The Challenges of Sustainably Feeding a Growing Planet

By Thomas W. Hertel
In collaboration with Uris L.C. Baldos
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Contributed paper prepared for presentation at the 59th AARES Annual Conference, Rotorua, New Zealand, February 10-13, 2015

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[1] Plenary address to the 59th annual meeting of the Australian Agricultural and Resource Economics Society, Rotorua, Feburary 11, 2015

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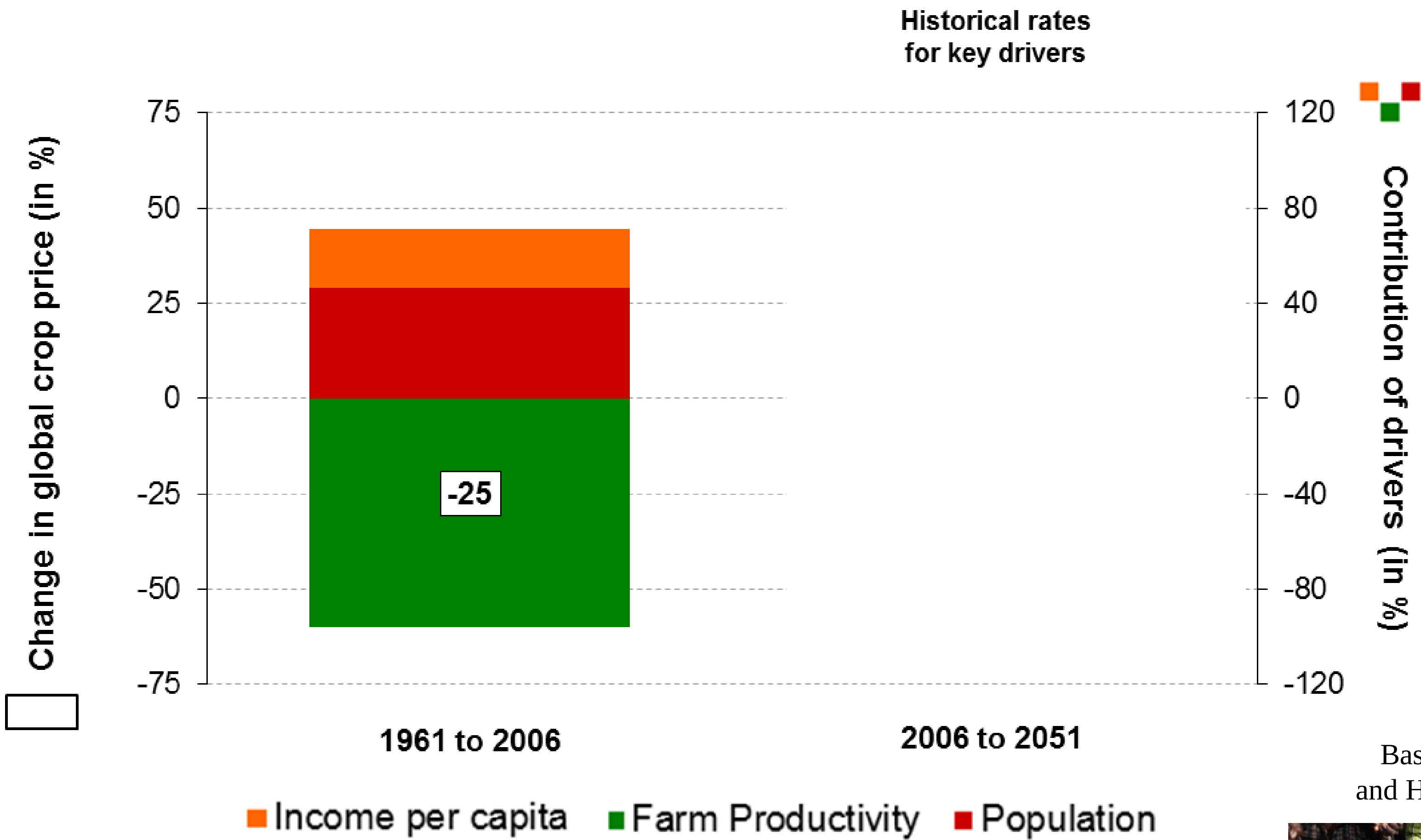
Overview of the talk

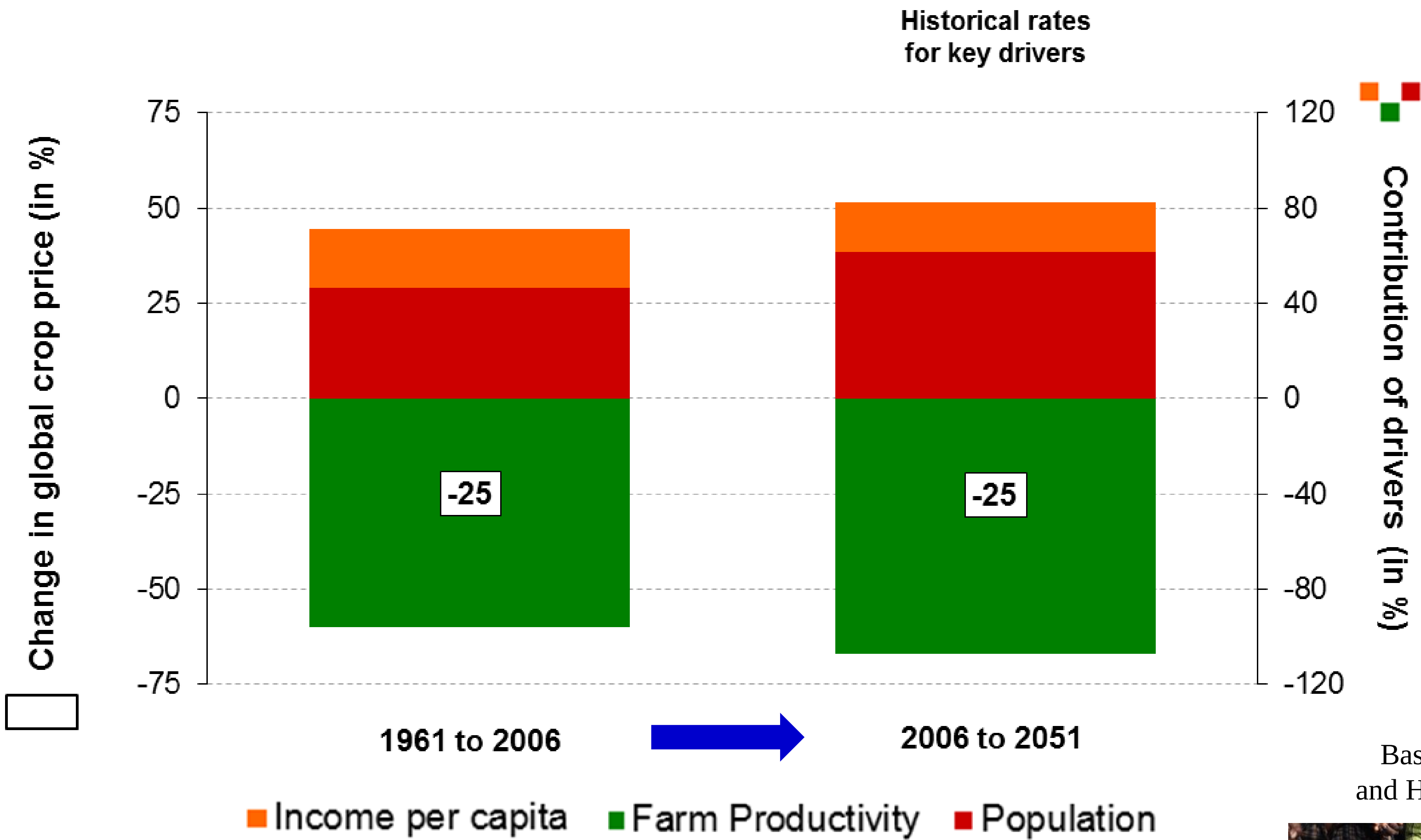
- **Demand-side drivers:**
  - **Changing relative importance of pop and income**
  - **Energy prices are the wildcard**
- **Supply-side:**
  - **Technological progress is key to food security**
  - **Reconciling slowing yields and rising TFP**
  - **Climate impacts and implications for food security**
- **Emerging issues:**
  - **Urbanization**
  - **Water scarcity**
  - **Food waste/loss as new sources of supply**
  - **Climate regulation**
- **How does it all add up?**

Historical analysis of global crop prices: 1961-2006
SIMPLE model, based on past trends of key drivers



Based on Baldos
and Hertel (2014a)

Naïve projections of global crop price to 2050: SIMPLE model, based on past trends of key drivers

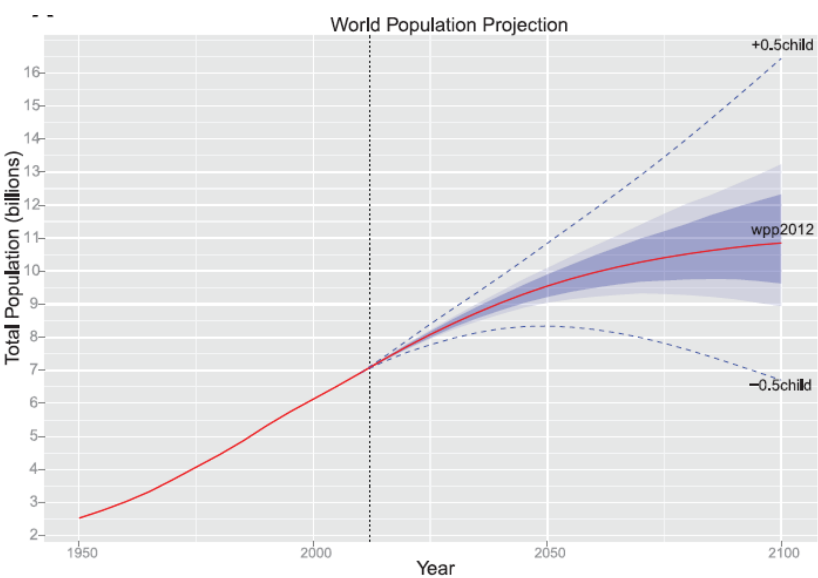


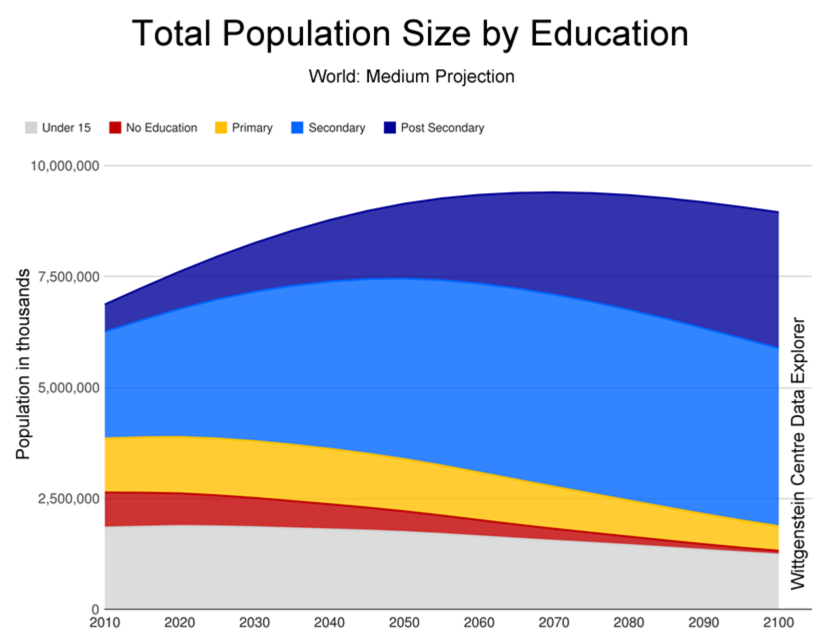
Based on Baldos and Hertel (2014a)

Future replicates past!! **Population** remains a dominant driver of food demand in naïve forecast

Global population in 2100: 9 or 11 billion?

