Climate Adaptation as Mitigation: Agricultural Productivity, Global Land Use and GHG Emissions

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based on joint work with

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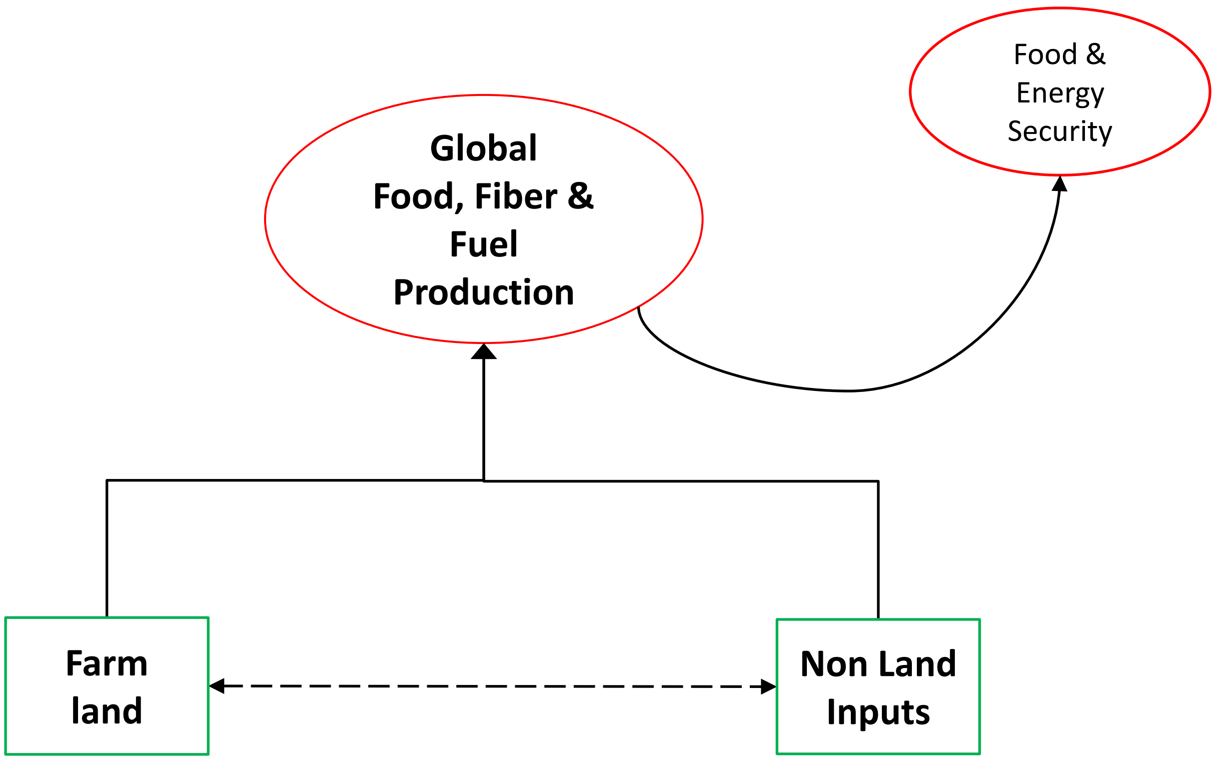
Objectives of the seminar

- Develop analytical foundations of agricultural adaptation and global land use/GHG emissions:
  - When will adaptation lower/raise global GHG emissions?
  - Understand role of key parameters; explore uncertainty
- Provide estimates of the mitigation and adaptation benefits of successful agricultural adaptation to ***changes in temperature and precipitation:***
  - with focus on plausible ranges of these estimates
  - Seek insights into which key factors influence mitigation effects

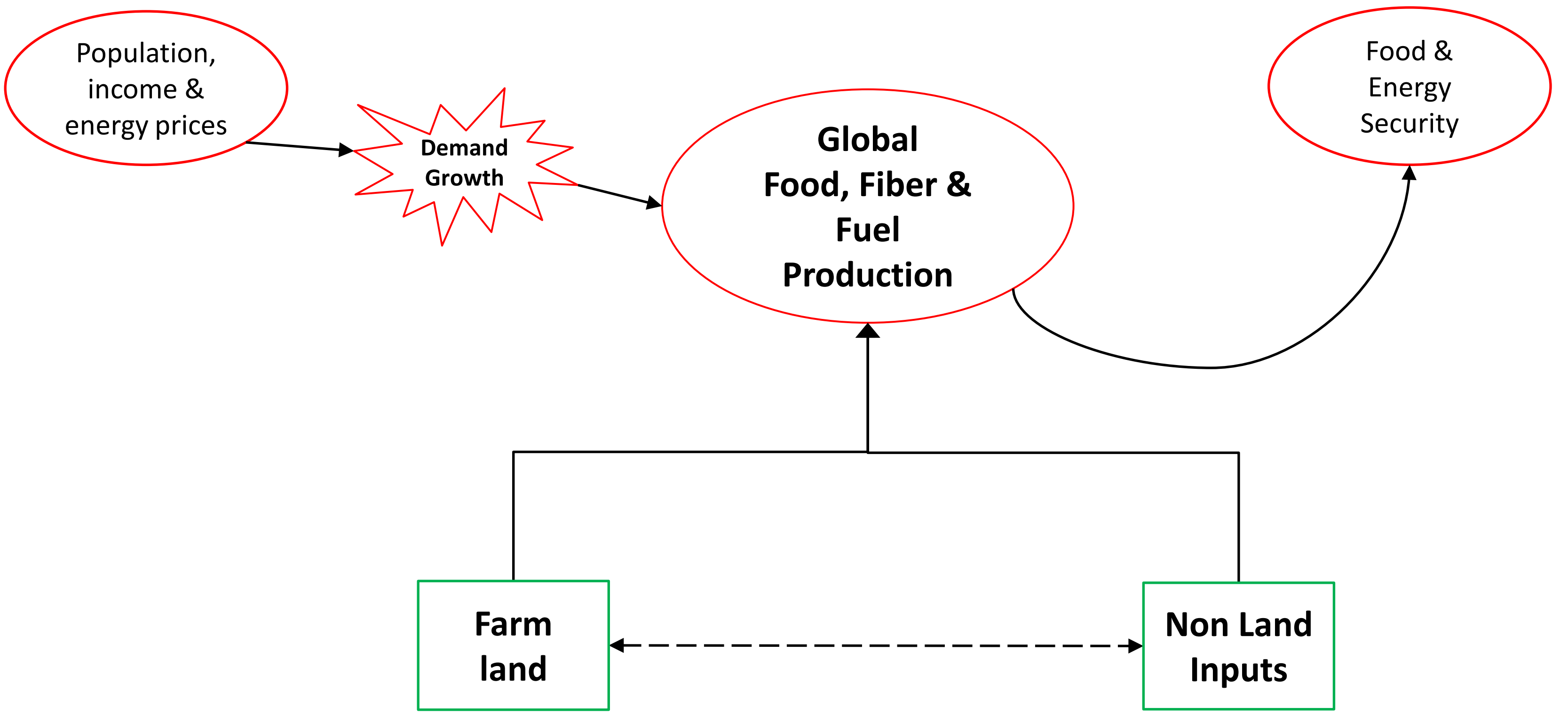
Background

- Large literature on investments in climate mitigation and adaptation
- Growing interest in the role of agricultural productivity gains (or losses) altering global land requirements – is such technological change "land-sparing?" (Wise et al., 2009; Stevenson et al., 2011; Ewers et al., 2009; Rudel et al, 2009; Gutiérrez-Vélez et al., 2012)
- The literature on the GHG impacts of these effects is limited – Burney, Davis & Lobell (2010), estimates around $10/CO2eq ton as return on investments in agricultural yields: 1961-1995
- Our hypothesis: *Successful agricultural adaptation to climate change will moderate global land conversion, thereby yielding significant climate change mitigation benefits*

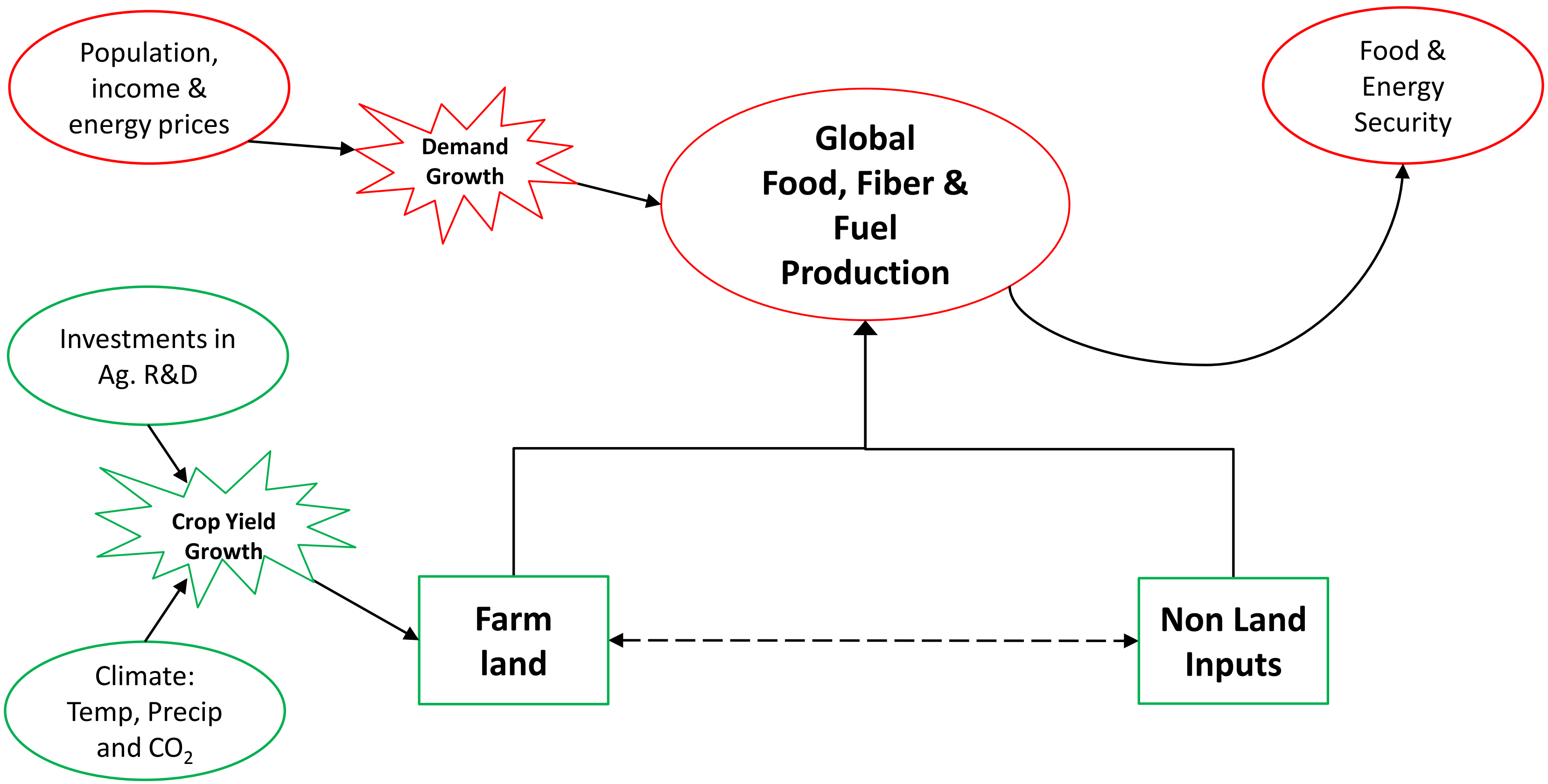
Exploring the Agriculture-Environment-Land Nexus



