* = [(\Delta_A^D + \Delta_L^S - \Delta_L^D) / 1] - \Delta_L^S = (\Delta_A^D - \Delta_L^D)$$

1. Elimination of deforestation reduces available cropland

2. However, in the absence of price responsiveness, the same amount of food is consumed (and yields are unchanged) so *the same amount of land lost to forest carbon sequestration must be converted elsewhere*

3. As a consequence, cropland will expand along with net demand growth, (net of trend yields)

Autonomous adaptation is essential if the withdrawal of cropland for environmental objectives is to reduce global land use

Thinking about *planned* adaptation and global land use

$$q_L^* = [(\Delta_A^D + \Delta_L^S - \Delta_L^D) / (1 + \eta_A^{S,I} / \eta_A^{S,E} + \eta_A^D / \eta_A^{S,E})] - \Delta_L^S$$


Adverse yield impacts of *climate change could be offset by planned adaptation* through R&D, thereby boosting yields relative to baseline

Autonomous (endogenous) adaptation

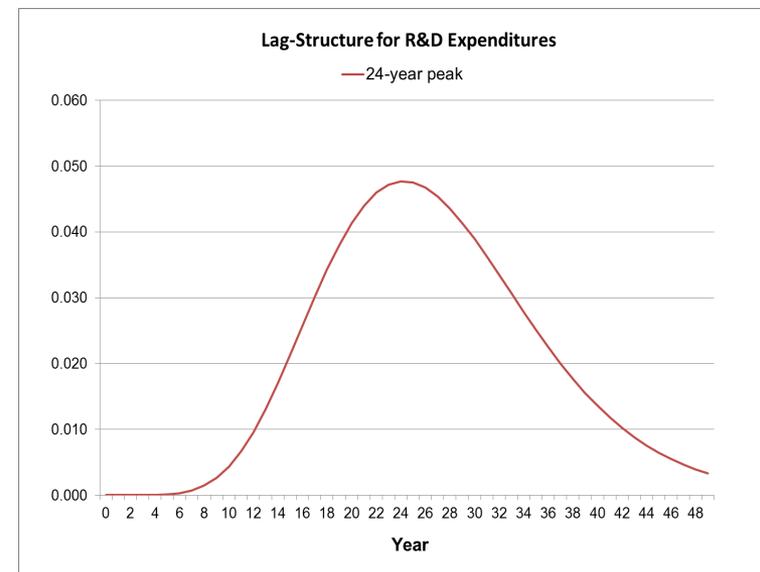
Thinking about *planned* adaptation and global land use

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Autonomous (endogenous) adaptation

....however, there is a long lag between spending and productivity impacts



Modeling the relationship between R&D spending and TFP growth

- A Bayesian hierarchical model linking US TFP growth to R&D stocks, and stocks to R&D spending within a linear framework with normal errors

$$T_t = \alpha_0 + \alpha_1 RD_t + \alpha_2 CI_t + \alpha_3 t + \varepsilon_{T_t} \sigma_T$$

$$RD_t = \sum_{i=0}^{49} \beta_{RD,i} XD_{t-i} + \varepsilon_{RD_t} \sigma_{RD}$$