- **UN: population stabilization unlikely this century**
- **IIASA: female education will lead to pop peak in 2070**

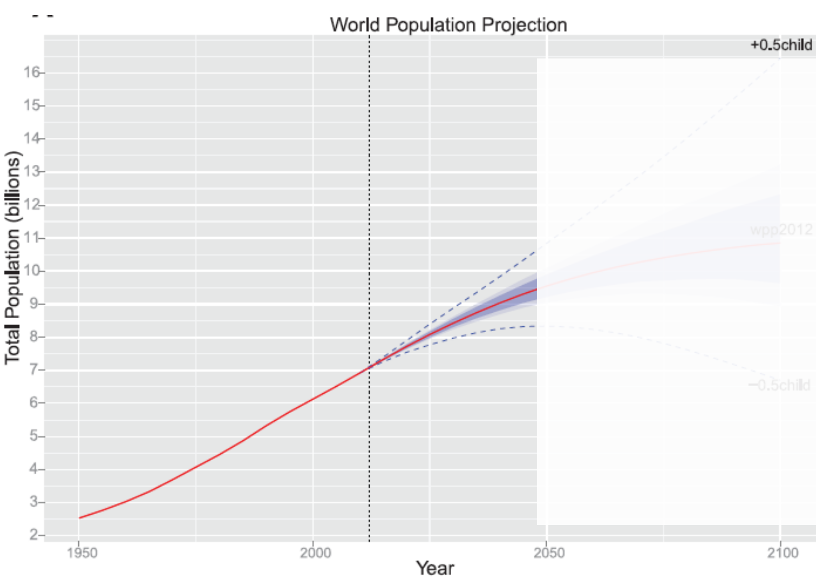


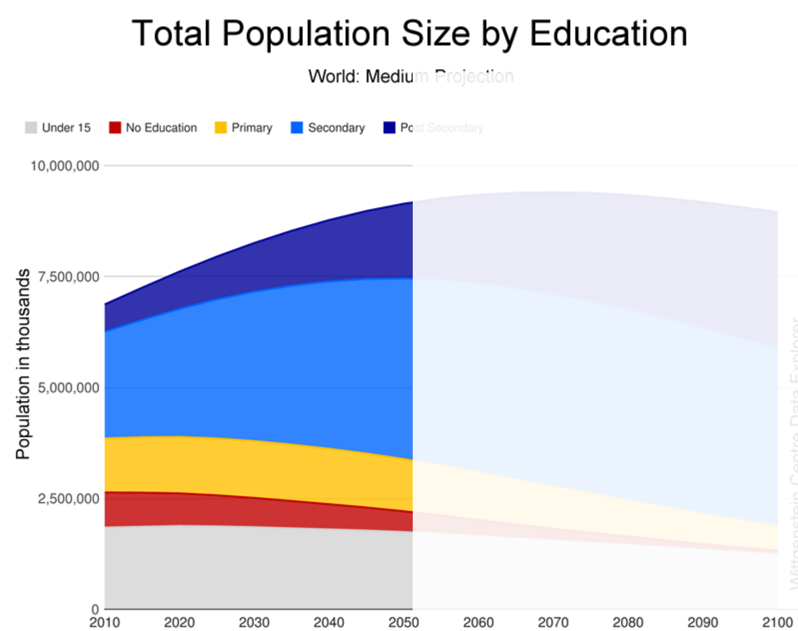


Sources: UN – Gerland et al. 2014
IIASA – Lutz and Samir, 2014

Fortunately for us, much less uncertainty/ disagreement about 2050

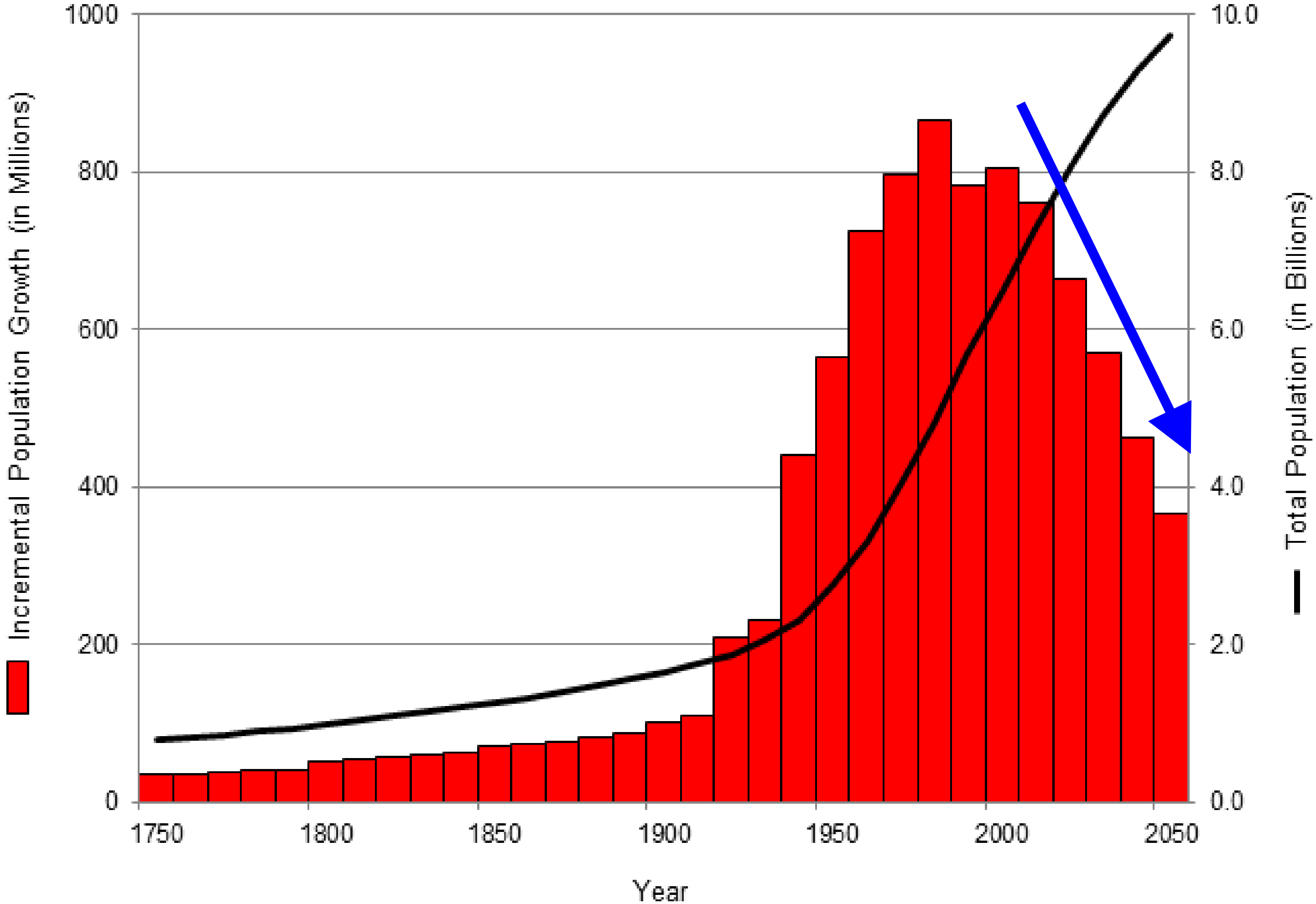
- UN: 2050 population will be 9.6bill
- IIASA: 2050 population of 9.3bill





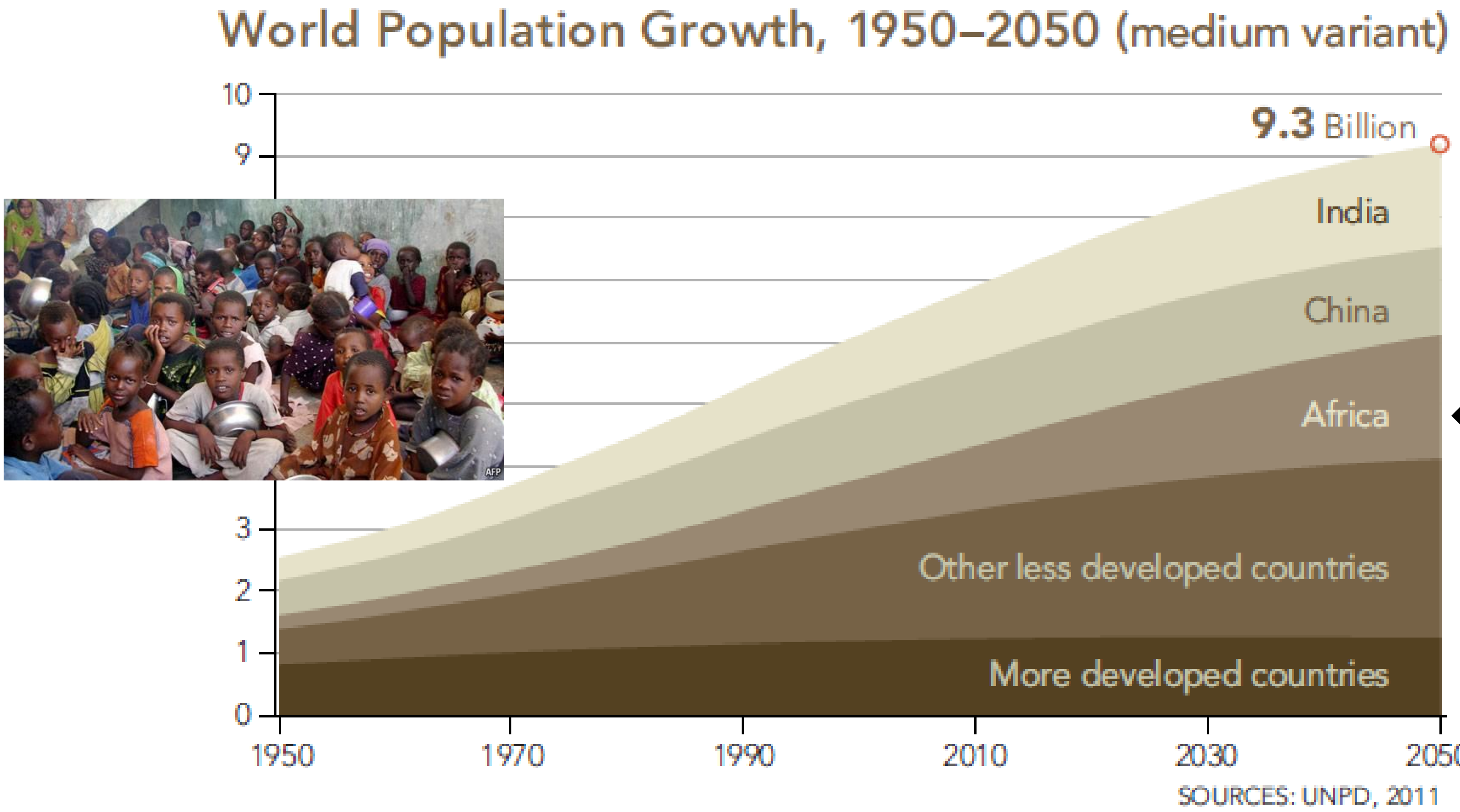
Sources: UN – Gerland et al. 2014
IIASA – Lutz and Samir, 2014

With slower global growth rate, the absolute decadal increment is shrinking



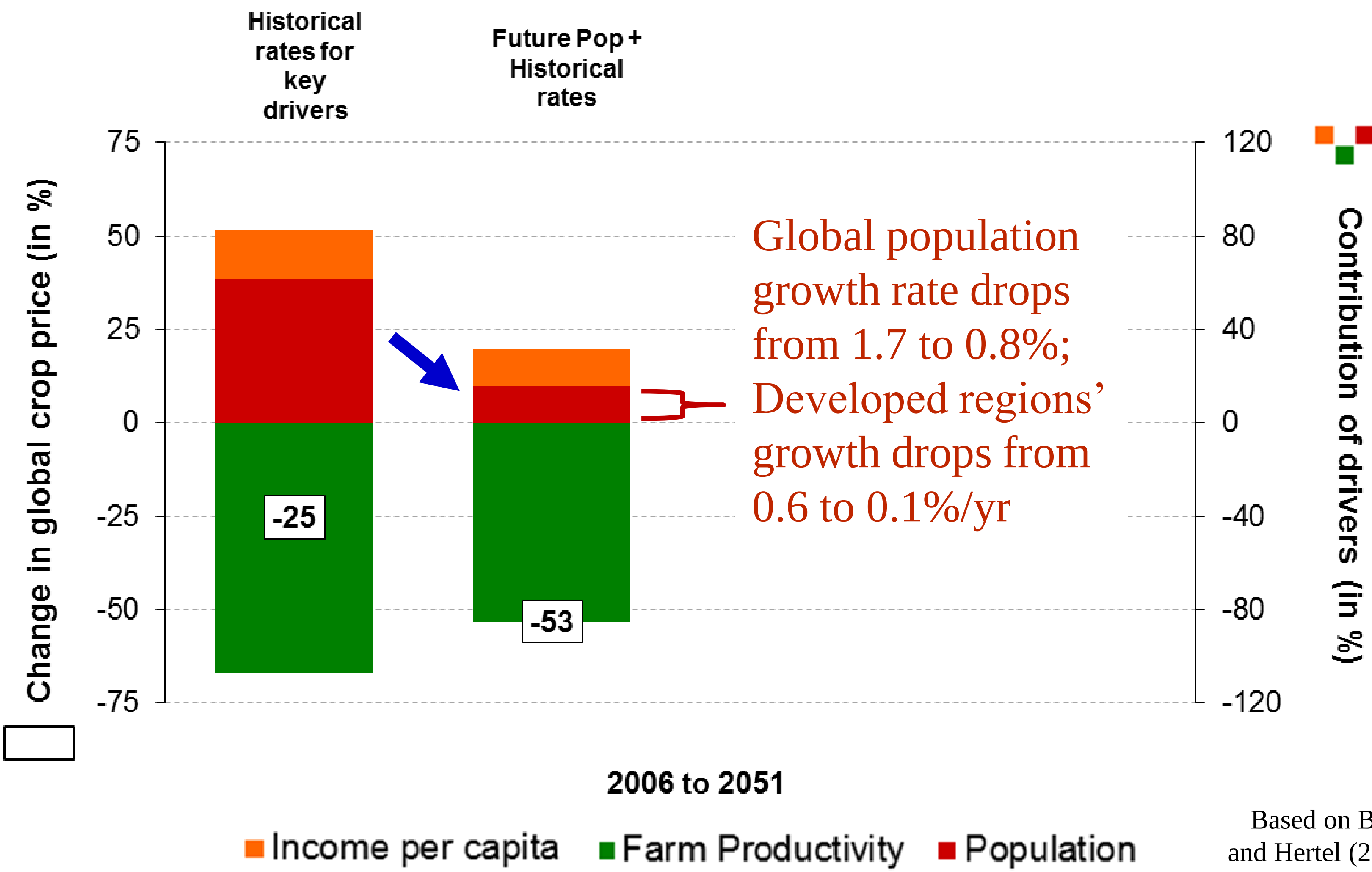
Annual increments to global population (10-year average), 1750-2050: Source: UNPD, 2000, 2011

Population growth is *most rapid* in Africa:
where capita food consumption is more modest



Extracted from Leslie Roberts, "9 Billion?", Science vol. 333, 29 July, 2011.