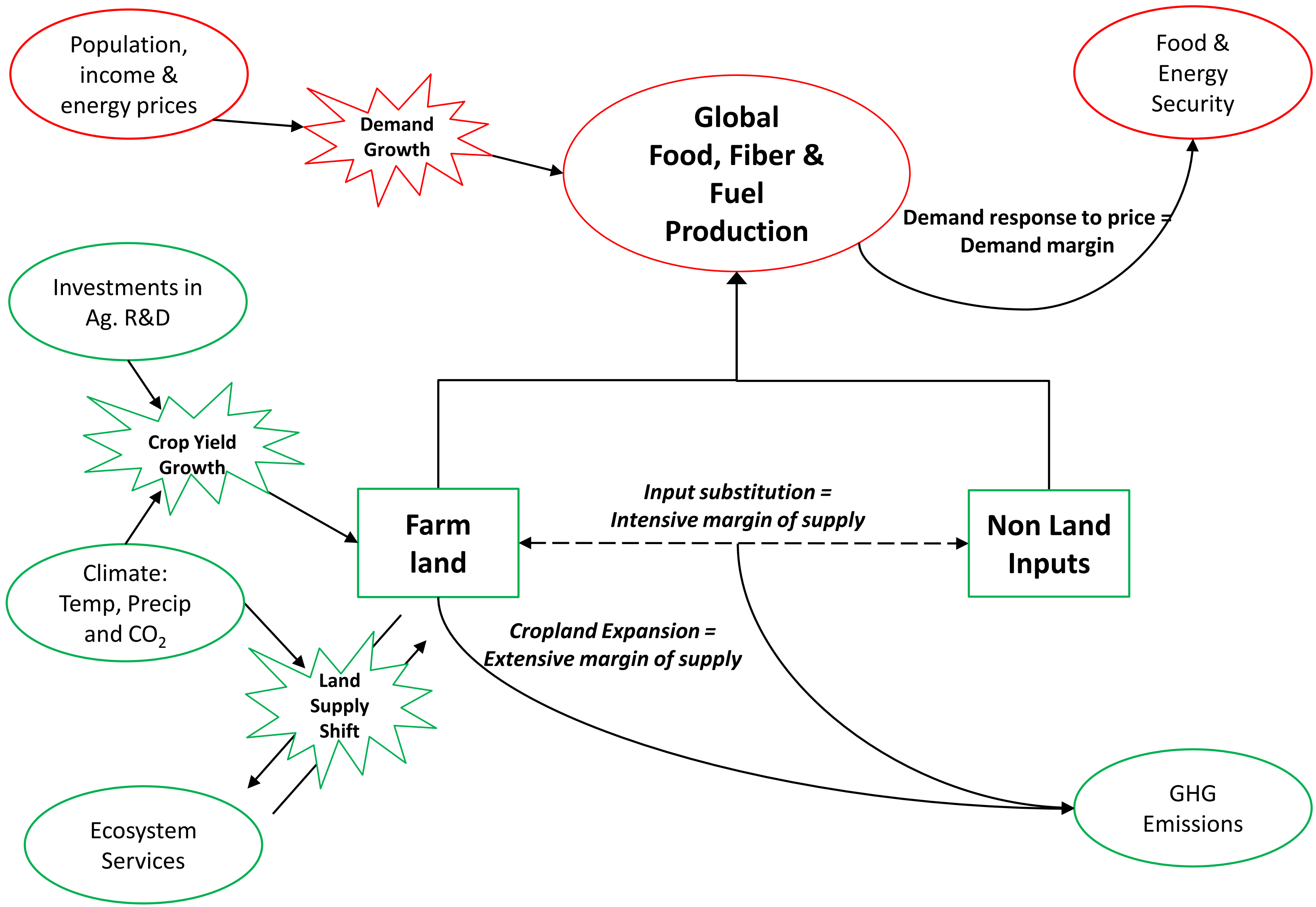
Demand growth is fueled by population, income and bioenergy growth



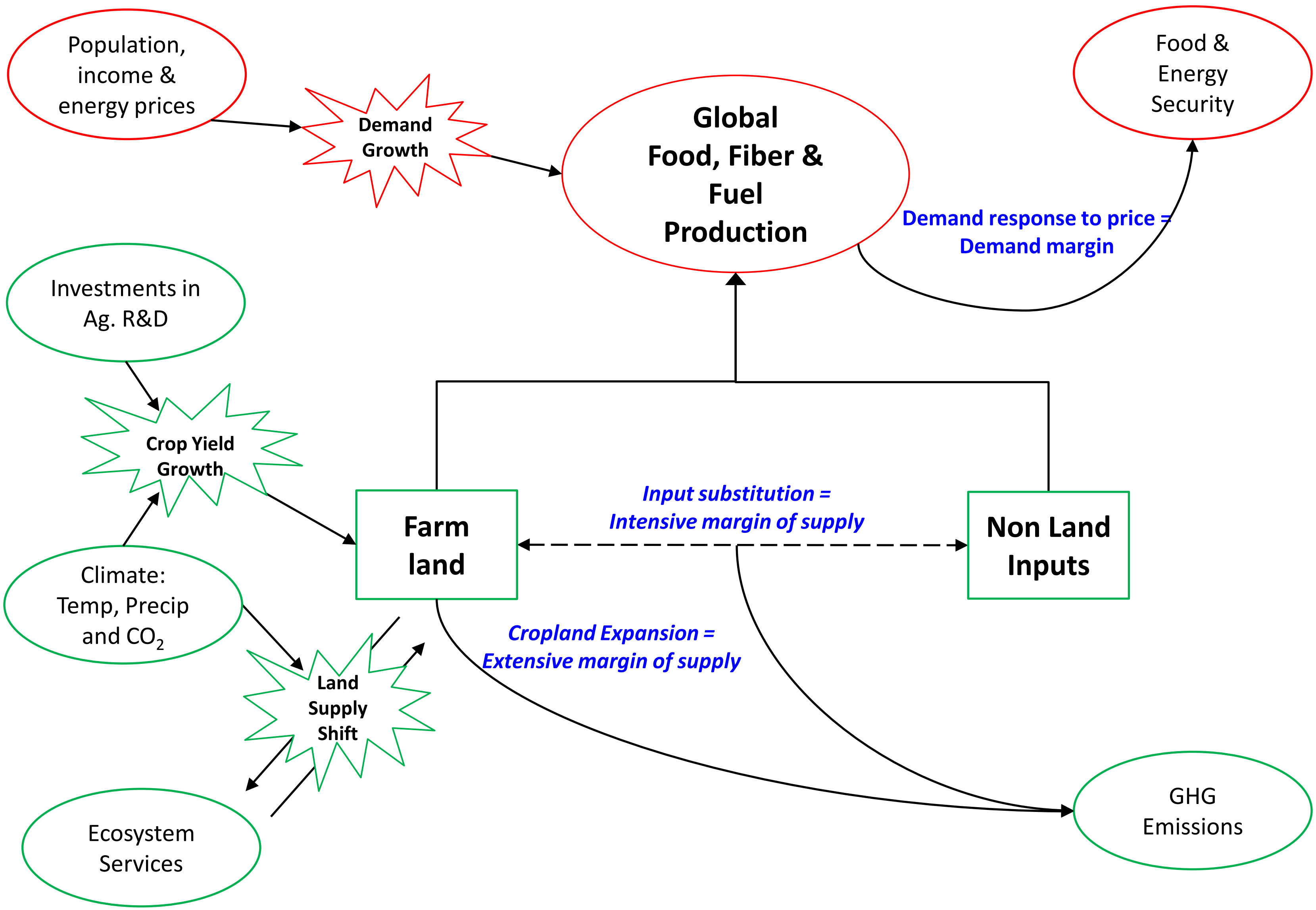
Yields are affected by technological progress and climate change



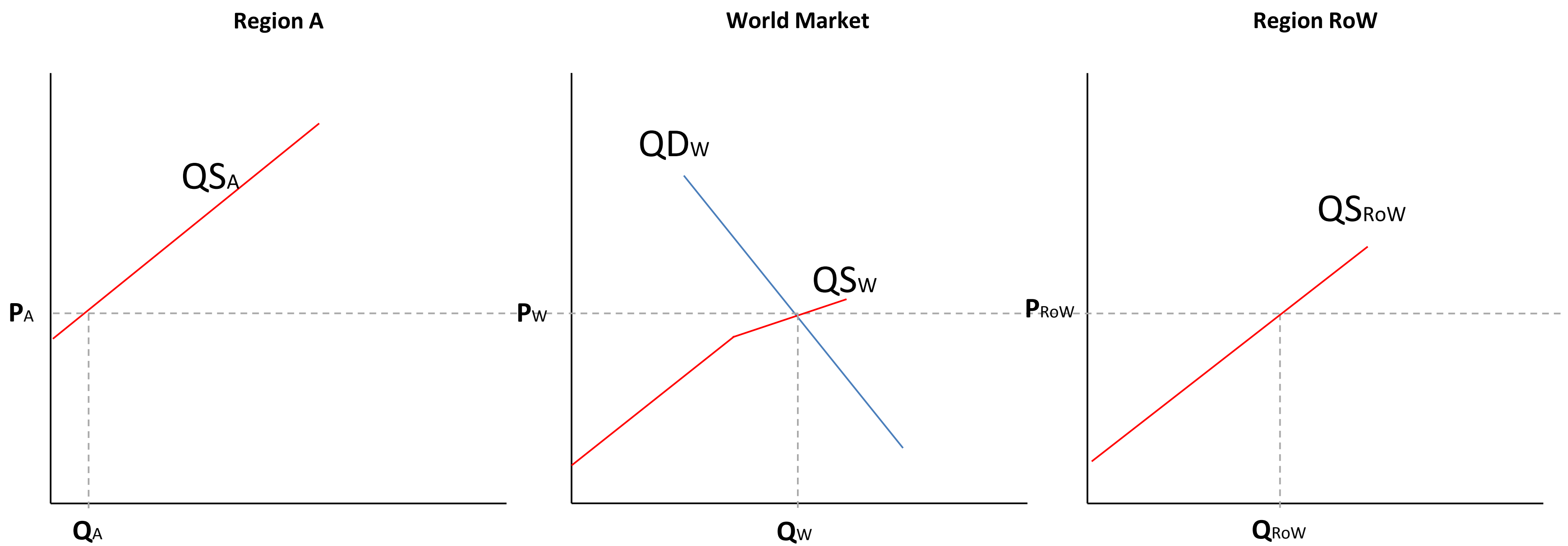
Land conversion leads to GHG emissions, while environmental factors alter cropland availability



Climate impacts are moderated by economic responses to scarcity

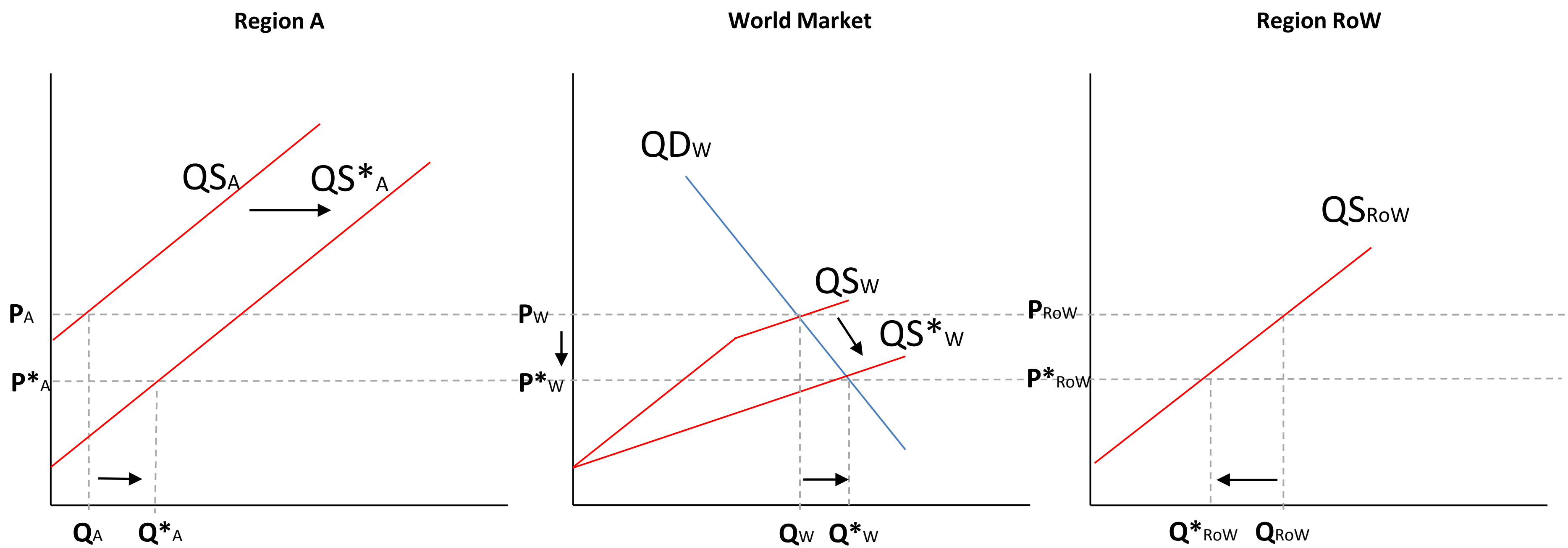


Global land use impacts of favorable adaptation to climate in region A



- Consider a two region model in which region A is affected by technology, whereas the rest of world (RoW) is not
- The world supply curve is based on the aggregation of supplies in regions A and RoW
- Intersection with world demand determines world price