T_t Agricultural total factor productivity

RD_t R&D knowledge capital stocks

CI_t Corn moisture stress index

t Time trend

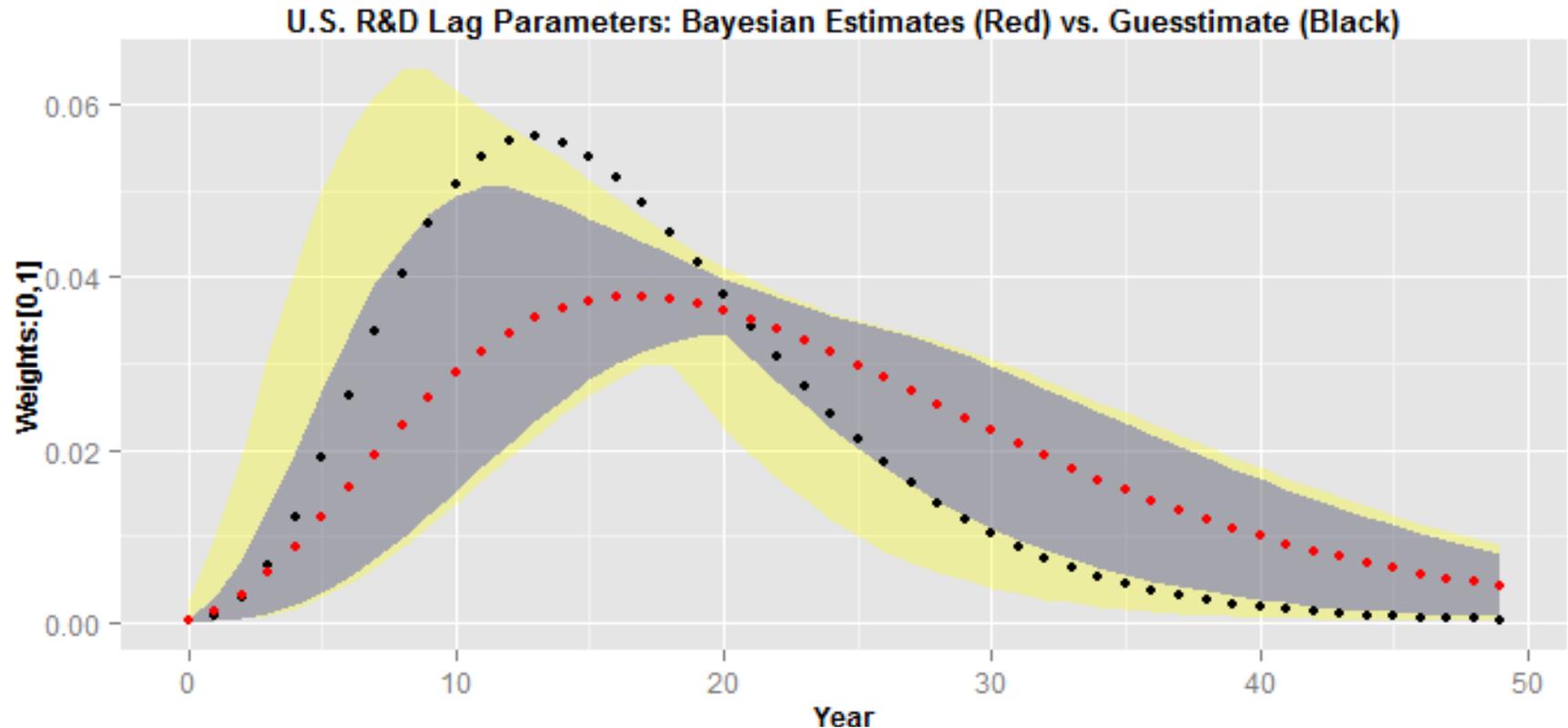
XD_t R&D spending

$\varepsilon_{T_t} \sigma_T, \varepsilon_{RD_t} \sigma_{RD}$ Error terms

Preliminary Results:

U.S. Public R&D : 1949-2011 using USDA national data for all of agriculture

- Estimated (posterior) R&D lag parameters in red, prior in black
- 80% CI in grey, 95% in yellow