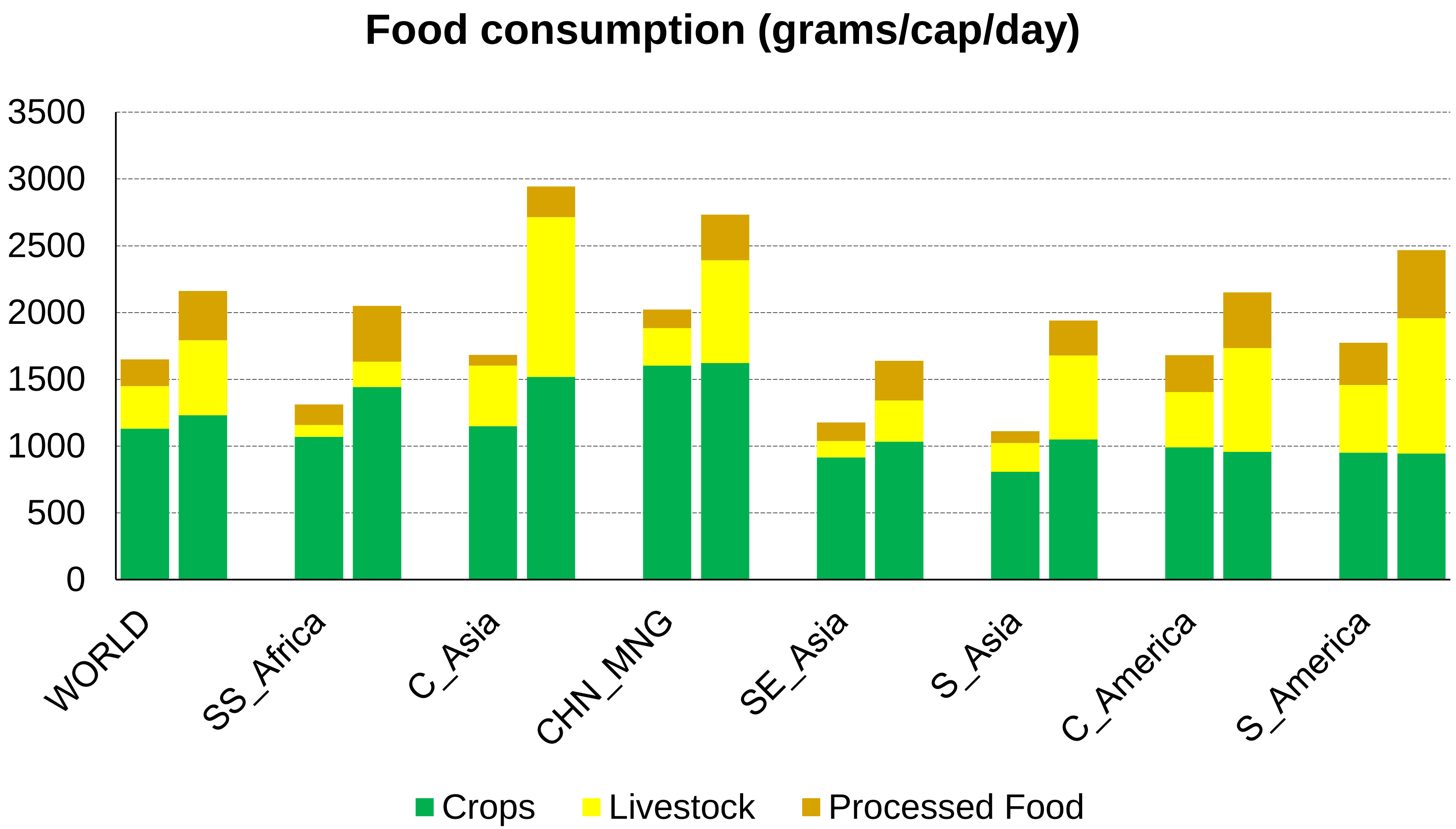
When we impose future population growth rates, projected change in global crop prices falls sharply…



Based on Baldos and Hertel (2014a)

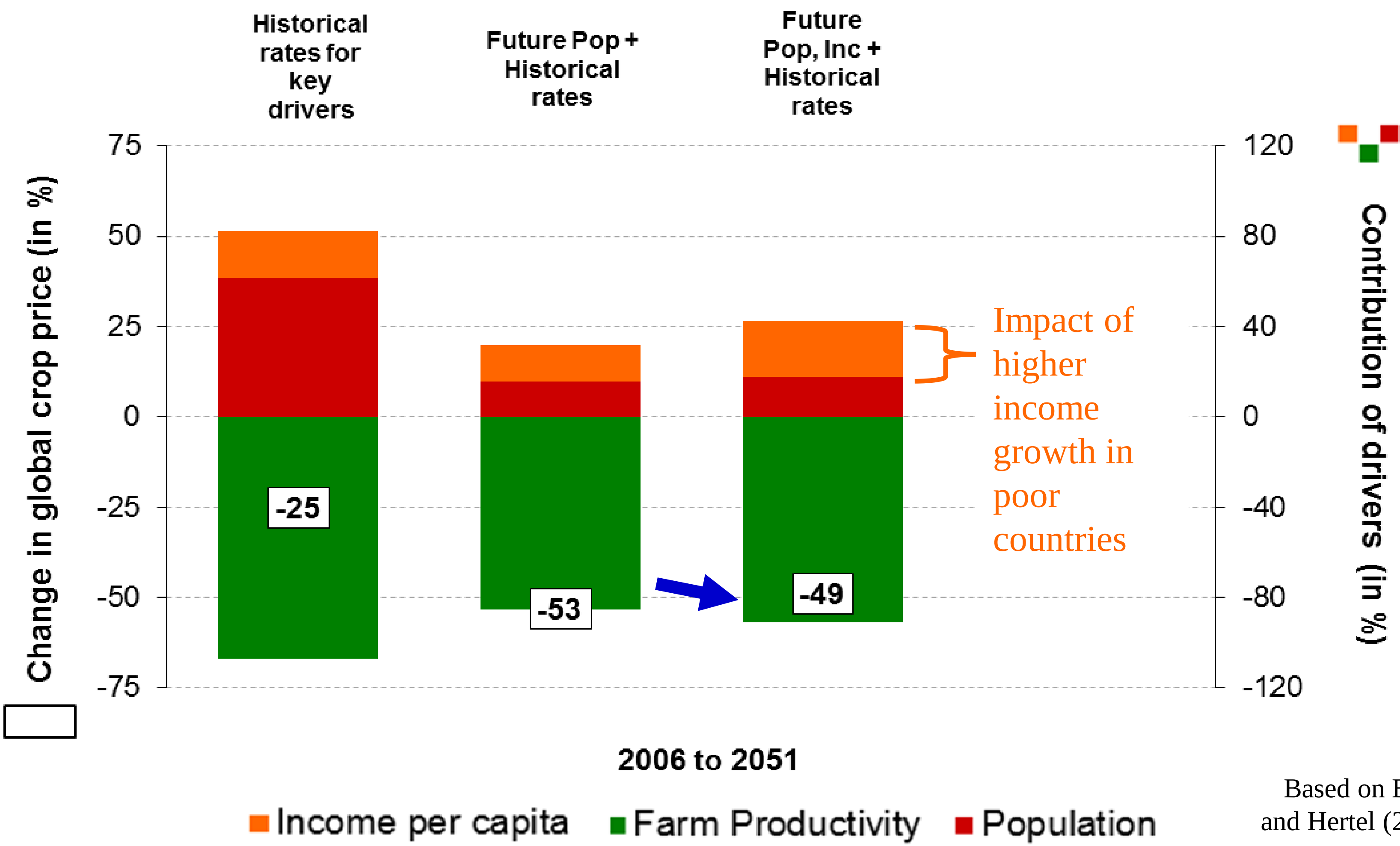
Relative contribution of population drops sharply by 2050

But income growth will affect food consumption : 2006 vs. 2050



Source: Baldos and Hertel (2014b)

More rapid growth in developing economies translates into larger impact of income growth on demand



Based on Baldos and Hertel (2014a)

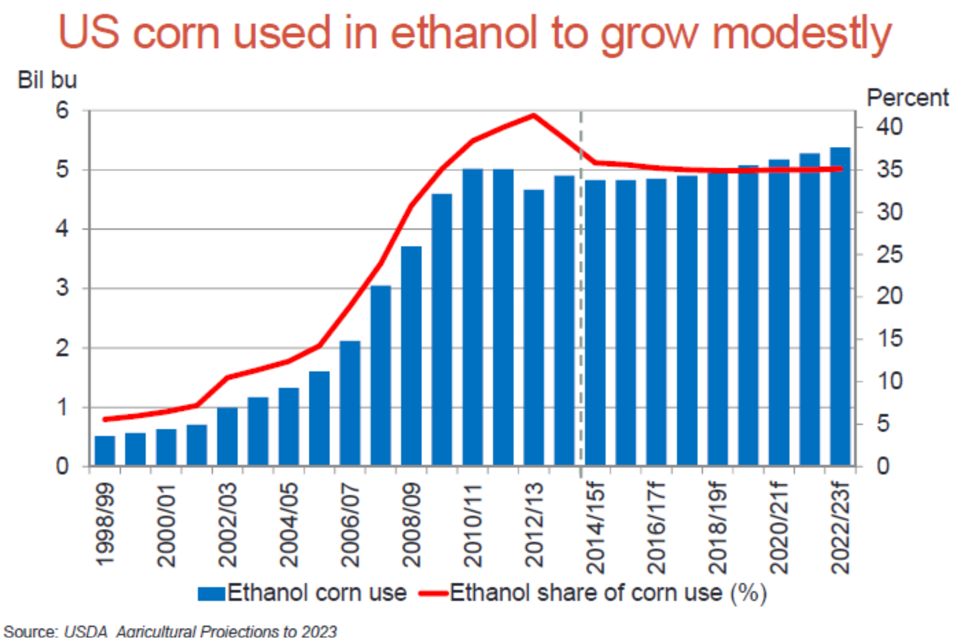
For the first time, income dominates population as a driver of agricultural demand

Overview of the talk

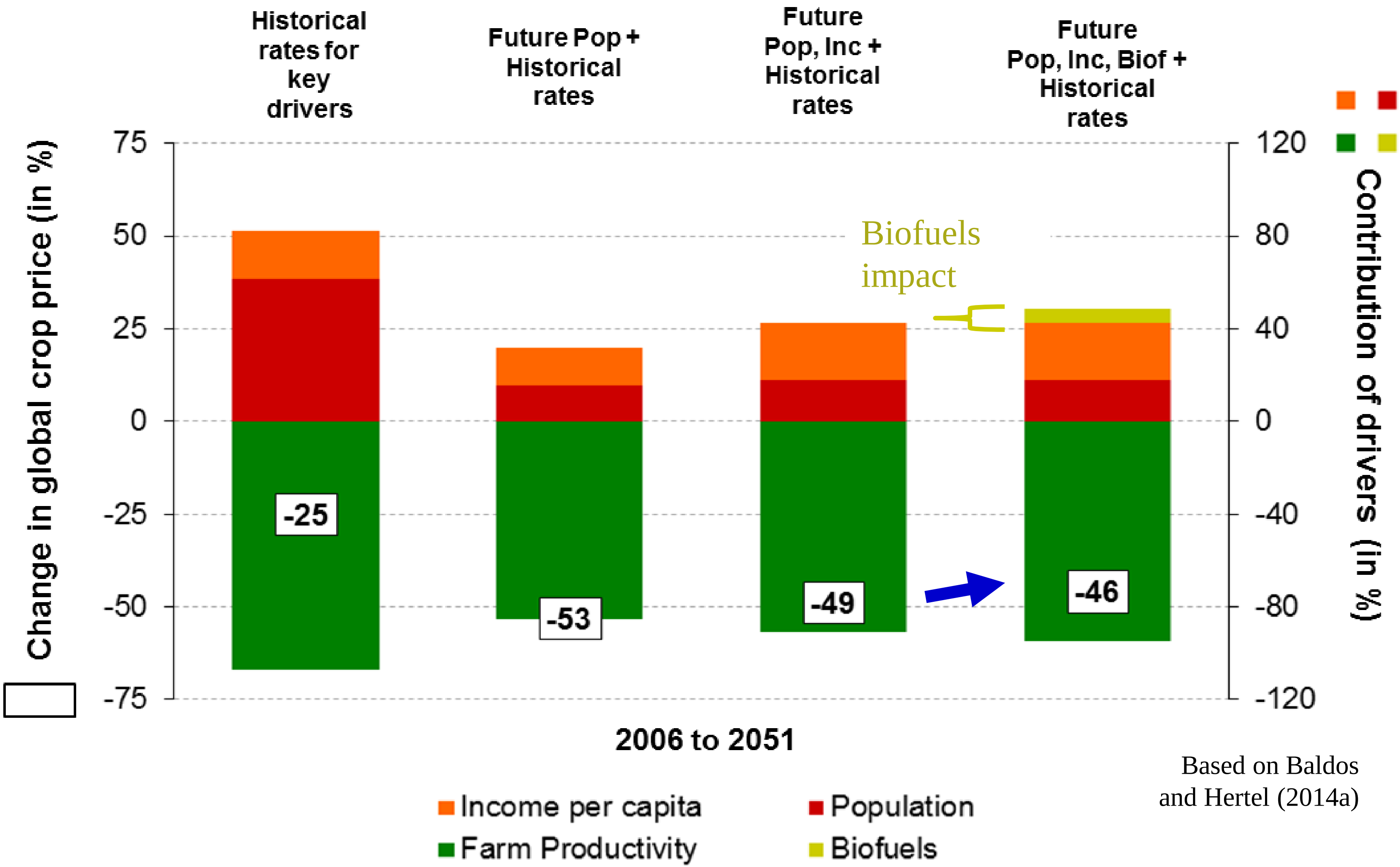
- **Demand-side drivers:**
  - Changing relative importance of pop and income
  - **Energy prices are the wildcard**
- Supply-side:
  - Technological progress is key to food security
  - Slowing yields and rising TFP
  - Climate impacts and implications for food security
- Emerging issues:
  - Urbanization
  - Water scarcity
  - Food waste/loss as new source of supplies
  - Climate regulation
- How does it all add up?