Global land use impacts of favorable adaptation to climate in region A



- Improvement in agricultural technology in A, relative to baseline, represents an outward shift in the global supply of crops, relative to no adaptation, so world price will be lower, relative to baseline
- Faced by a lower world price, but unchanged technology, *producers in the non-adapting rest of the world (RoW) contract production and cropland*
- ***However, the impact on cropland use in A is ambiguous***

Land use impacts of adaptation (1)

- *Land use change in the adapting region (A) is ambiguous because*:
  - Improved technology *reduces area required for given output*
  - But *expect output in region A to increase*
  - However, *lower prices dampen incentive to expand*
  - Outcome depends on price elasticity of demand

- What is missing in literature is a comprehensive analysis of the impacts on *global* land use and emissions: as it turns out, *the global impact is also ambiguous*

Land use impacts of adaptation (2)

Land use change in response to one percent TFP growth, in adapting region depends on the demand elasticity facing region A:

$$q_L^A = \varepsilon_S^{A,X} (\varepsilon_D^A - 1) / (\varepsilon_D^A + \varepsilon_S^A)$$

But the demand elasticity facing region A *is a combination of the global demand elasticity and the RoW supply elasticity.*

Trade economists call this the EXCESS demand elasticity:

Excess demand elasticity A →

$$\varepsilon_D^A = (\varepsilon_D^W + (1-\alpha)\varepsilon_S^{RoW}] / \alpha$$

Global demand elasticity for crops

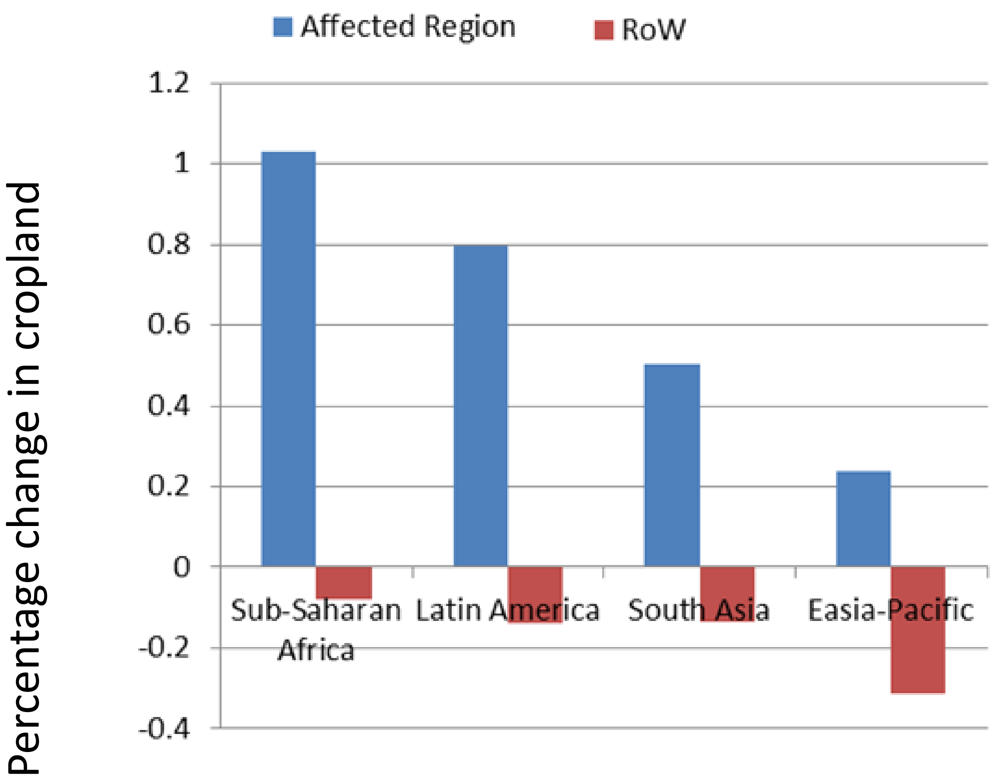
Weighted ROW supply elasticity

Share of A in global output

So land use in A can expand, *even if global demand elasticity is zero*

Illustrative Calculations

Using 15 year supply elasticities



Adapting region: smaller to larger

- Based on FAO data and estimates of long run supply responses
- Implications of adaptation equal to a 1% productivity improvement, by singe developing regions, and their respective RoW regions
- Excess demand is elastic for all regions, so cropland in adapting regions rises in every case – more so for smaller regions

What can we say about the global land use impacts?

- Jevons' paradox arises when technological progress (successful adaptation in this case) leads to an increase in global land use
- In the special case where supply response in both regions is equal, then the condition for Jevons' paradox to obtain is:

$$\varepsilon_D^W > (\alpha / \delta)(\varepsilon_S^W + 1) - \varepsilon_S^W$$

Production share/area share = yields in A / Global average yields

- Which is ***more likely when world demand for crops is more elastic and A has small yields, relative to the world***

What about GHG emissions?

- Not surprisingly, the critical condition for a rise in global emissions from land cover change in the wake of adaptation is quite similar
- Again, *in the special case* where supply response in both regions is equal, for worldwide emissions to rise we require:

$$\varepsilon_D^W > (\alpha / \gamma)(\varepsilon_S^W + 1) - \varepsilon_S^W \Rightarrow e^W > 0$$

↑

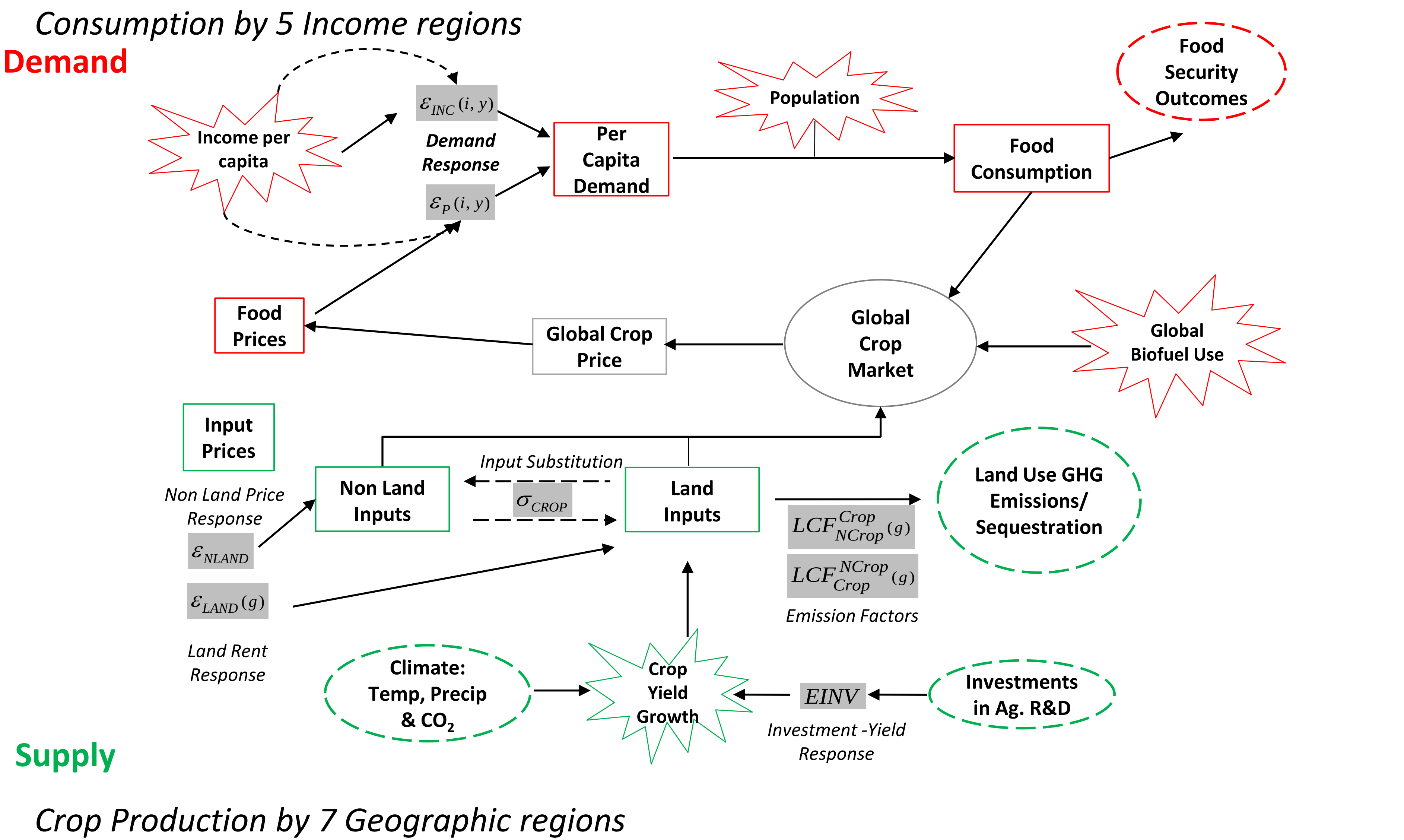
Production share/emissions share = 'emissions efficiency' of adapting region / Global avg

- Emissions efficiency = tons of output/tons of carbon from land conversion
- The condition for emissions to rise is *more likely when world demand for crops is more elastic and A has low relative emissions efficiency*
- Evidence suggests that emissions efficiencies are low in the tropics (West et al., PNAS, 2010), ***leading to the potential for adaptive investments in low income regions to lead to a rise in emissions***, relative to baseline