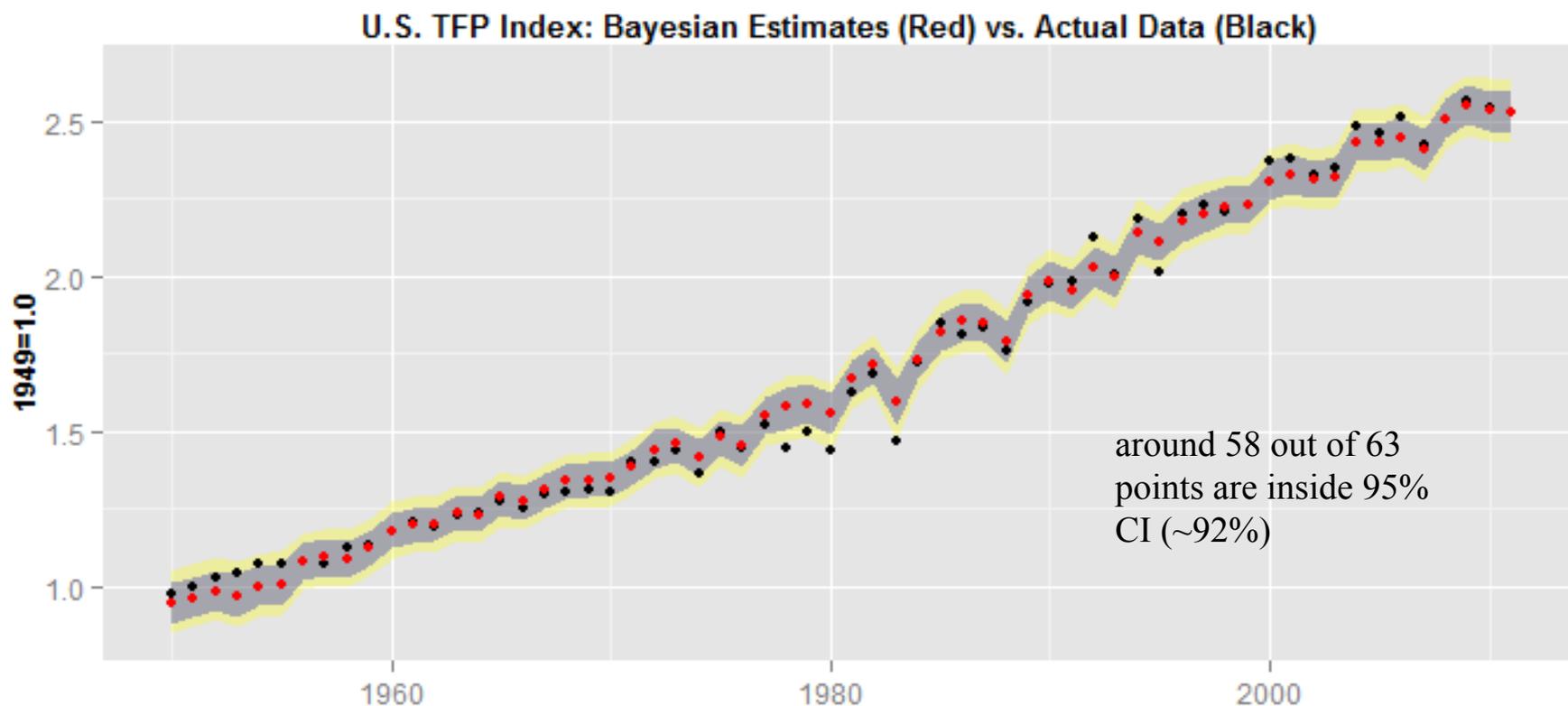


Source: Baldos, Viens, Hertel and Fuglie, 2015

Preliminary Results:

U.S. Public R&D : 1949-2011 using USDA national data

- Reconstructed TFP Index (USDA data: black vs. our results)
- A crucial “validation metric” : Empirical Coverage Probability
 - # data points inside yellow band must be roughly 95% of total # data points



Source: Baldos, Viens, Hertel and Fuglie, 2015

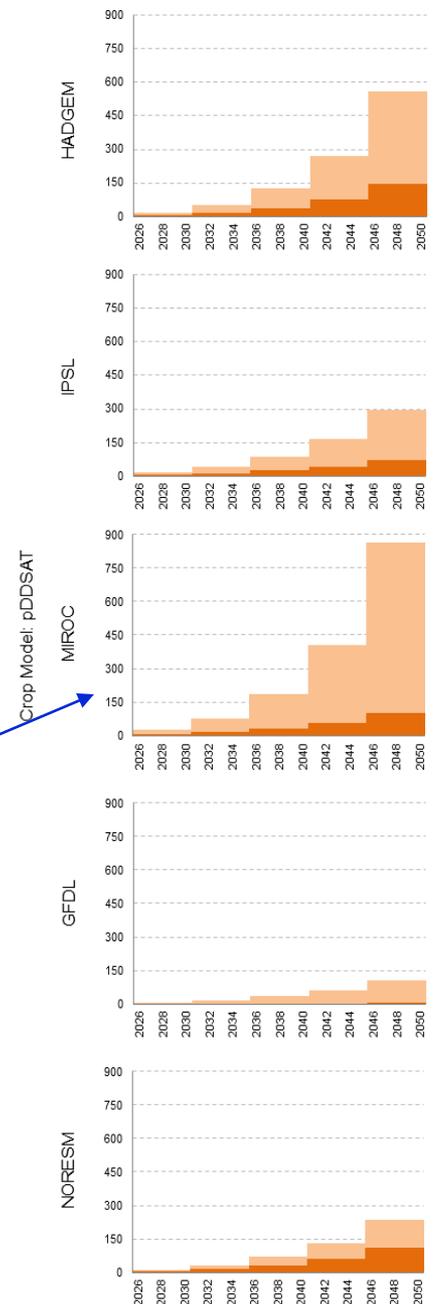
We have combined the R&D model with global estimates from the literature to investigate the role of R&D in adaptation to climate change

Make regional R&D investments, beginning in 2026, to offset adverse impacts of T & P changes by 2050

The path of adaptation spending required remains quite uncertain

The path of adaptation spending required remains quite uncertain due to climate and crop model uncertainty

Agri. R&D Spending (in B 2005 PPP\$)



Source: Baldos, Hertel and Fuglie, 2015

Conclusions

- **Climate impacts in agriculture remain highly uncertain**
- **Greatest uncertainty likely in tropics where data are weakest and countries are poorest and least equipped for adaptation**
- **Significant interactions between adaptation and land-based mitigation and use of an economic framework helps to draw these out**
- **R&D has been key driver of TFP in agriculture and holds great promise for future adaptation, but also has *long lags which, when combined with uncertainty, to make this a challenging problem (John Reilly's point)***

Historical validation: How well does the R&D story explain agricultural productivity growth?