Low oil prices and environmental concerns have curbed growth in biofuels; lowered cost of intensification

- Biofuel subsidies and mandates gradually being rolled back
- Low oil and gas prices lessen economic incentive; lower cost of intensification of agriculture
- Further biofuels growth looks less likely – unless oil prices rise or 2G biofuels become part of climate policy



Most of biofuel growth from 2006 has already been felt



Based on Baldos and Hertel (2014a)

… this is the IEA 'Current Policies' scenario

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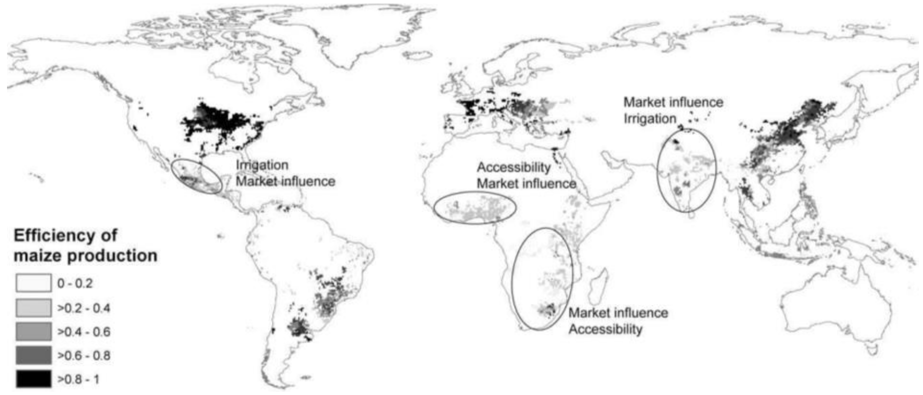
Technological progress is key to food security, but there are divergent views… *Pessimists focus on slowing crop yield growth*

- **Yield growth has slowed in key breadbaskets has slowed to less than 0.5%/yr (Fischer et al.)**
  - ***Actual yield = yield gap ratio x potential yield***
- **Fischer et al. project slowing of *potential yield growth*:**
    - **Interception of photo-synthetic radiation by leaves**
    - **Radiation use efficiency**
    - **Harvest index**
  - **Biophysics limit first and third to 20% maximum increase**
  - **Radiation efficiency has more potential for improvement**
- **Potential yield growth *depends critically on R&D*:**
  - **Alston, Beddow and Pardey document slowdown in US R&D, mirrored in Japan and Europe (also Australia)**
  - **Also, funds increasingly diverted from farm-level research**
  - **Reluctance to embrace GMOs slowing potential yield gains**

Pessimists focus on slowing crop yield growth

- **Yields can also grow by closing the yield gaps**
- **Gaps are the result of a variety of factors:**
  - **Poor infrastructure/lack of market access**
  - **Absence of irrigation**
  - **Limited information about technology**
  - **Lack of credit**
- **These challenges will take time to address**



Darkened areas are more efficient – serve to “set the frontier”.
Circled areas are inefficient; primary source of production inefficiency labeled

Source: Neumann et al. (2010): frontier production function

Pessimists focus on slowing crop yield growth

- **Simple arithmetic means linear trending yields must result in slower growth rates as yield levels rise**
- **Plateaus evident for wheat and rice**

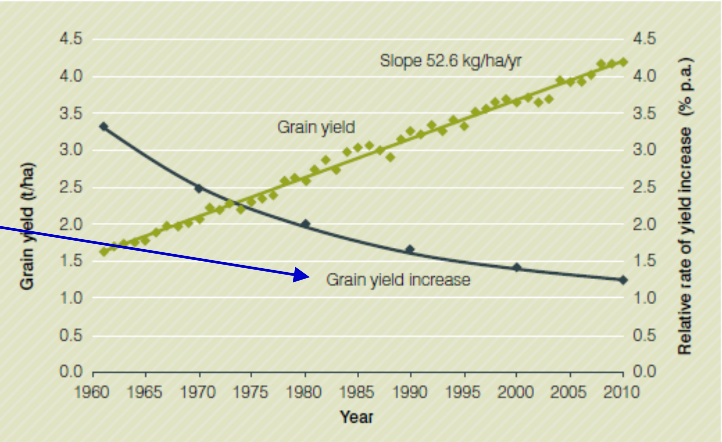
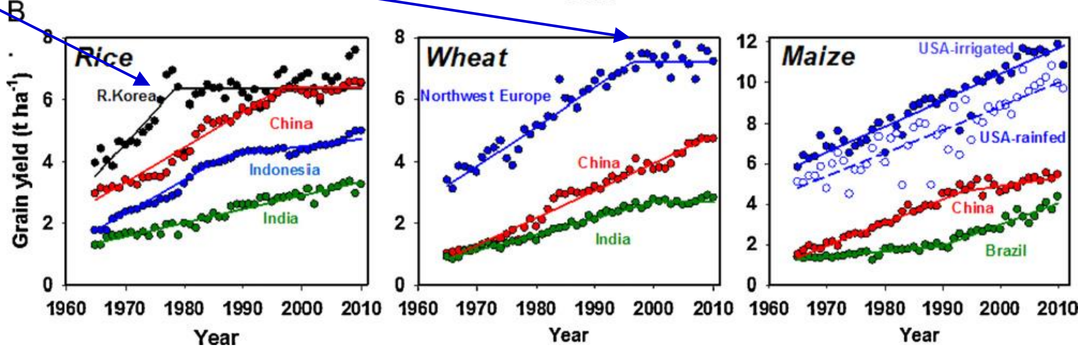


Figure 1.1 World yield of wheat, rice and maize (arithmetic average) and the annual relative rate of yield increase between 1960 and 2010. Standard error of slope = 0.7 kg/ha/yr, R_{sq} = 0.992. Source: FAOSTAT (2013)

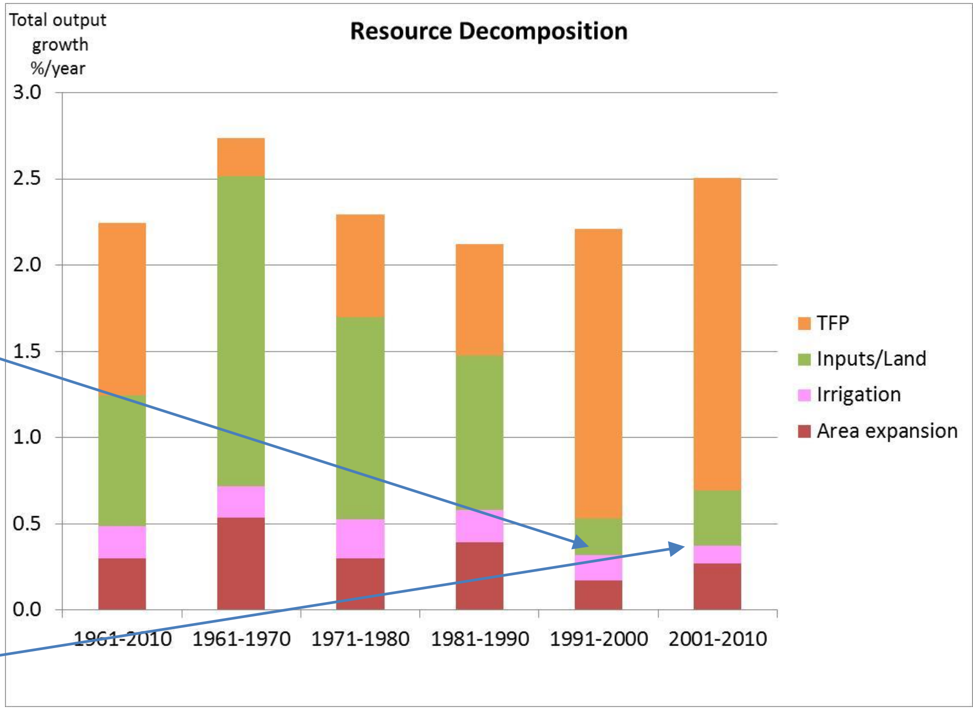


Sources: Fischer et al. 2014 and Grassini et al (2013)

Technological progress is key to food security, but there are divergent views… *Optimists tend focus on strong TFP growth*

- **Slowing yield growth has been due to economic factors:**
  - **declining prices from 1980 to 2005 reduced incentives**
  - **intensification fell to just 10% of global output growth in 90's**
- **This process can be reversed in the face of rising scarcity**

Annual growth rate by decade, global average

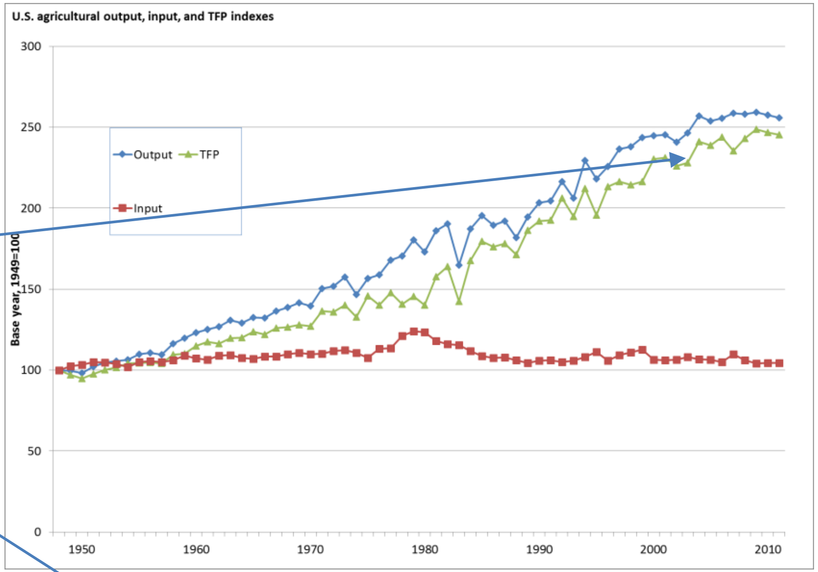


Source: Fuglie (2012)

Optimists tend to focus on strong TFP growth

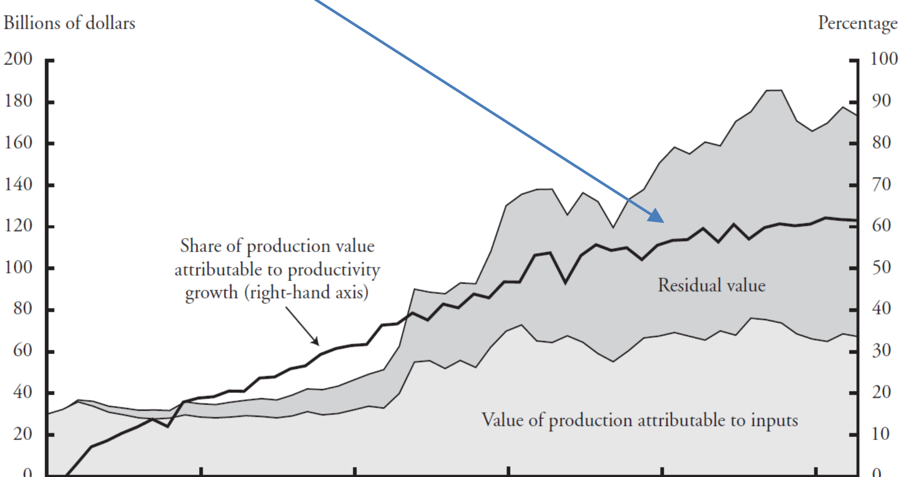
- **US output growth since 1960 almost entirely due to TFP/MFP growth**
- **Although we see a pronounced slow-down in TFP/MFP growth in the United States in past decade….**

Source: Economic Research Service, USDA.



Source: Alston et al., 2010

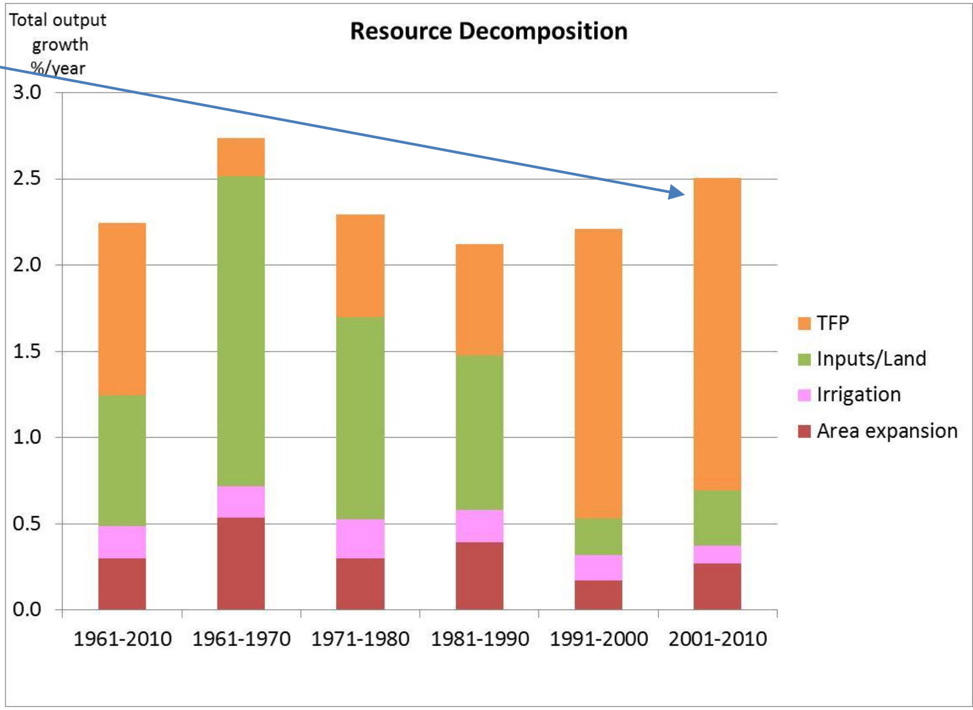
Figure 12-1 U.S. Agricultural Output Value Attributable to Productivity Growth, 1949–2002



Optimists tend focus on rising TFP growth

- But *global* TFP growth has risen to historic levels in 2000's
- Alston and Pardey (JEP, 2014) show that *global* land and labor productivity grew more rapidly over past two decades than over 1961-1990 period (driven heavily by China where continue to benefit from reforms)