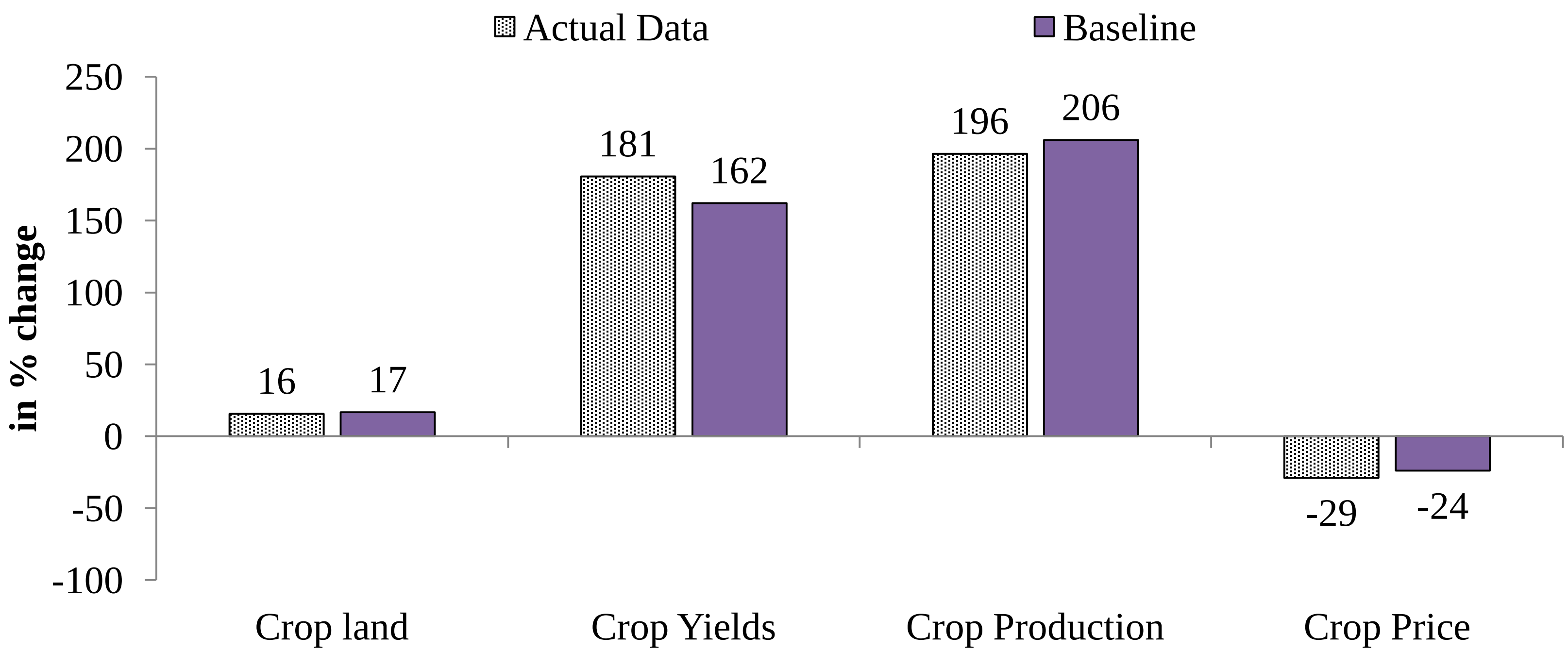
Empirical Model: Numerical investigation of adaptation

- Global partial equilibrium model (SIMPLE)
  - Food sectors include crop, livestock, processed foods
  - 7 Geographic regions (crop supply and cropland use)
  - 5 Income regions (commodity demand, supply of non-food, derived demand for crops and supply of livestock and processed foods)
  - Non-land inputs now less than perfectly elastic in supply
- Global market clearing condition for crops
  - Single world crop price
  - Regional market clearing conditions for livestock and processed foods
- Tracks changes in the following:
  - Cropland use and GHG emissions from cropland change (two types of conversion: cropland to ‘other lands’ & ‘other lands’ to cropland)
  - Agricultural investments in research & development facilitate adaptation to higher temperatures, changing precipitation

SIMPLE: a Simplified International Model of agricultural Prices, Land use and the Environment



SIMPLE Validation: Can we predict historical output changes as well as the mix of extensive and intensive contributions?

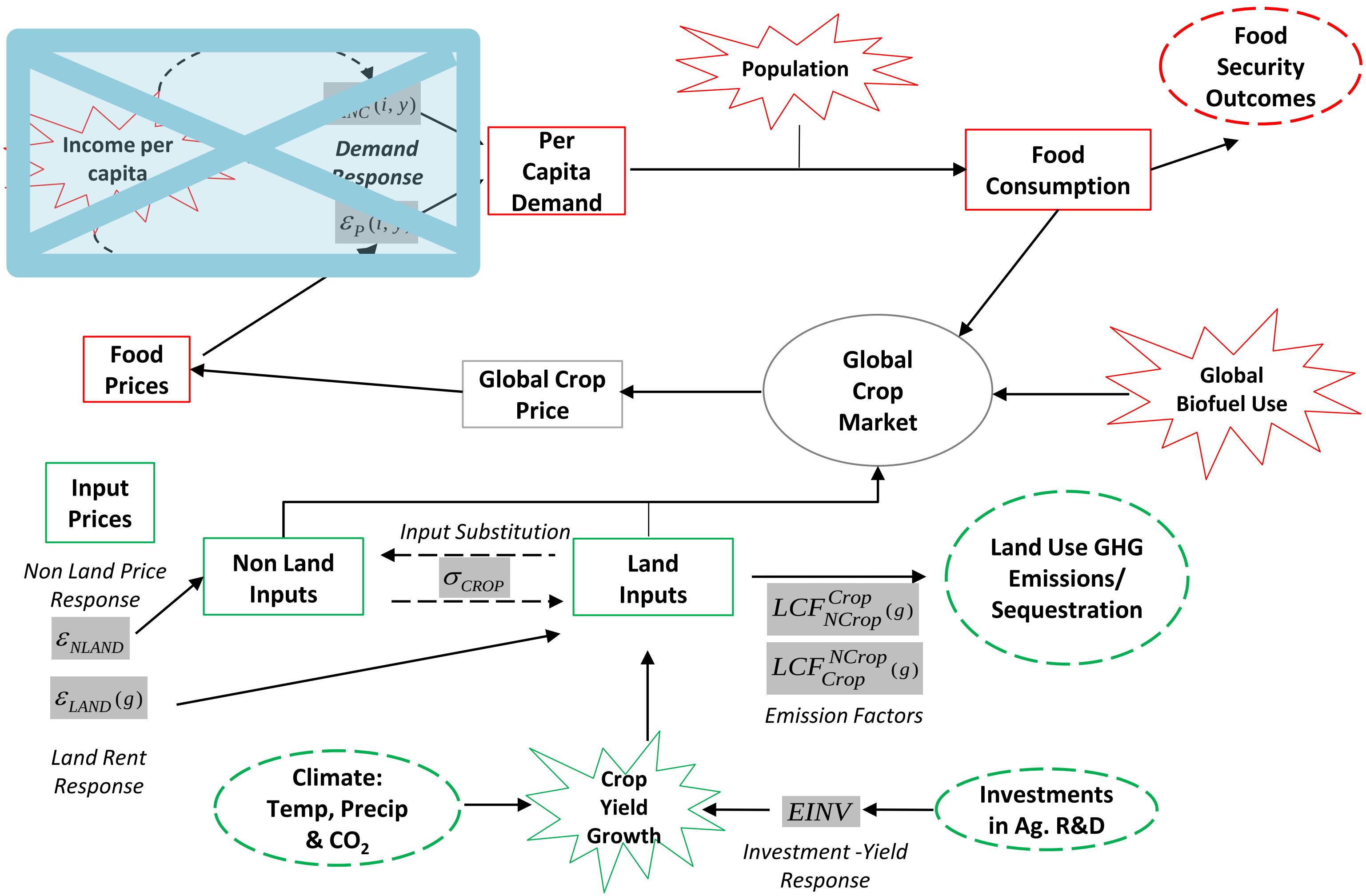


- Historical validation over a 45-year period (1961-2006)
- Exogenous drivers are **pop, income, estimated total factor productivity growth**, by region and sector (Fuglie & others)
- ***Model determines* level and mix of global food consumption, area and *yields***

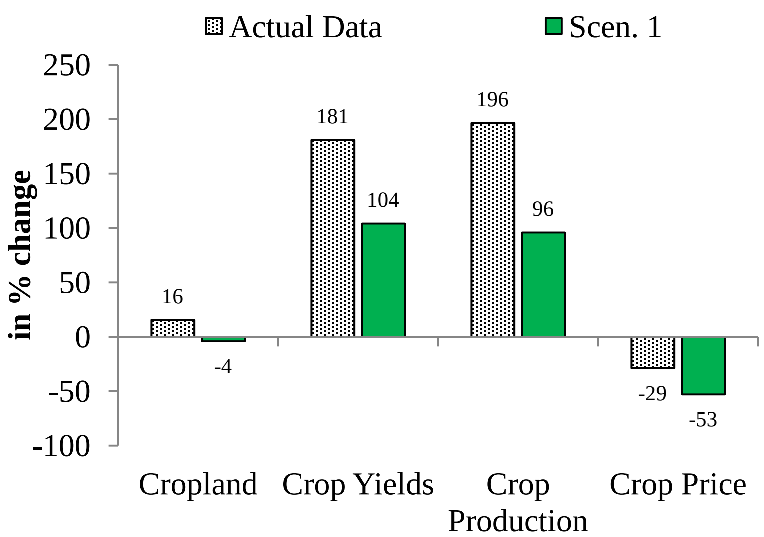
Using SIMPLE as a laboratory to explore limitations of existing IAMs

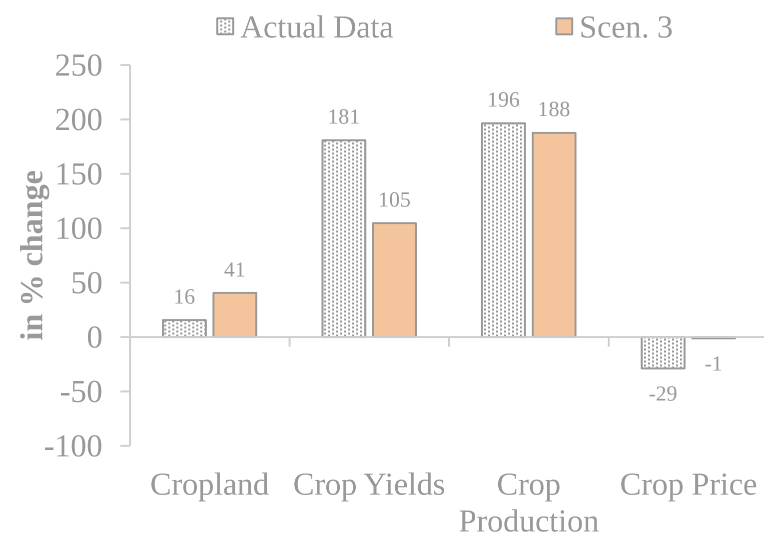
- While SIMPLE is simple in its representation of biophysical processes and spatial resolution, it is richer in economic structure than many IAMs
- Can use it to explore implications of omitting key economic factors
- Revisit historical validation with restricted model:
  - Fixed per capita demands (income and price are no longer demand drivers)
  - Constant income and price responses over time (invariant to income level)
  - Absence of any intensive margin