Annual growth rate by decade, global average

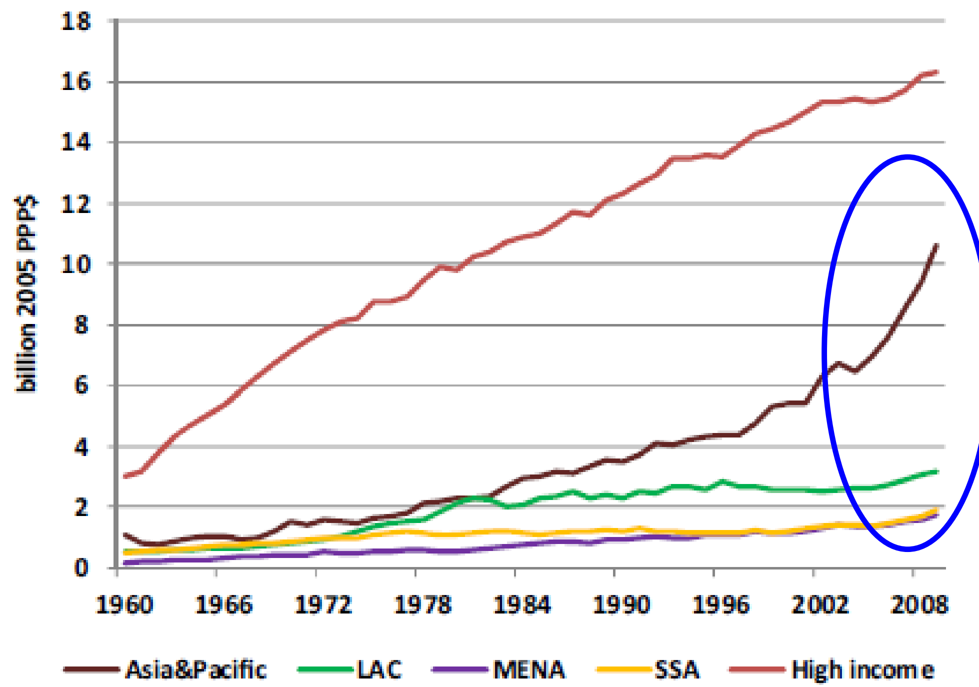


Source: Fuglie (2012)

And global public spending on R&D has responded strongly to the food crisis

- **China, India and Brazil lead the way**
- **CGIAR spending has grown sharply**
- **Private agr R&D is also up strongly (43%) from 2000-2008 (Fuglie et al.,)**
- **If sustained, should see payoffs over coming 5 decades (Alston et al., 2010)**

Public spending on agricultural R&D

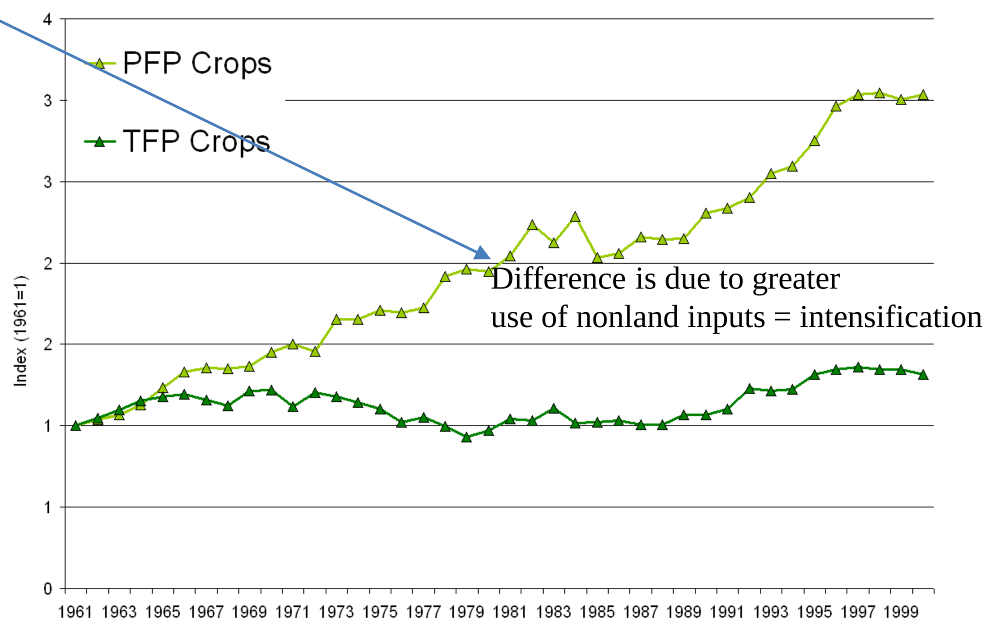


Source: Pardey, Alston and Chan-Kang, 2013

There is room for reconciliation of the two schools of thought

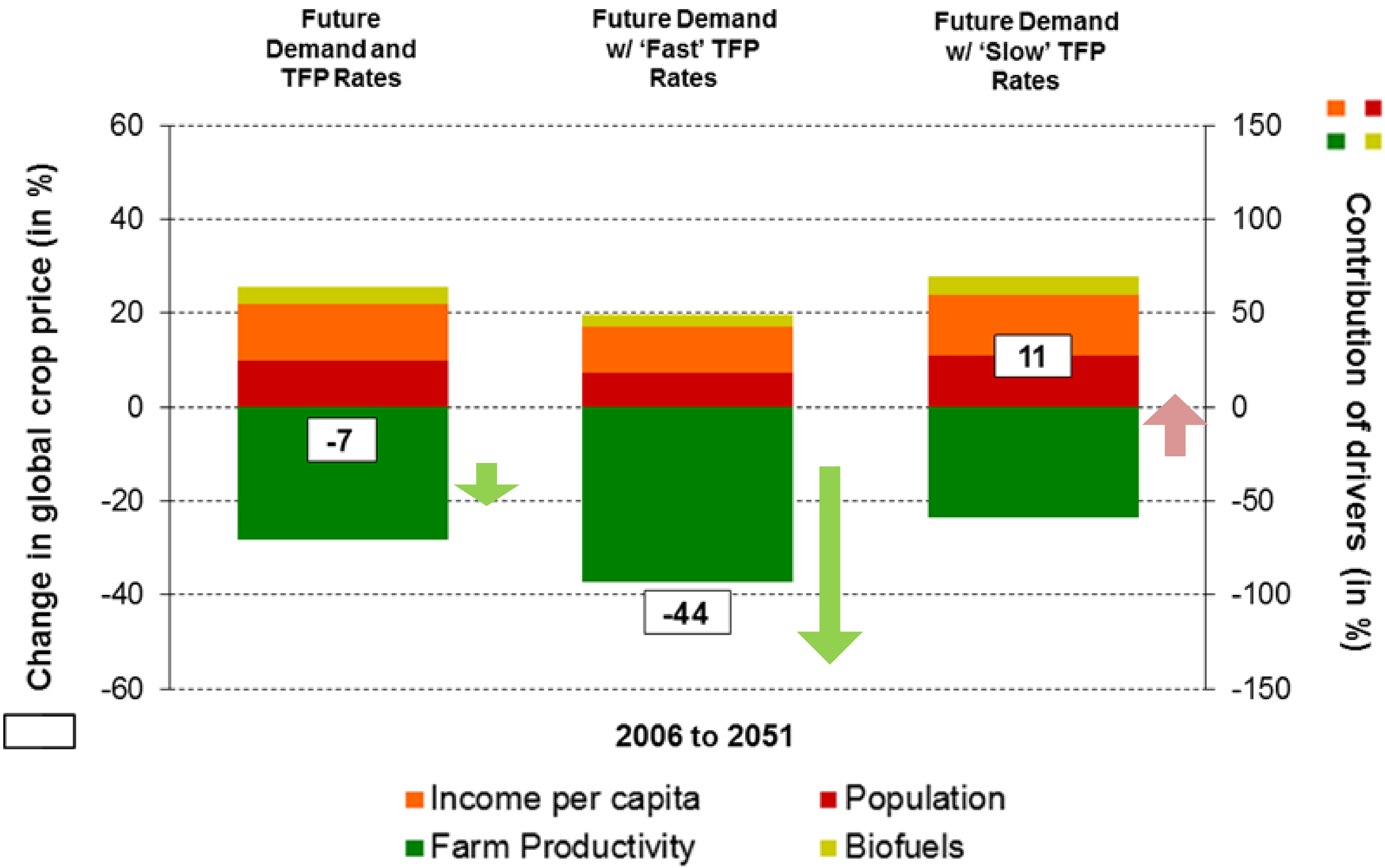
- **Divergence of TFP and yields arises due to intensification**
- **Divergence of staple grains and total agr TFP in India:**
  - **Nick Rada: agricultural TFP has been rising, even as staple grains yields have been falling**
  - **Due to productivity gains in high value crops**
- **Also: yield growth may be slowing, but so too is population; required growth is just half 1961-2007 period (Bruinsma)**
- **Ultimately, yields and TFP play different roles in the food system:**
  - **Yields = primary driver of land use, given TFP and aggregate demand**
  - **TFP drives prices, given input levels**

Indexes of TFP and Yields (PFP) for China Crops



Source: Ludena et al.

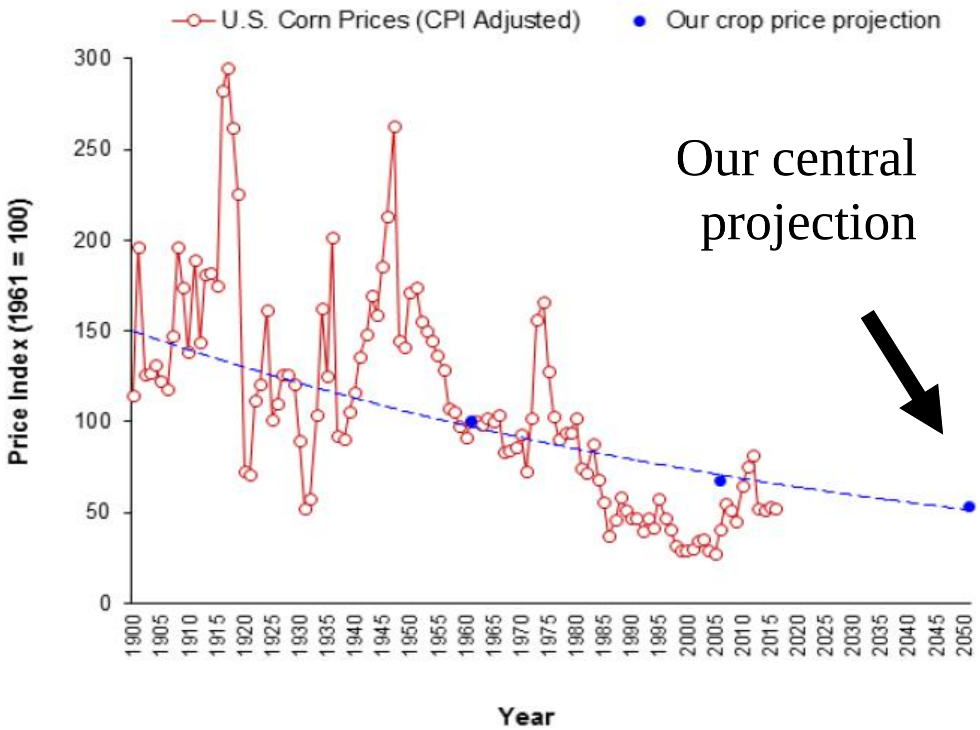
Productivity growth is critical for future outcome; slower growth could lead to food price rise – but baseline flat to declining



Ludena et al Global Crops TFP Growth	p.a.	Years
Baseline	0.94	2001-40
Slow Rates	0.70	2031-40
Fast Rates	1.30	2001-10

Source: Baldos and Hertel (2014a)

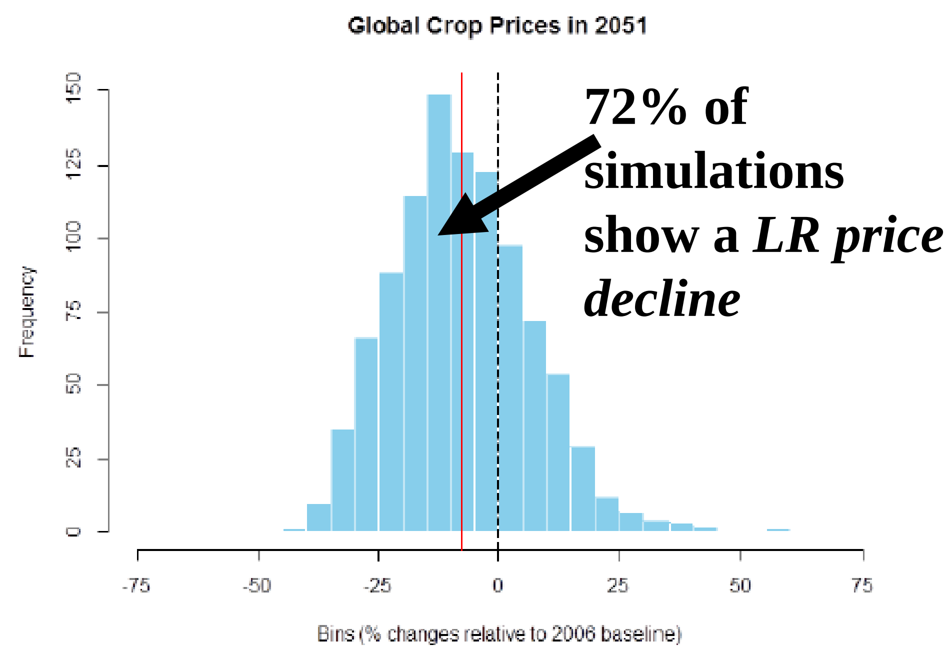
Based on projected growth rates in the core drivers of change: population, income and technology….



….we expect a resumption of the downward trend in long run crop prices

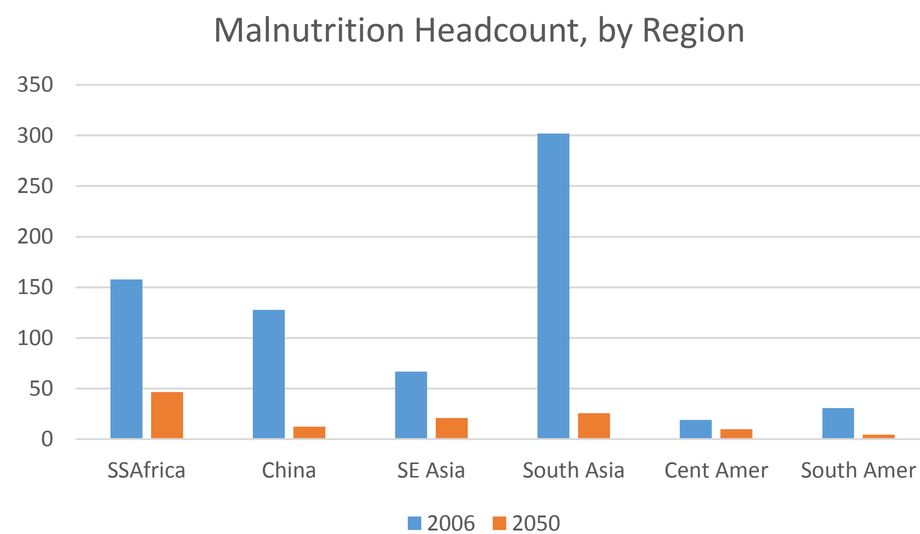
Factoring in uncertainty about *all* drivers and economic responses, we find that the majority of outcomes *point to a long run price decline*

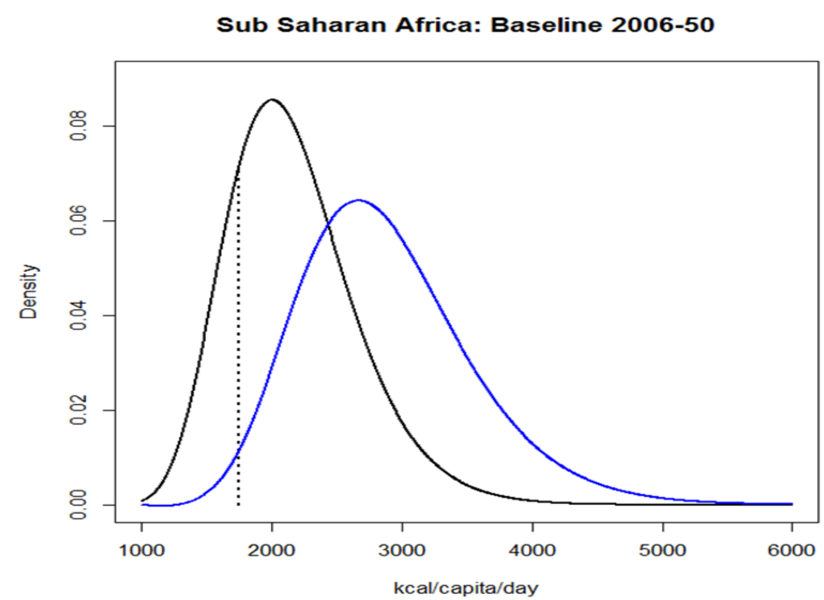
Monte Carlo Analysis: 1,000 model simulations sampling from distributions of drivers and responses



Implications for food security in 2050

- **Simulated with SIMPLE model**
  - **Validated over historical period (Baldos and Hertel, 2013, 2014)**
  - **15 regional markets are either:**
    - **Segmented (historical economy)**
    - **Integrated (future world?)**
  - **Baseline driven by:**
    - **Population and income growth**
    - **Productivity growth in crops, livestock and food processing**
  - **Analyze full distribution of caloric intake to predict malnutrition headcount and gap**
  - **Combination of TFP and income growth greatly reduces malnutrition in 2050**





Source: Baldos and Hertel (2014b)

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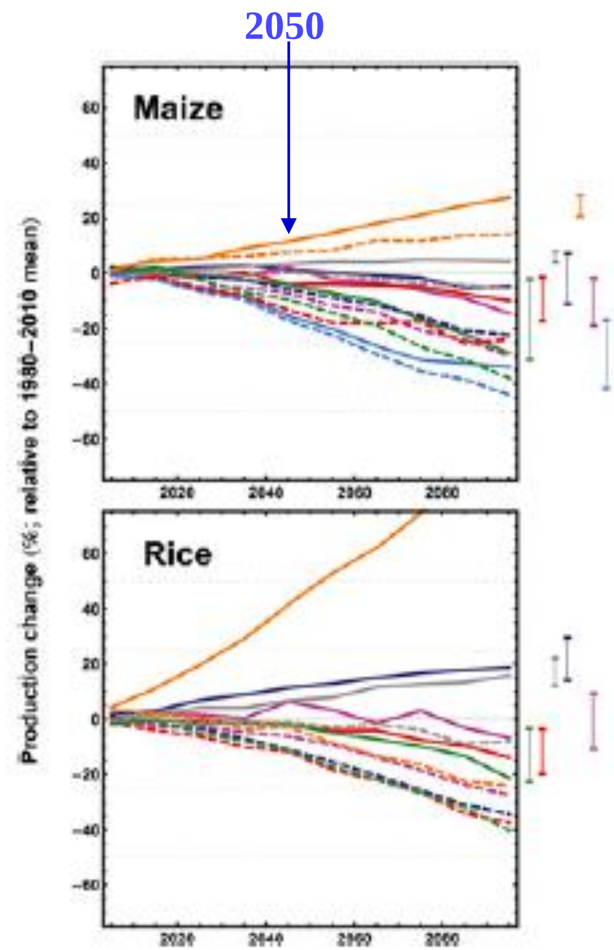
How will this be story be altered by climate change?

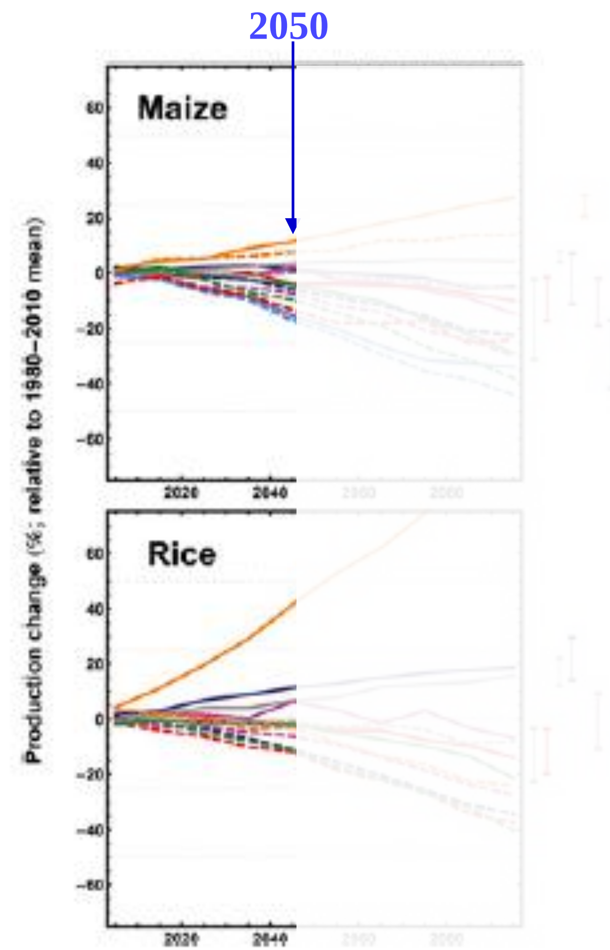
- **IPCC WGII states:**
  - **"median yield impacts from 0 to -2%/decade over rest of century"**
  - **"negative impacts of more than 5% are more likely than not after 2050"**



Source: Rosenzweig et al. 2013, PNAS; Results from 7 crop models (dashed lines omit CO2 effects)

But impacts at mid-century are more modest

- **IPCC WGII states:**
  - **“negative impacts on avg yields become likely in the 2030’s”**
  - **“median yield impacts from 0 to -2%/decade over rest of century”**

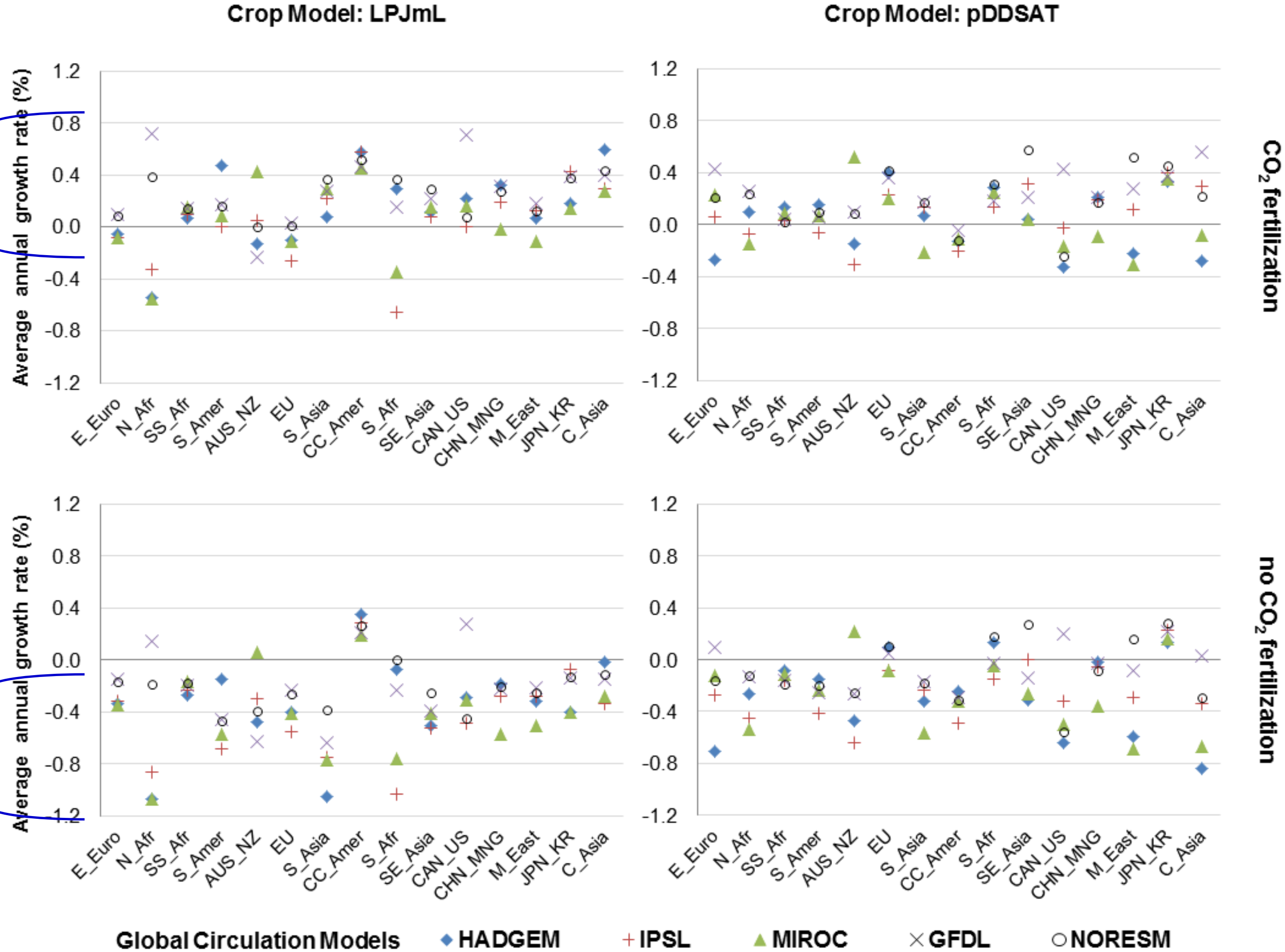


Source: Rosenzweig et al. 2013, PNAS; Results from 7 crop models (dashed lines omit CO2 effects)

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

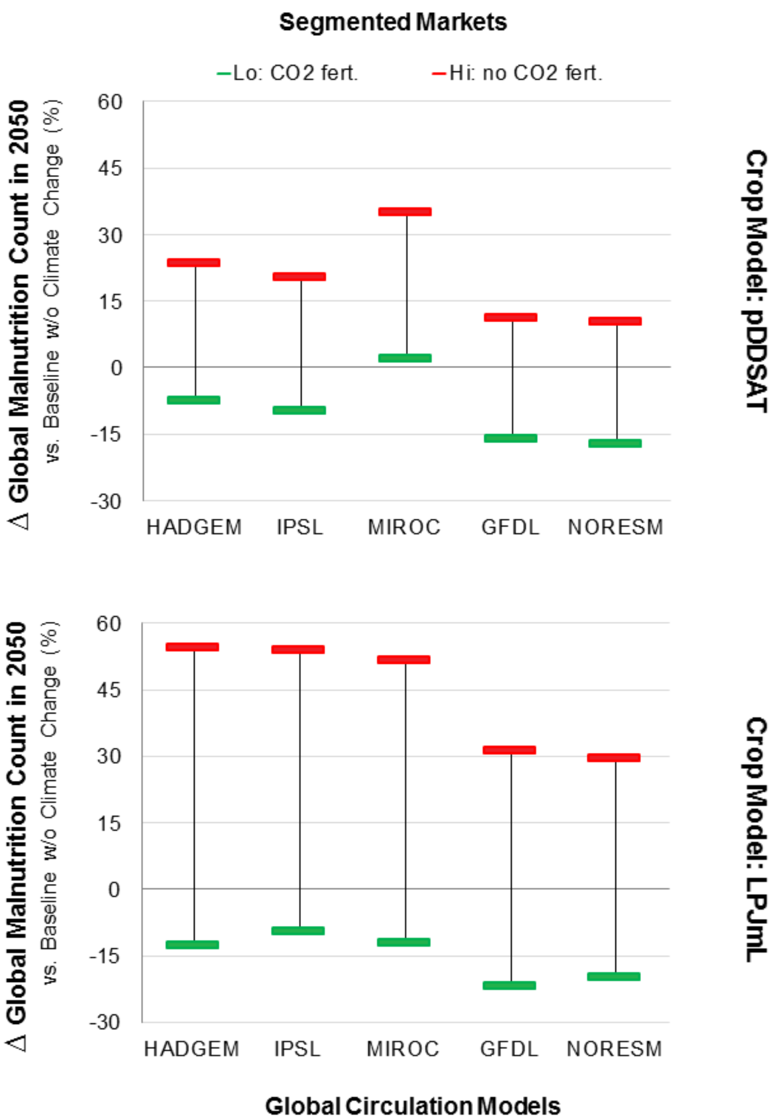
Global avg. crop impacts are ***positive under CO2 fert at mid-century*** mark