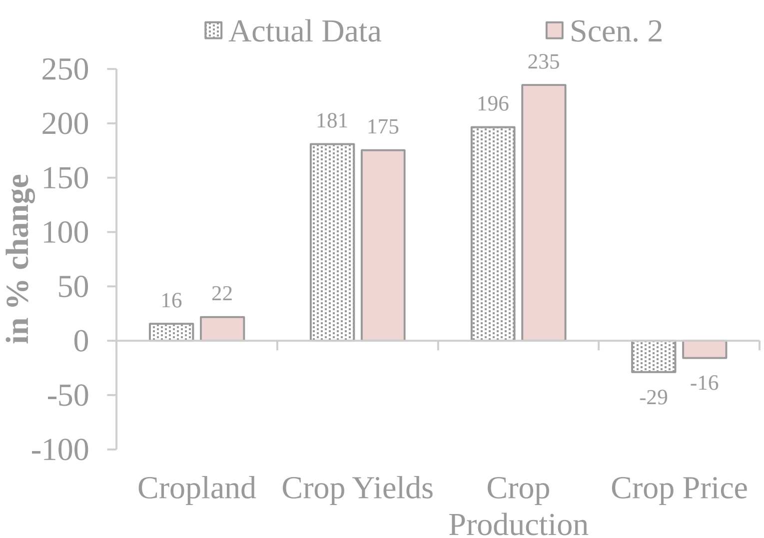
Fixed per capita demands in SIMPLE



Implications of fixed per capita demands

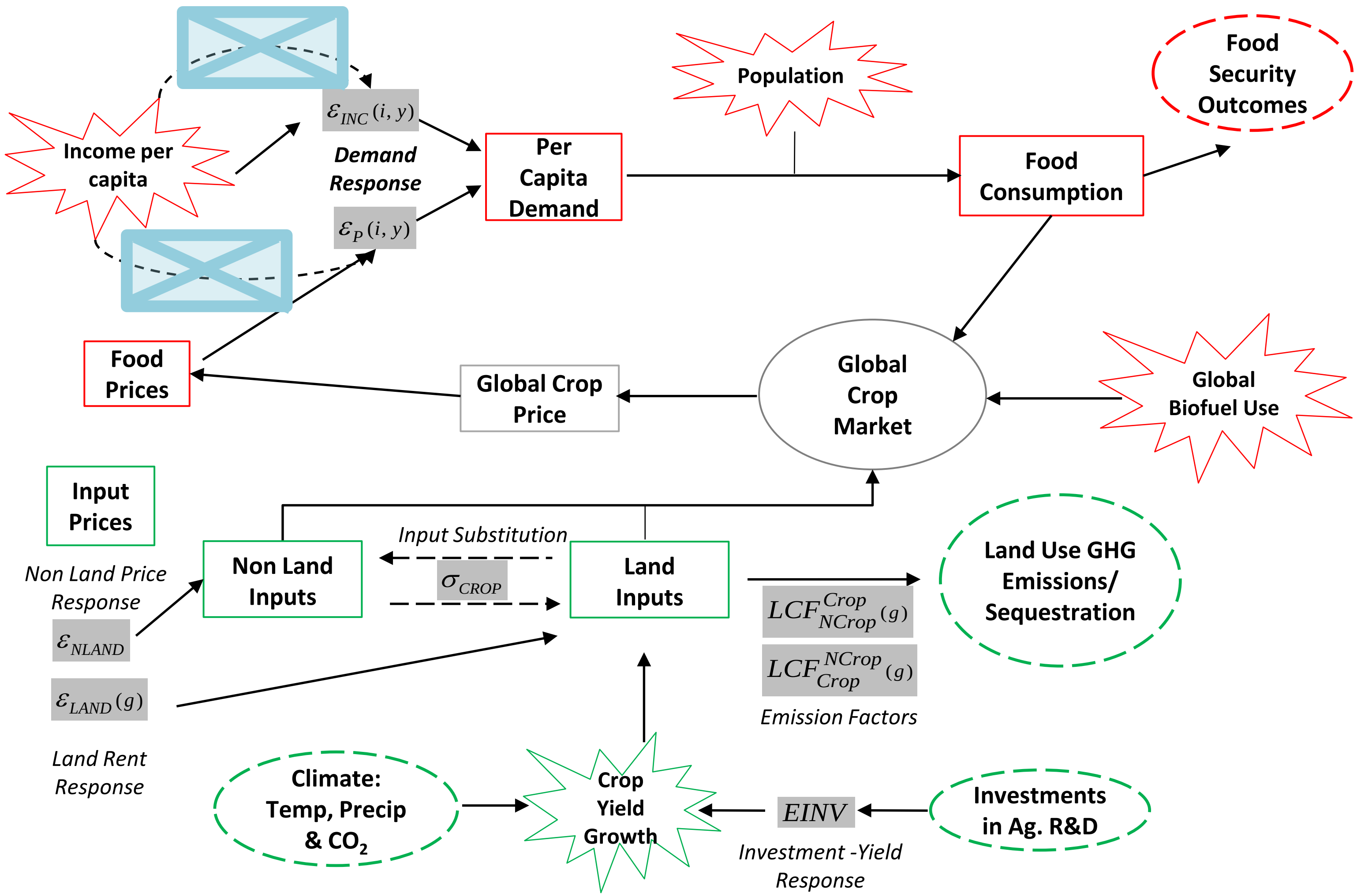




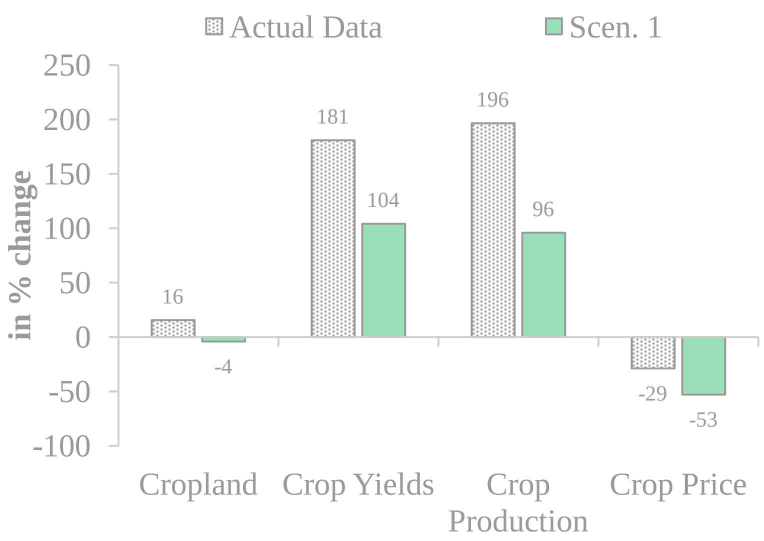


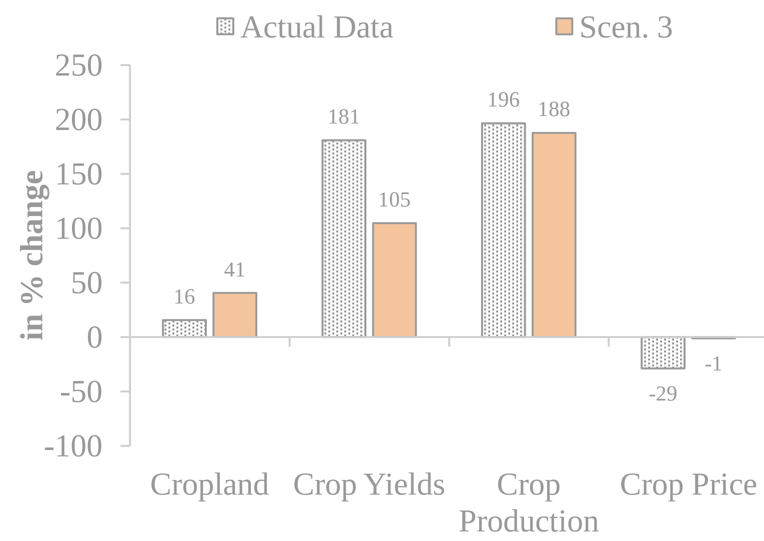
- With fixed per capita consumption, composition of diets is unchanging
- This leads to the ***underestimation*** of global production, yields and cropland use

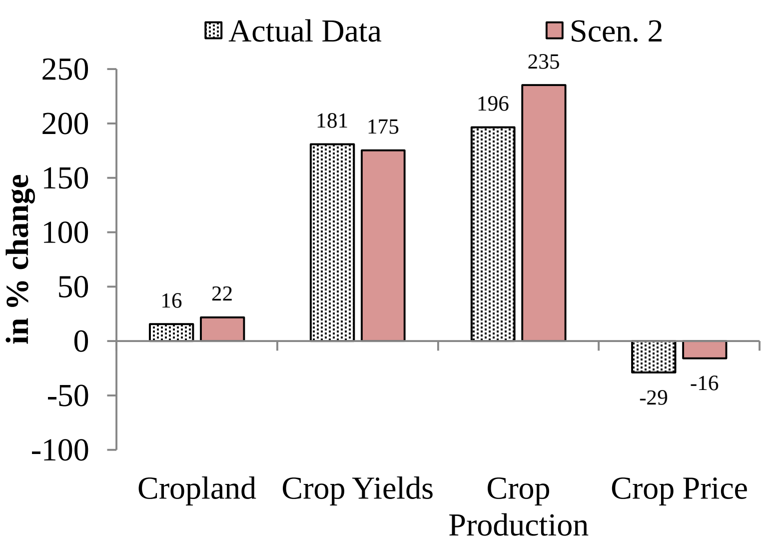
Constant income and price response of demands in SIMPLE