Temp and precip changes shift most impacts are ***negative in absence of CO2 fertilization***



Source: Baldos and Hertel (forthcoming)

Impact of climate change on global malnutrition in 2050

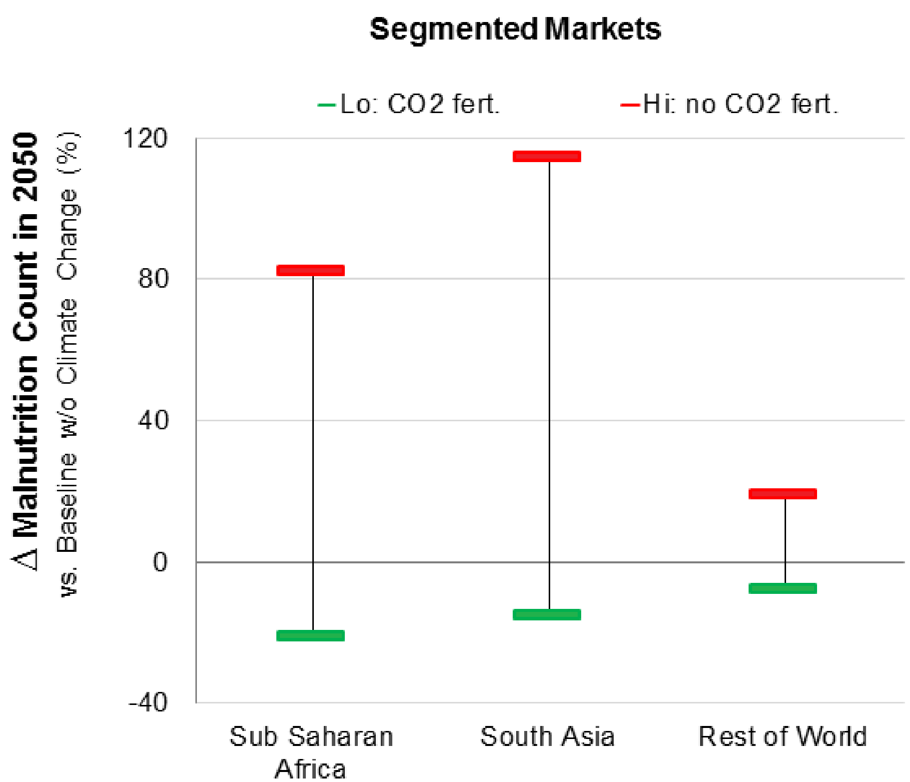


- Uncertainty inherited from both climate and crop models
- CC generally boosts global malnutrition in 2050 – possibly by as much as 50%, relative to baseline;
- Some model combos result in slight improvements in 2050, relative to baseline

Source: Baldos and Hertel (forthcoming)

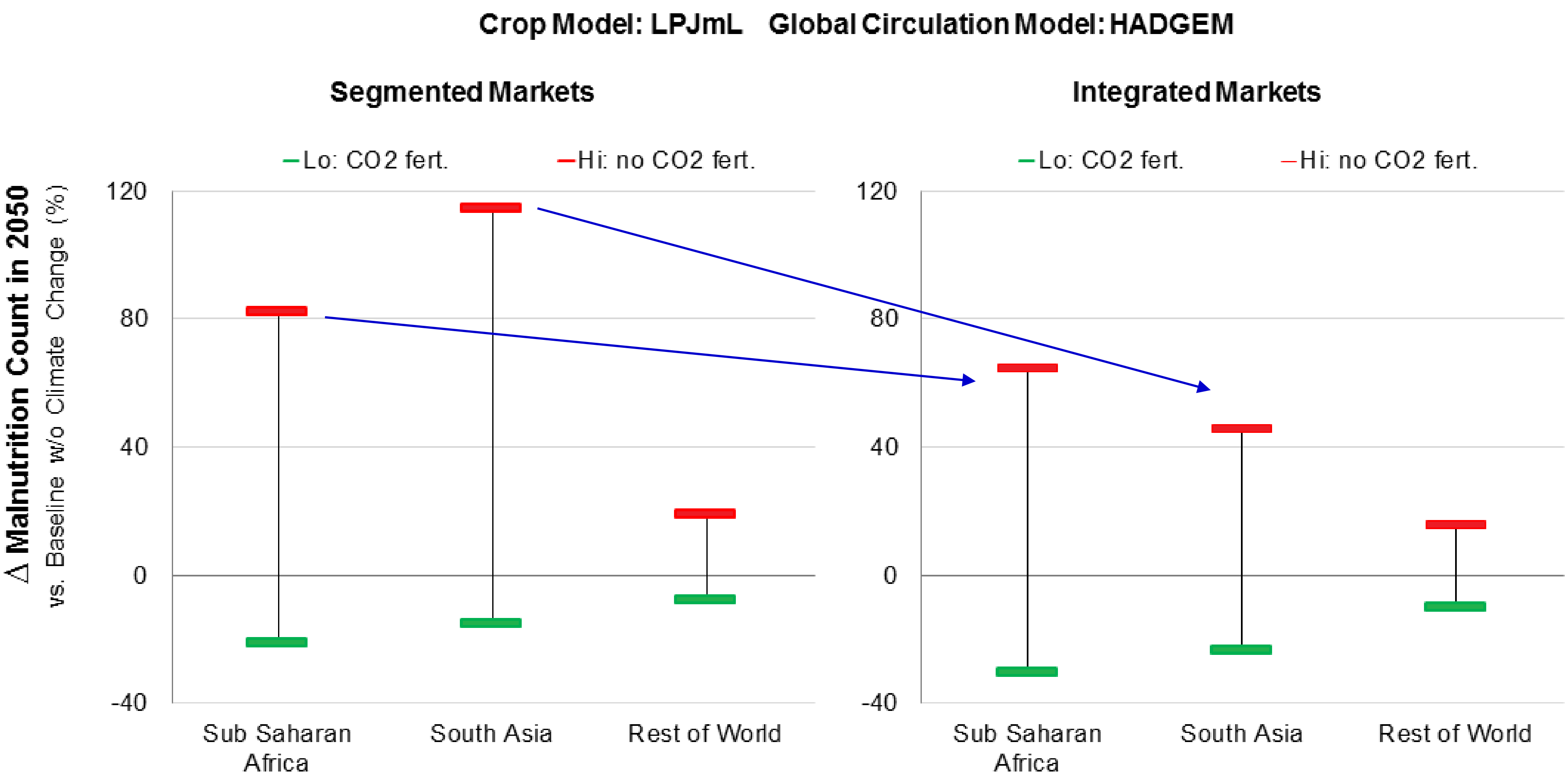
Impact of climate change on regional malnutrition in 2050: HADGEM/LPJmL combination

- **Greatest potential for adverse impacts are in South Asia (up to 120% rise in malnutrition, *relative to the 2050 baseline*)**
- **Sub Saharan Africa, maximum rise, *relative to 2050 baseline*, is 80%, while Rest of World small**
- **HADGEM/LPJmL only combination shown here**



Source: Baldos and Hertel (forthcoming)

Market integration moderates most severe nutritional impacts



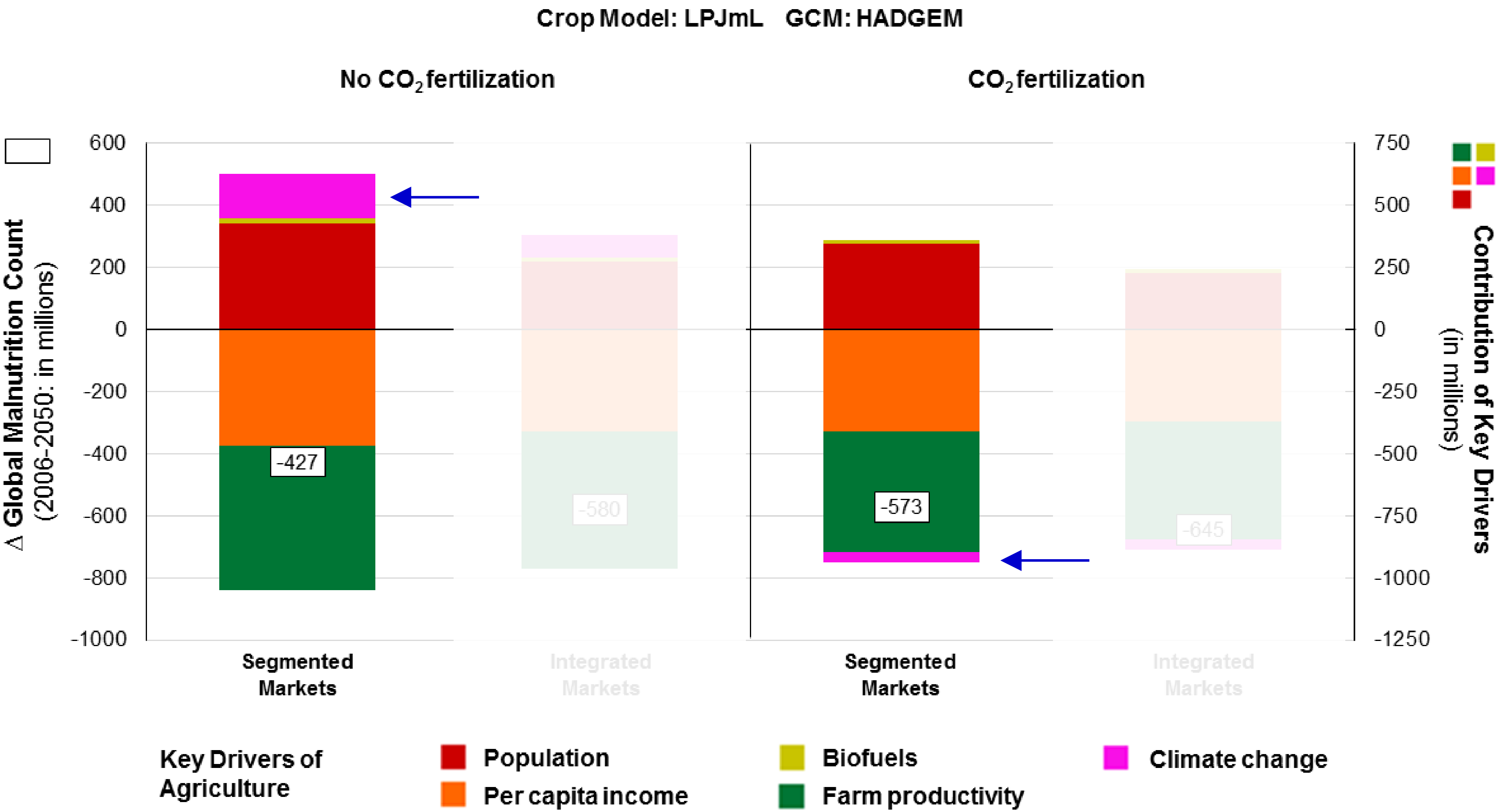
Source: Baldos and Hertel (forthcoming)

However, crop impact models do not reflect full extent of uncertainty

- **Most biophysical crop models were developed for other purposes – *not focused on impacts of extreme temps***
- **White et al. review 221 studies using 70 crop models to assess climate impacts and find *only a handful consider*:**
  - **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)**
- **As a consequence, IAMs likely *understate impact of climate change in the low income tropics***

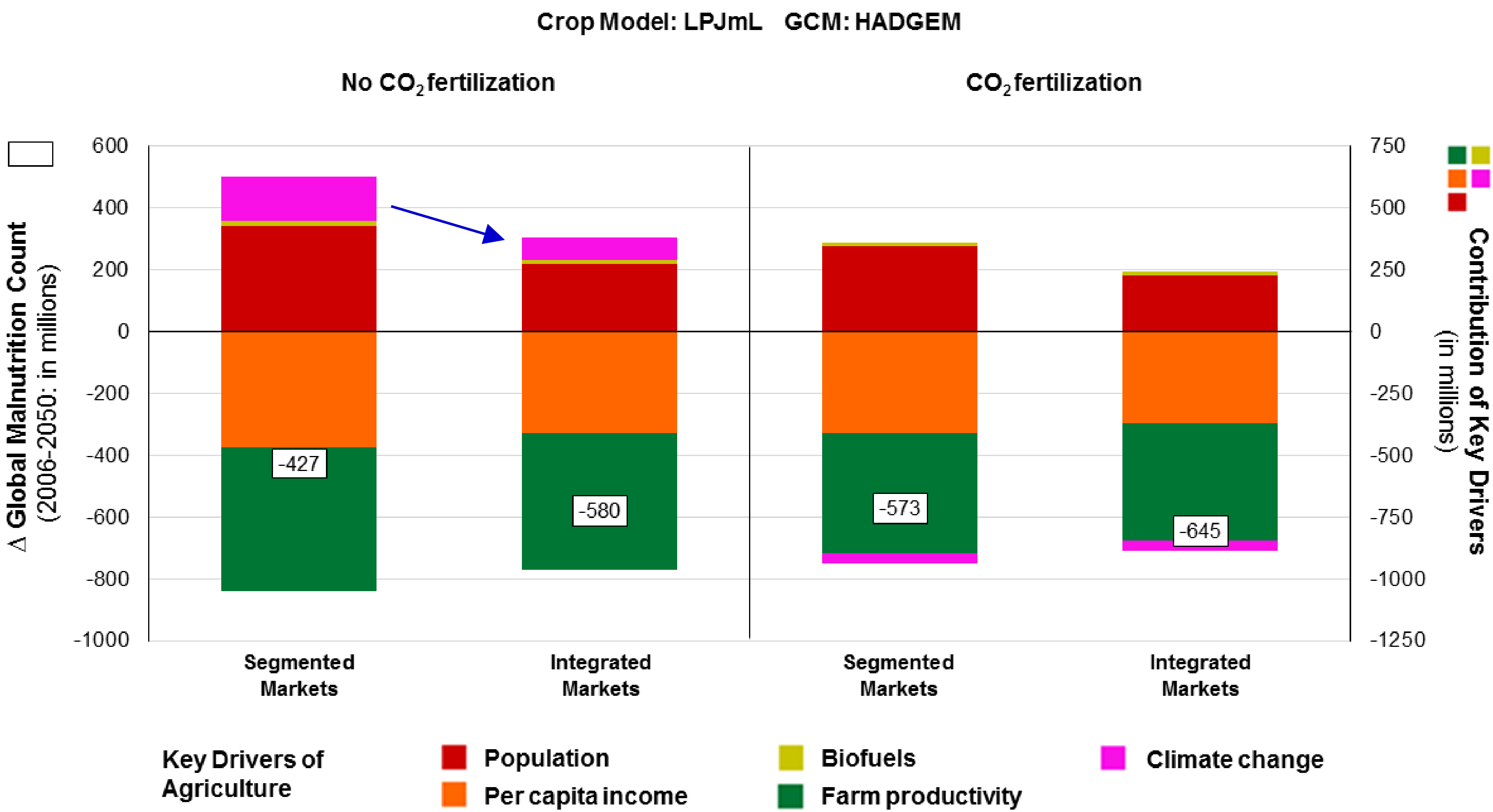
Source: Hertel and Lobell (2014)