Implications when Demand response does not *evolve with income*

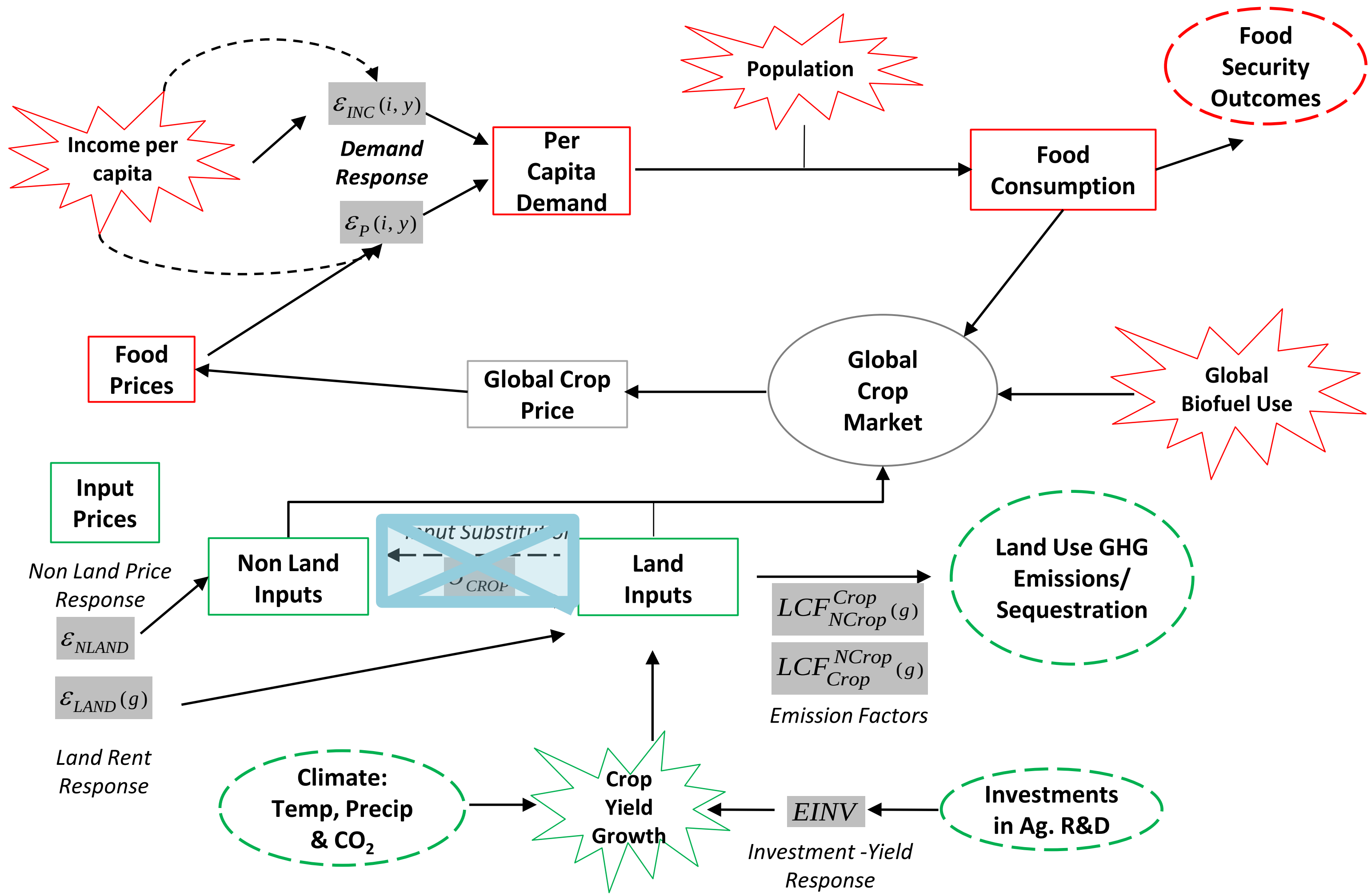




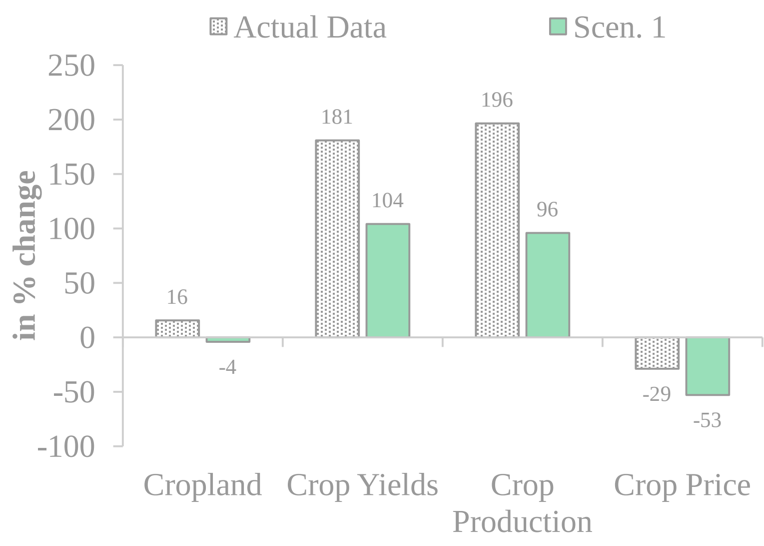


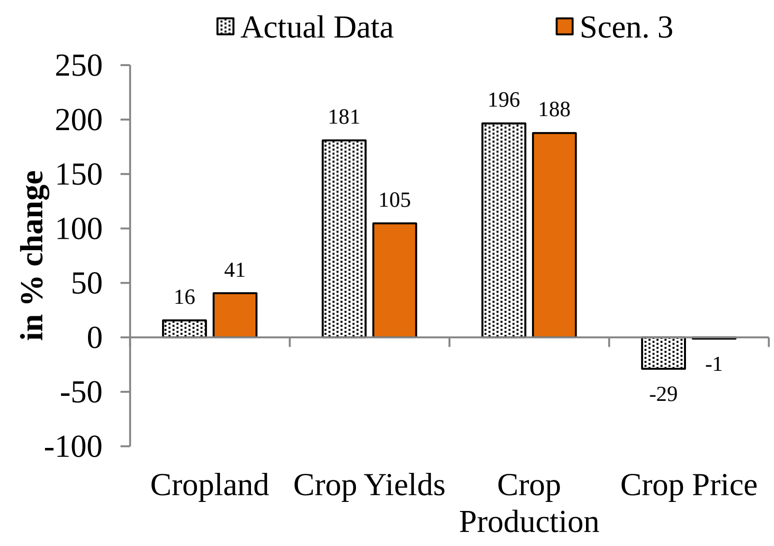
- If demand response does not evolve with income, consumers will spend additional income on the same commodity/food
- This leads to the ***overestimation*** of global production and cropland use

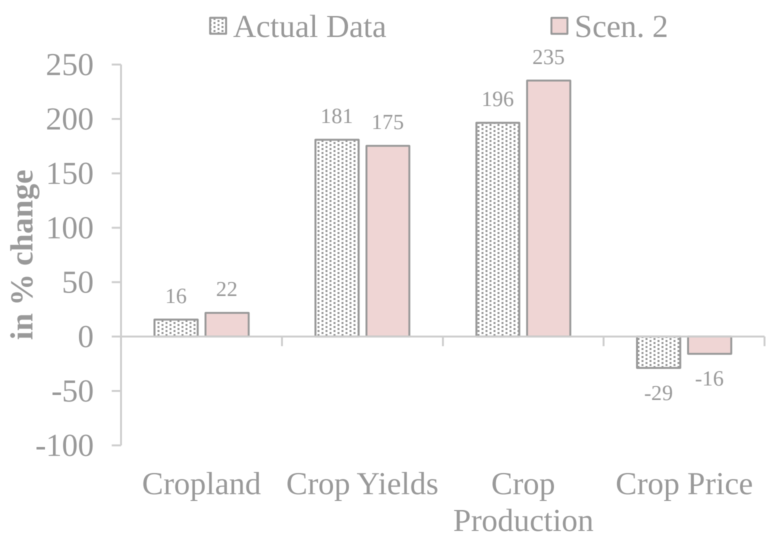
Eliminating the intensive margin of supply response in SIMPLE



Implications of omitting the Intensive Margin



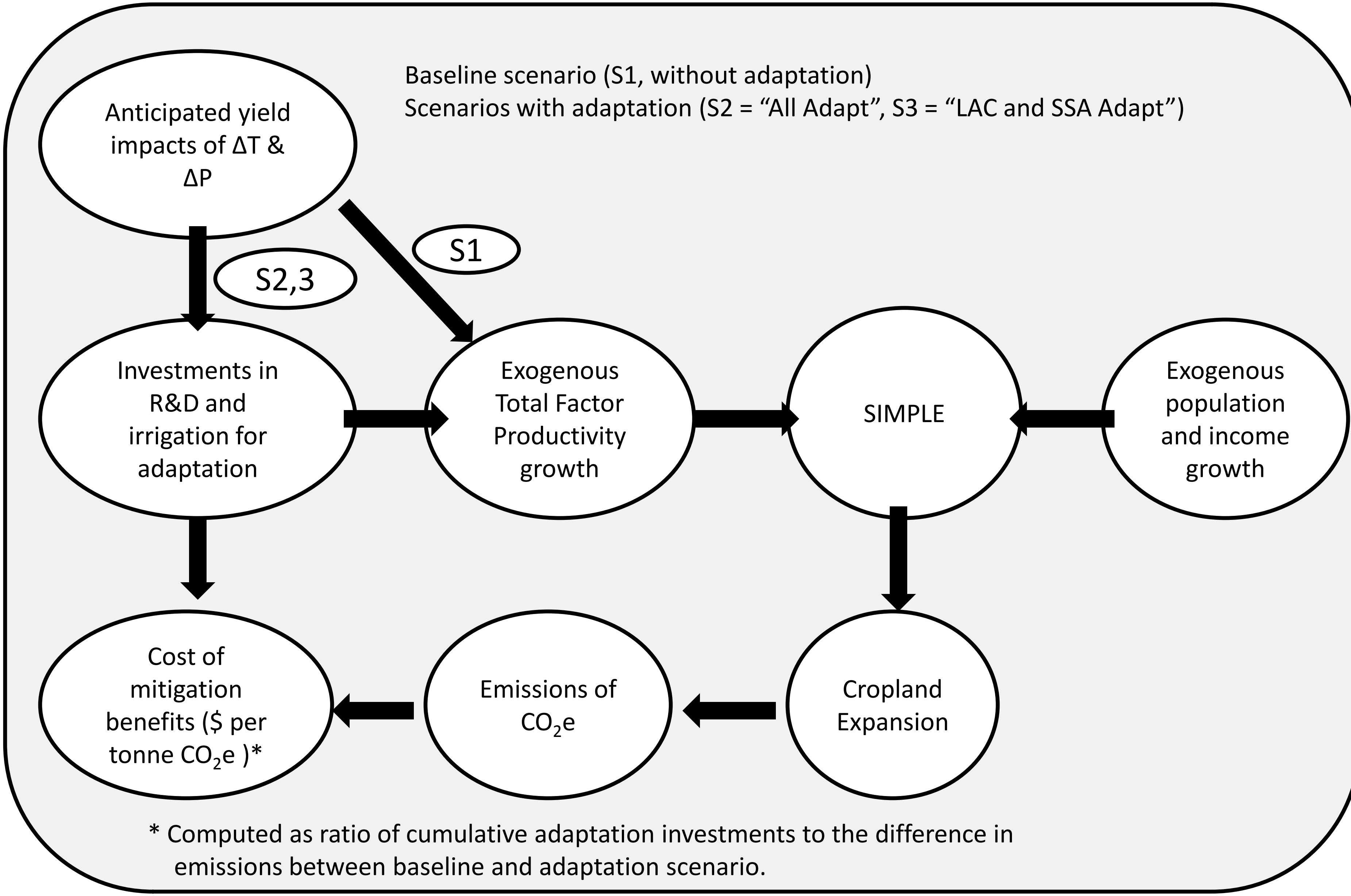




- Without the intensive margin, crop yields will be dictated by our ***exogenous*** productivity growth
- This leads to the ***underestimation*** of crop yield change and ***overestimation*** of cropland use

Looking Forward: 2006-50
Our Experimental Design

- Reference case (S1)
  - Crop demand changes
    - Demand growth due to growth in income and population, moderated by price increases
    - Derived demand for crop inputs by the livestock and processed food sectors (via final demand and productivity changes)
    - Industrial demand for crops from global biofuel use
  - Crop supply changes
    - Urbanization reduces available croplands
    - Projected crop yield growth from Bruinsma (2009)
    - Climate change induced yield changes from Muller et al (2010)
- Two adaptation scenarios (S2 & S3)
  - Negate adverse yield effects of rising temperatures, changing precipitation overcome via R&D
  - S2: All regions adapt
  - S3: Only Latin America and Sub Saharan Africa



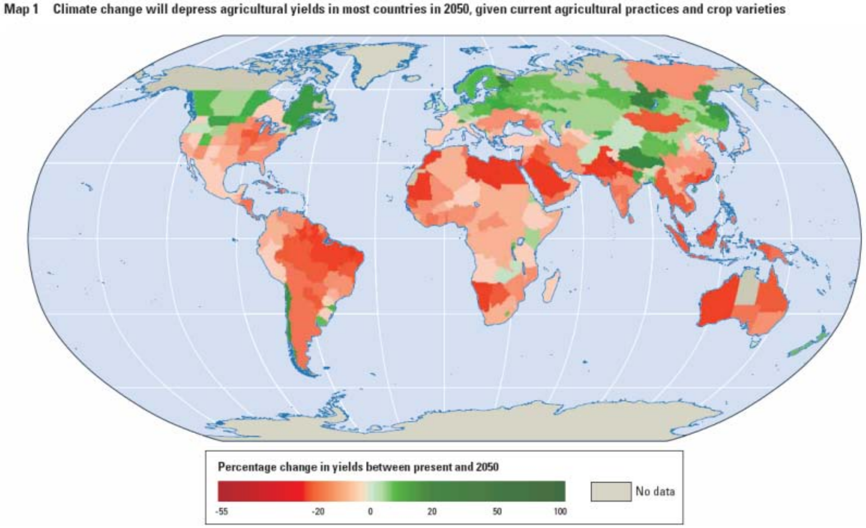
Baseline scenario (S1, without adaptation)
Scenarios with adaptation (S2 = "All Adapt", S3 = "LAC and SSA Adapt")
Anticipated yield impacts of ΔT & ΔP
S2,3
S1
Investments in R&D and irrigation for adaptation
Exogenous Total Factor Productivity growth
SIMPLE
Exogenous population and income growth
Cost of mitigation benefits ($ per tonne CO_2e)*
Emissions of CO_2e
Cropland Expansion
* Computed as ratio of cumulative adaptation investments to the difference in emissions between baseline and adaptation scenario.

Projected Impacts on Crop Productivity

- Draw here on Mueller et al: background study for 2010 WDR which used the LPJ[2] Agricultural Model (Bondeau et al) to simulate aggregate grain yields by region
- Includes autonomous (endogenous) shifts in sowing dates and varieties, but does not allow for new technologies
- Shows a familiar pattern of gains from CO2 and limited warming impacts in high latitudes, bigger losses in tropics

CO2 fertilization present

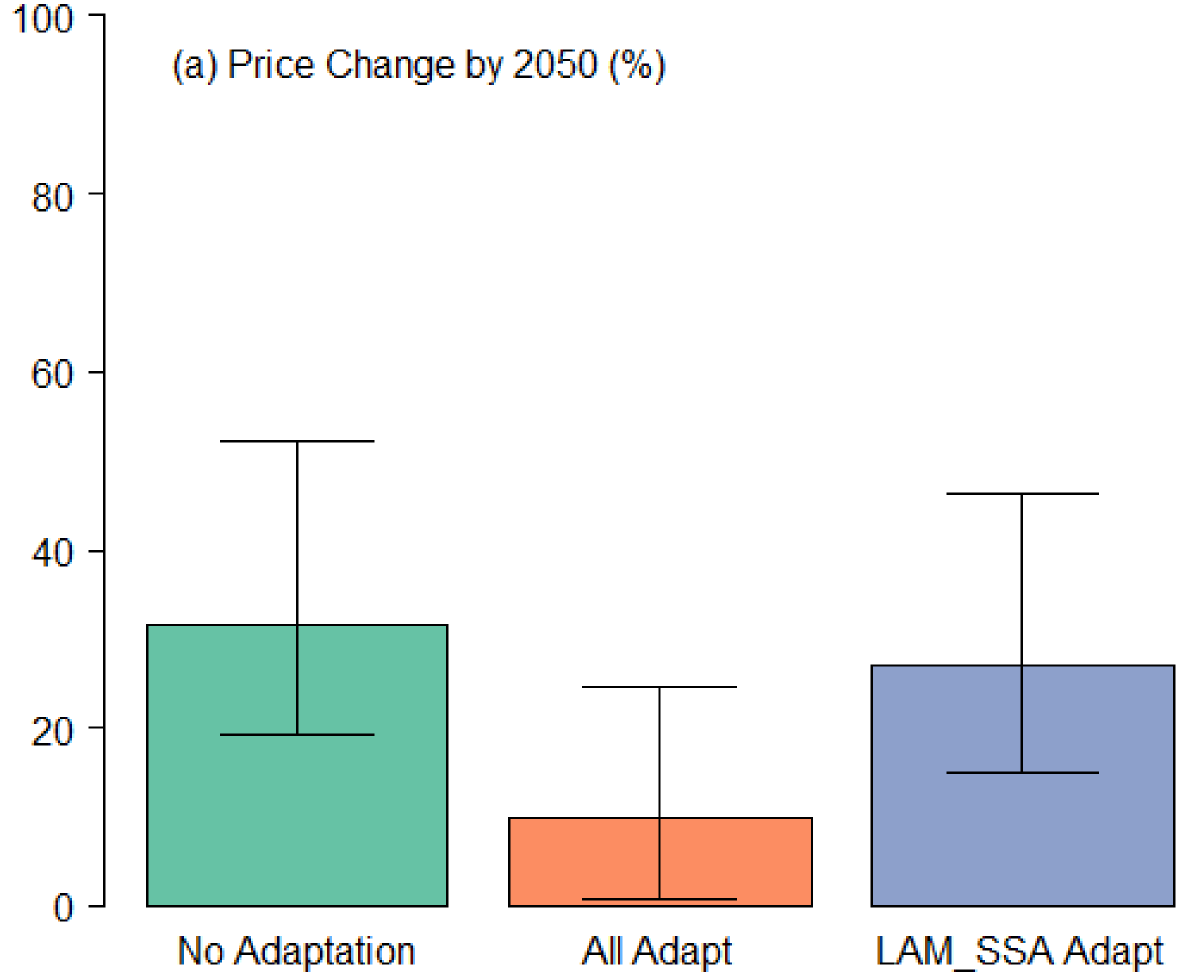
Map 1 Climate change will depress agricultural yields in most countries in 2050, given current agricultural practices and crop varieties



Yield Reductions due to changes in Temp & Precip ***[No CO2 Fertilization]***	2006-2050 (in %)
E_Asia_Pac	**-17.0**
Eur_C_Asia	**+1.9**
L_Amer_Carr	**-7.4**
M_East_N_Afr	**-13.4**
N_America	**-6.4**
S_Asia	**-28.0**
S_S_Africa	**-6.9**

[2]http://www.pik-potsdam.de/research/projects/lpjweb

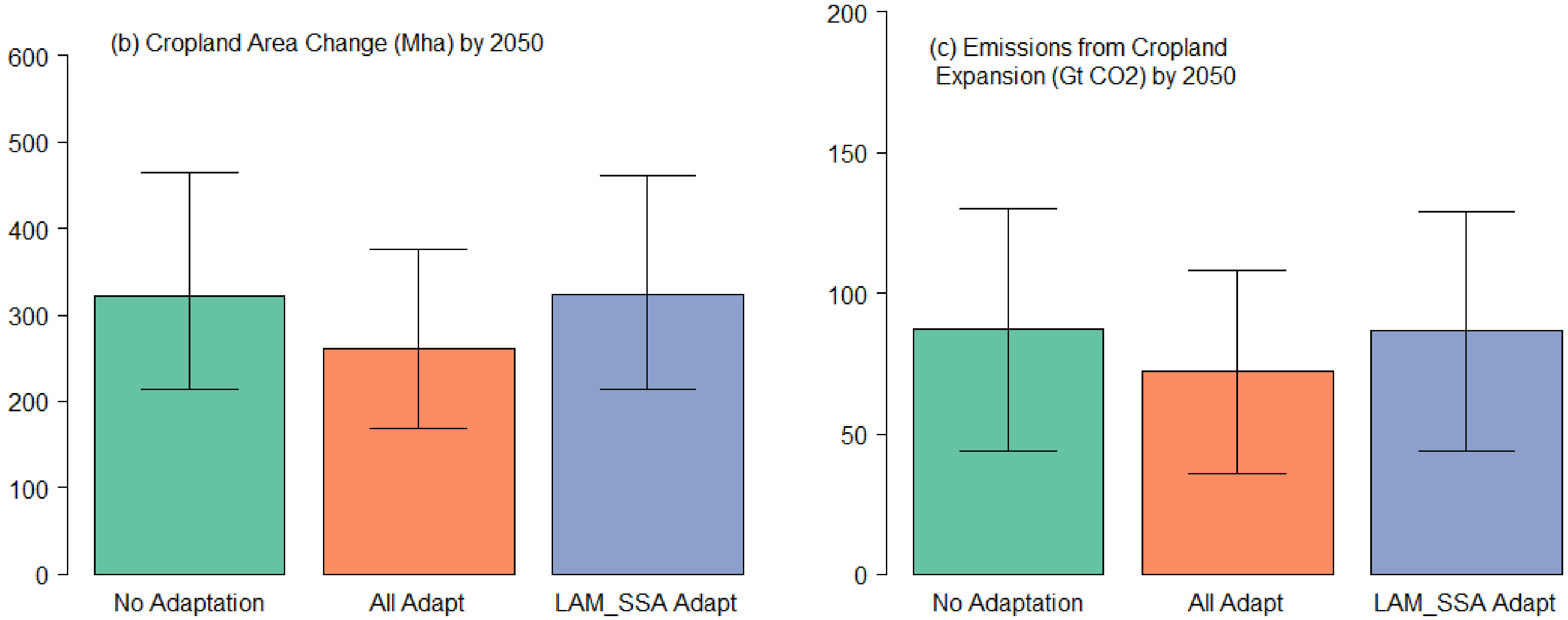
Global Price Impacts (no CO2 fert)



Baseline does not include CO_2 fertilization

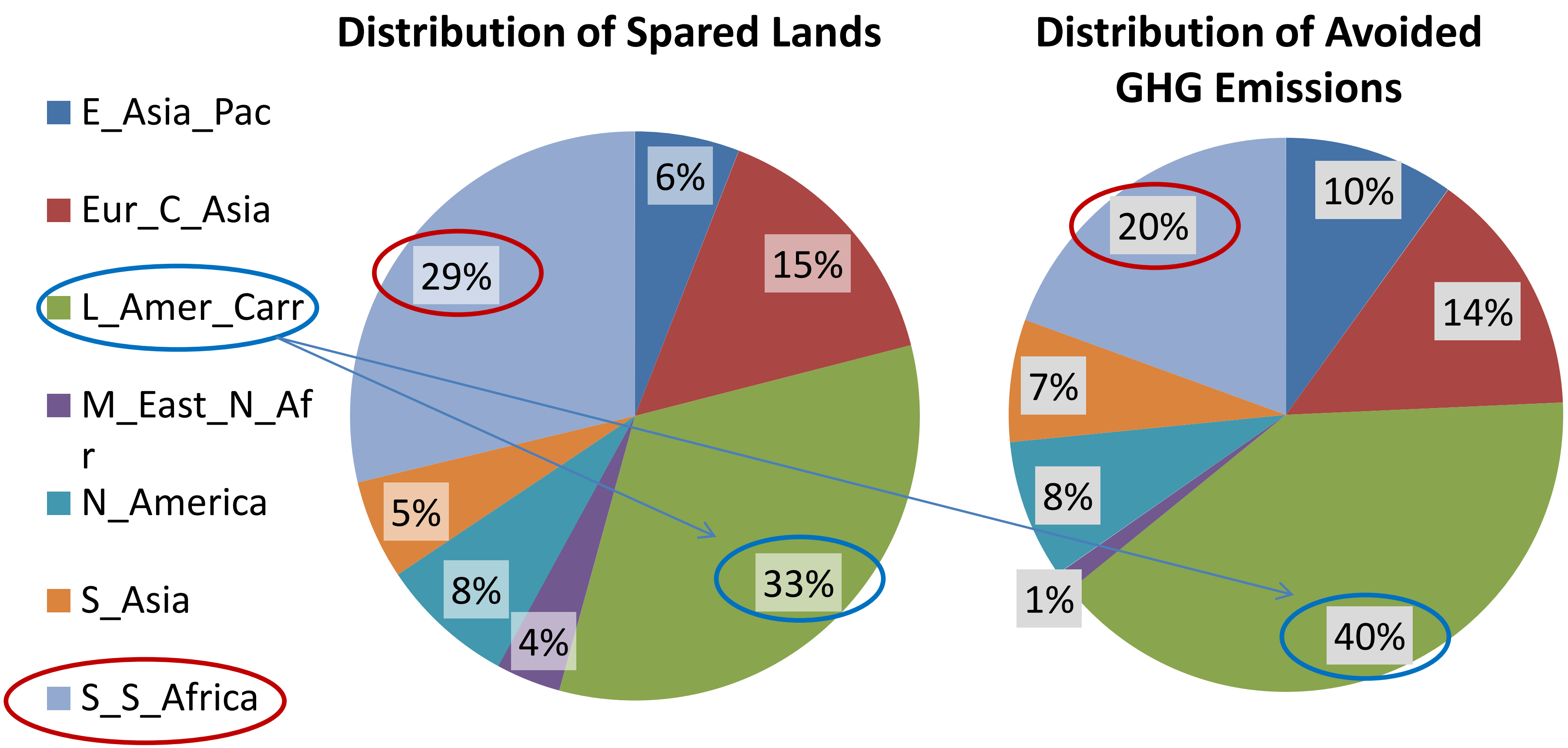
Lobell, Baldos & Hertel, ERL (2013)

Global land use and emissions impacts



Lobell, Baldos & Hertel, ERL (2013)

All Regions Adapt: S2-S1

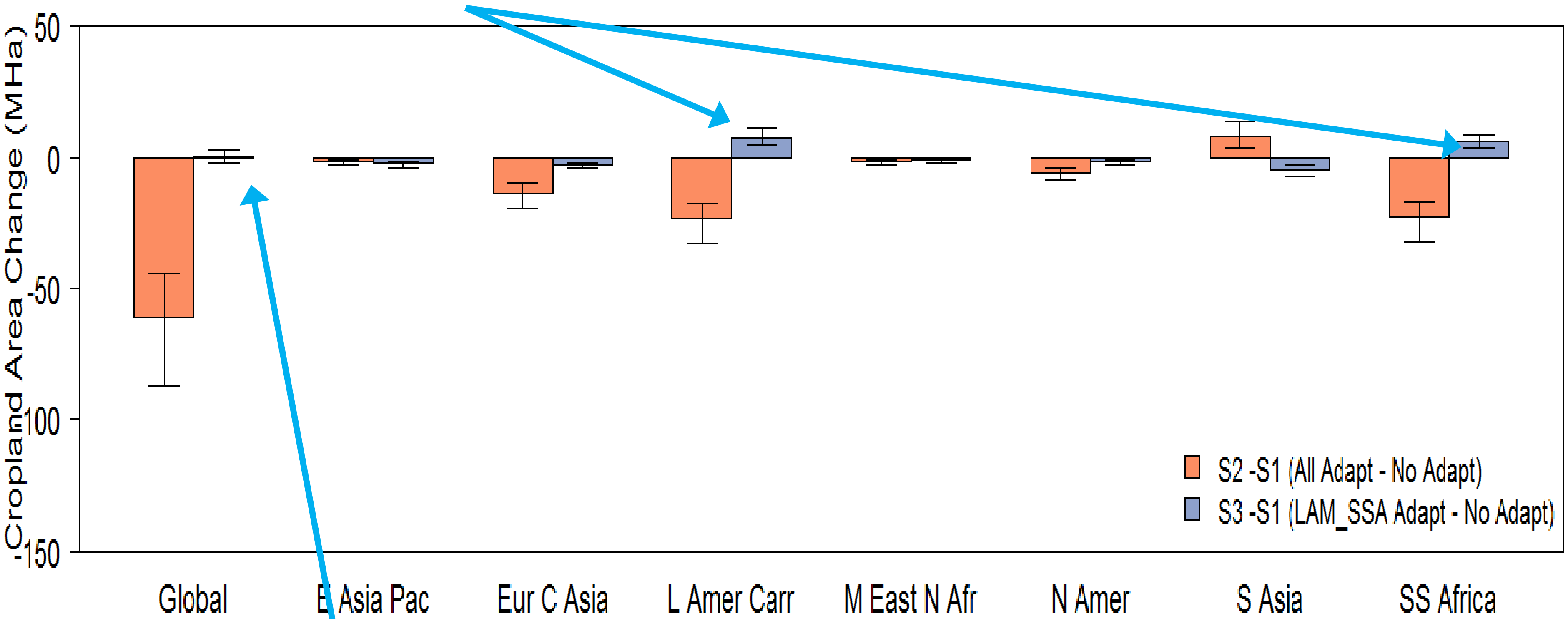


If all regions adapt then:
-> 99.5 million hectares of ‘other land’ are spared
-> 26.8 billion tonnes of CO2 eq. emissions are avoided
(from ***direct land use change emissions***)

Lobell, Baldos & Hertel, ERL (2013)

Impacts of Adaptation on Land Use

Partial adaptation scenario:
Adapting regions boost land use, RoW regions reduce land use; global land use is ambiguous

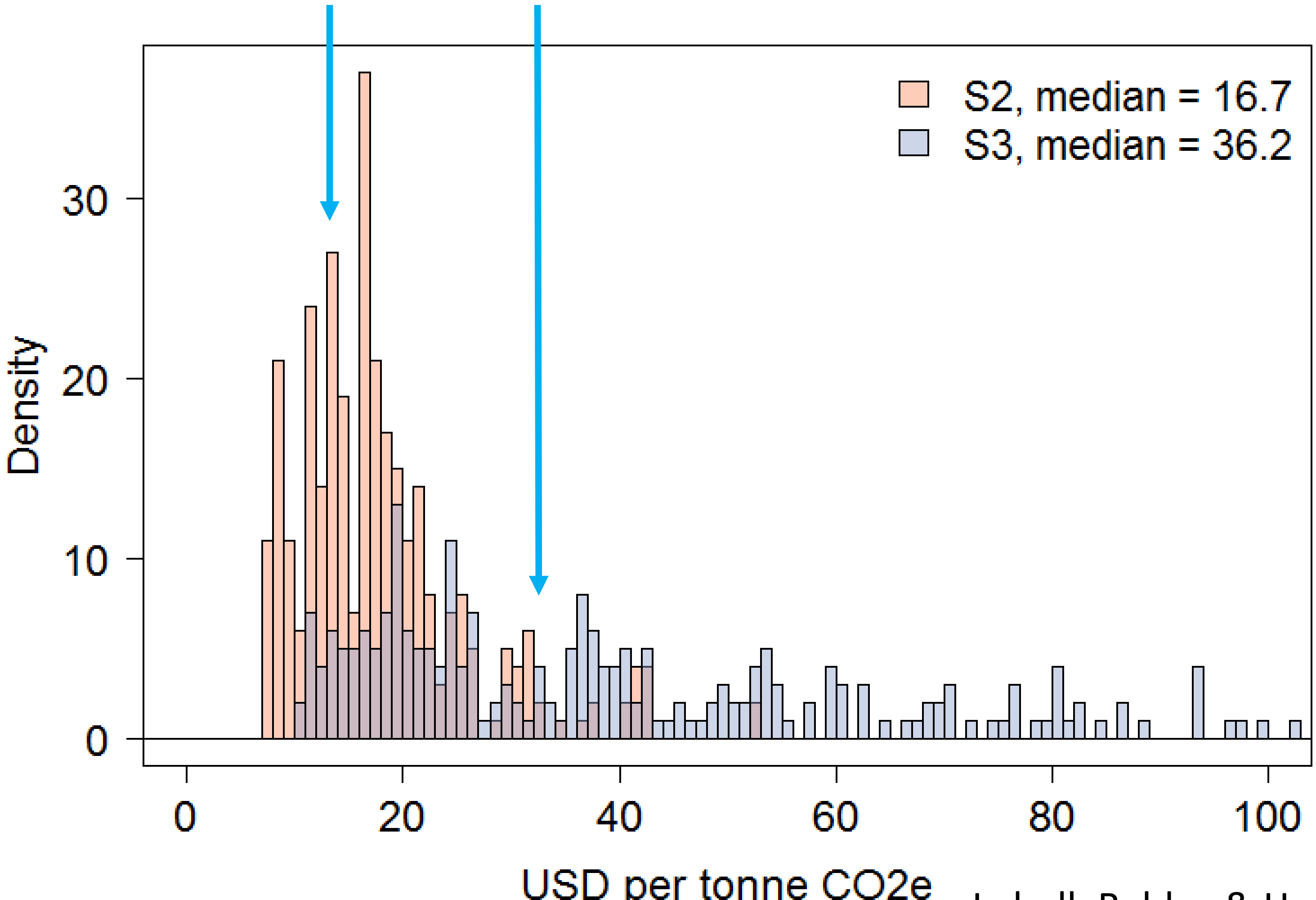


Jevons' paradox revisited: When only LAM and SSA Adapt, there is potential for an increase in global land use

Lobell, Baldos & Hertel, ERL (2013)

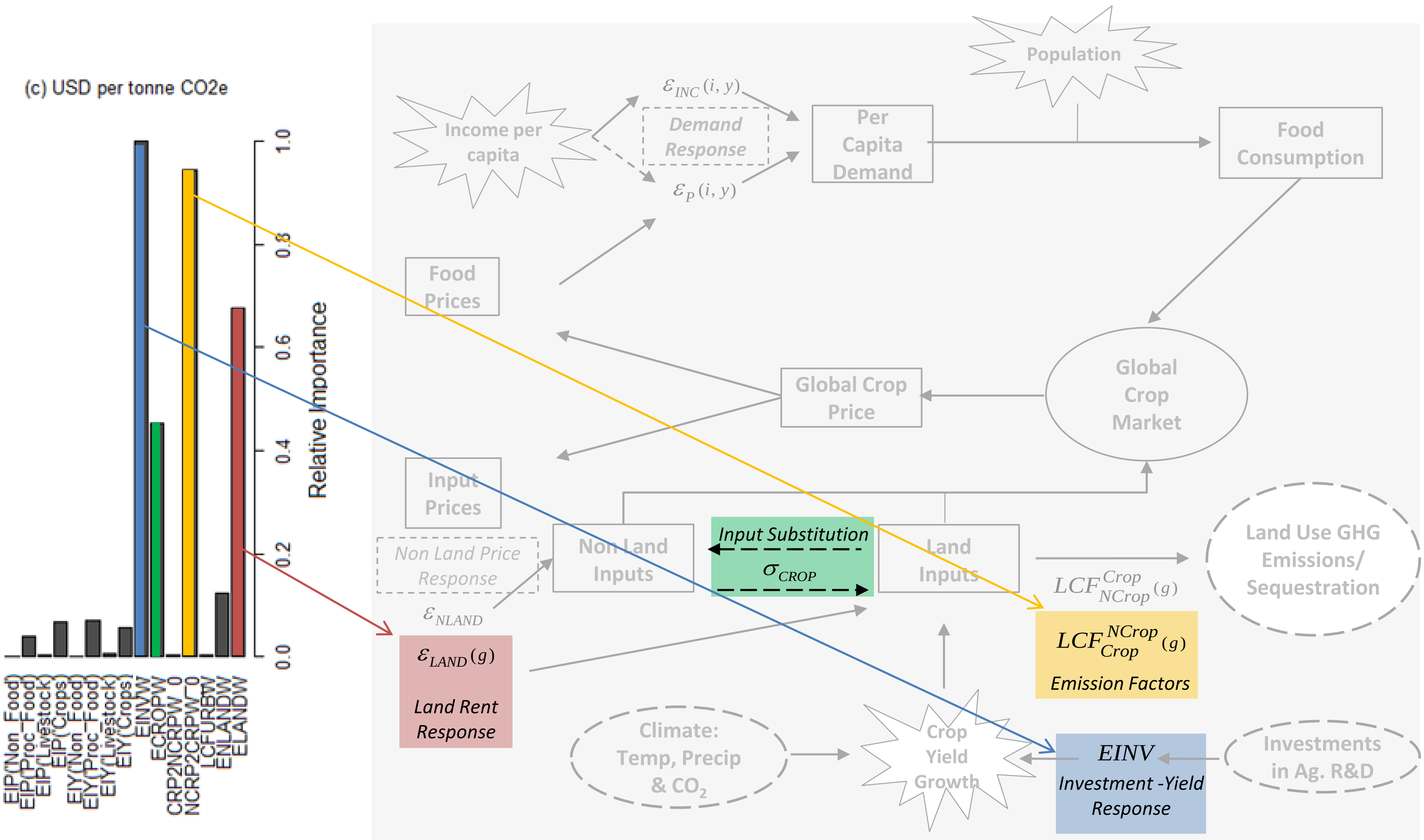
Cost of achieving mitigation through adaptation

All Regions Adapt: $16.7/tCO2e **LAmer and SS_Afr Only Adapt: $36.2/tCO2e**



Lobell, Baldos & Hertel, ERL (2013)

Which Parameters Drive these Results?
Morris Method of Sensitivity Analysis



Conclusions (1)

- By spending $225billion on global adaptation research between 2006 and 2050, 61Mha of cropland conversion could be avoided, thereby reducing GHG emissions by 15Gt for an avg *mitigation cost of $15/t CO2e*

- This is comparable to the cost of other mitigation programs, yet these *benefits come in addition to* the direct benefits from successful adaptation

Conclusions (2)

- Adaptation benefits: lower food prices *reduce global malnutrition by 17 million persons*, relative to baseline

- *Focusing on developing country regions alone* generates *far fewer co-benefits*; indeed emissions may even rise due low yields, low emissions efficiencies and high land supply response (Jevons' paradox); yet these are the very regions most likely affected.

Limitations and Extensions

- *SIMPLE is simple*: insufficient spatial and commodity resolution to satisfy needs of IAM community
- An important conceptual limitation has to do with the absence of rainfed-irrigation distinction. We expect this to lead us to *underestimate the mitigation benefits of adaptation*
- Refer to Taheripour, Hertel and Liu (2013) analysis of land use and biofuels expansion (climate shock has similar effects on land use)
- Constraining expansion of key irrigated areas due to water availability causes greater expansion in rainfed areas where:
  - Lower yields, so require more area expansion for given demand
  - More carbon/hectare means greater GHG releases upon conversion of additional cropland
- In the case of US biofuels shock, this amounted to *a 25% increase 25%* in grams of carbon/MJ of biofuel capacity