Climate change in the context of other drivers of change



Source: Baldos and Hertel (forthcoming)

Main effect of market integration is to moderate malnutrition under worst case CC scenario



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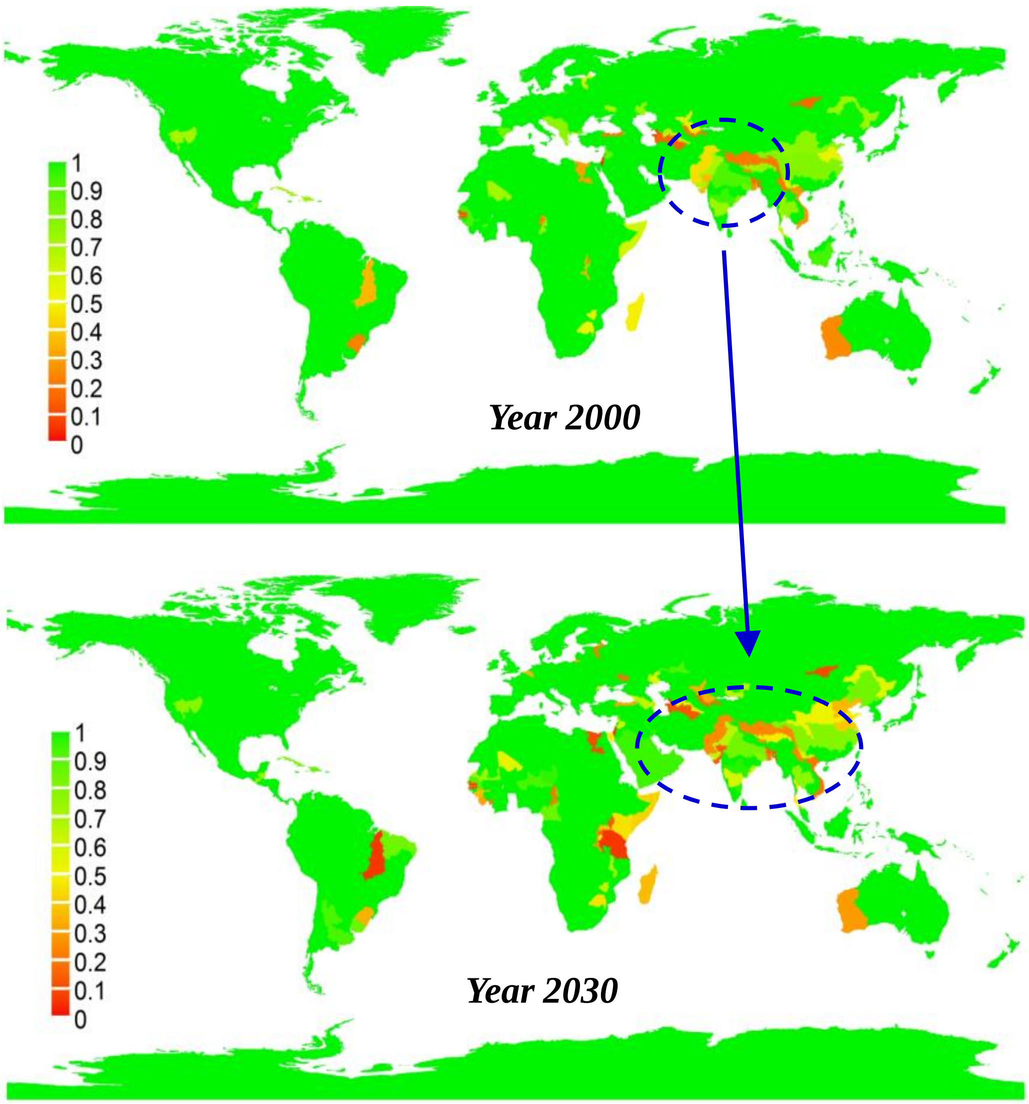
Future water scarcity will also shape food trade

Index of irrigation water availability

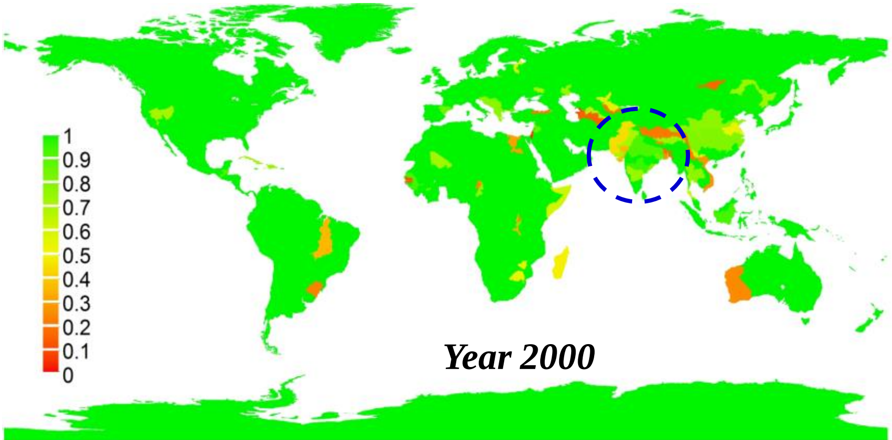


Source: Liu et al. (2013)

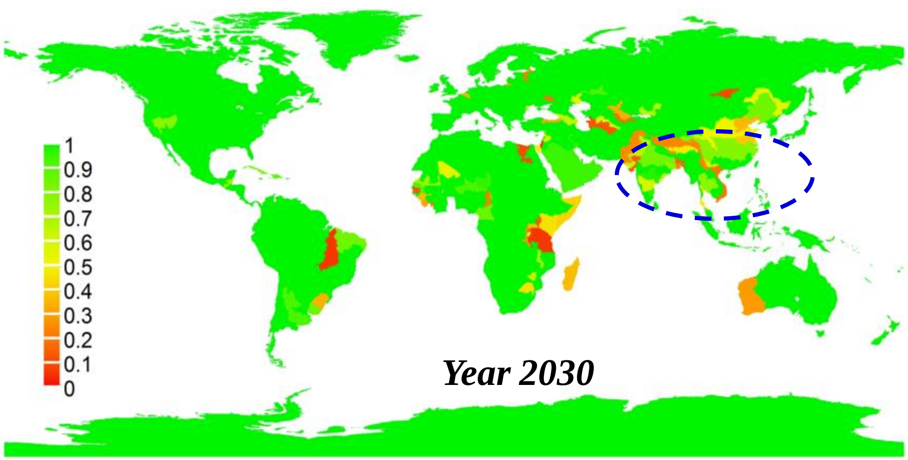
Increased scarcity of water for irrigation – particularly in South Asia and China

Future water scarcity will also shape food trade

Index of irrigation water availability



Increasing water scarcity alters the geography of food trade



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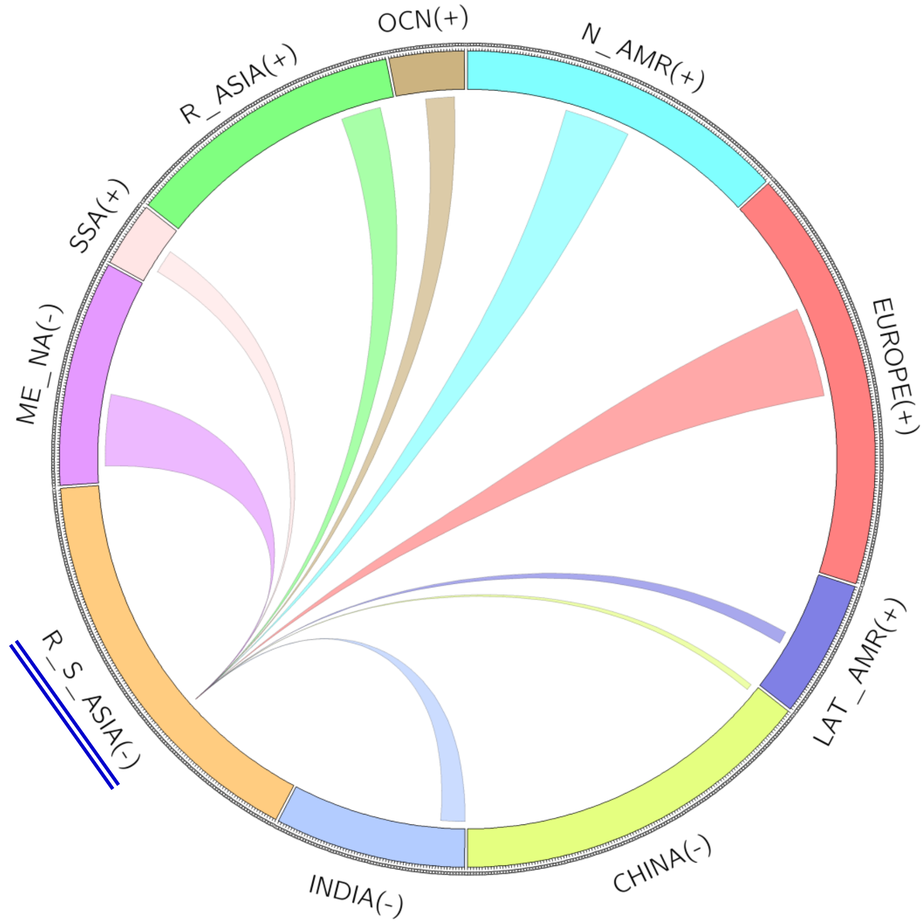
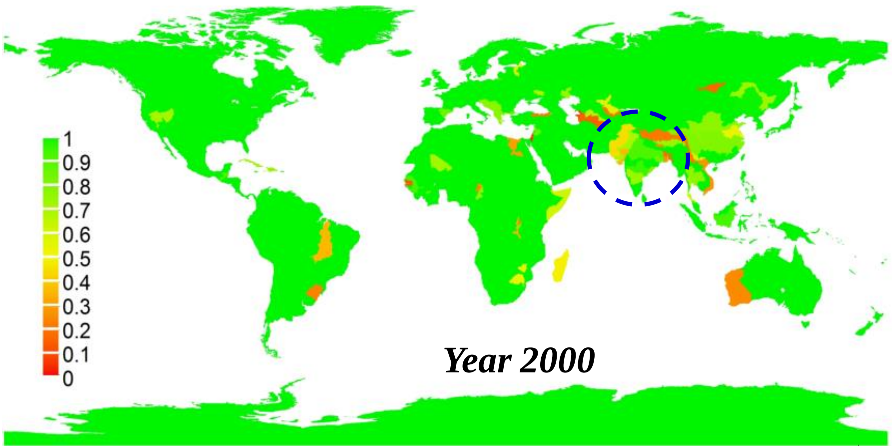


Regions facing the most severe water scarcity are most likely to increase net food imports

Future water scarcity will also shape food trade

Index of irrigation water availability



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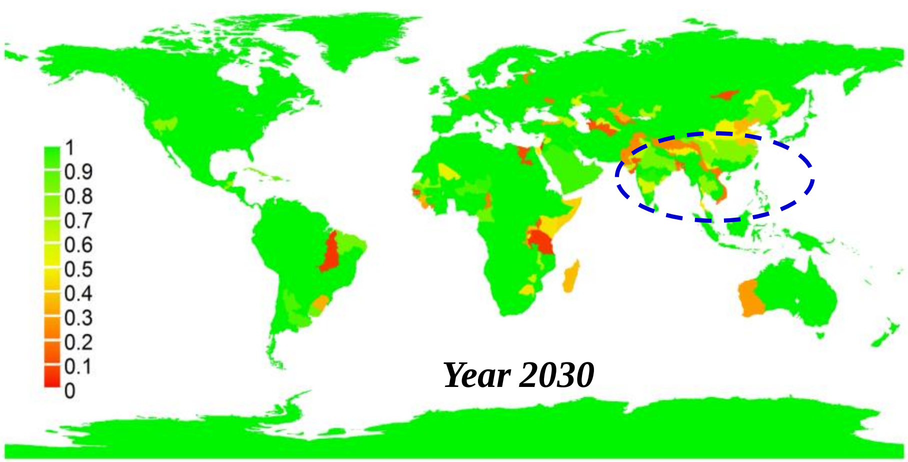
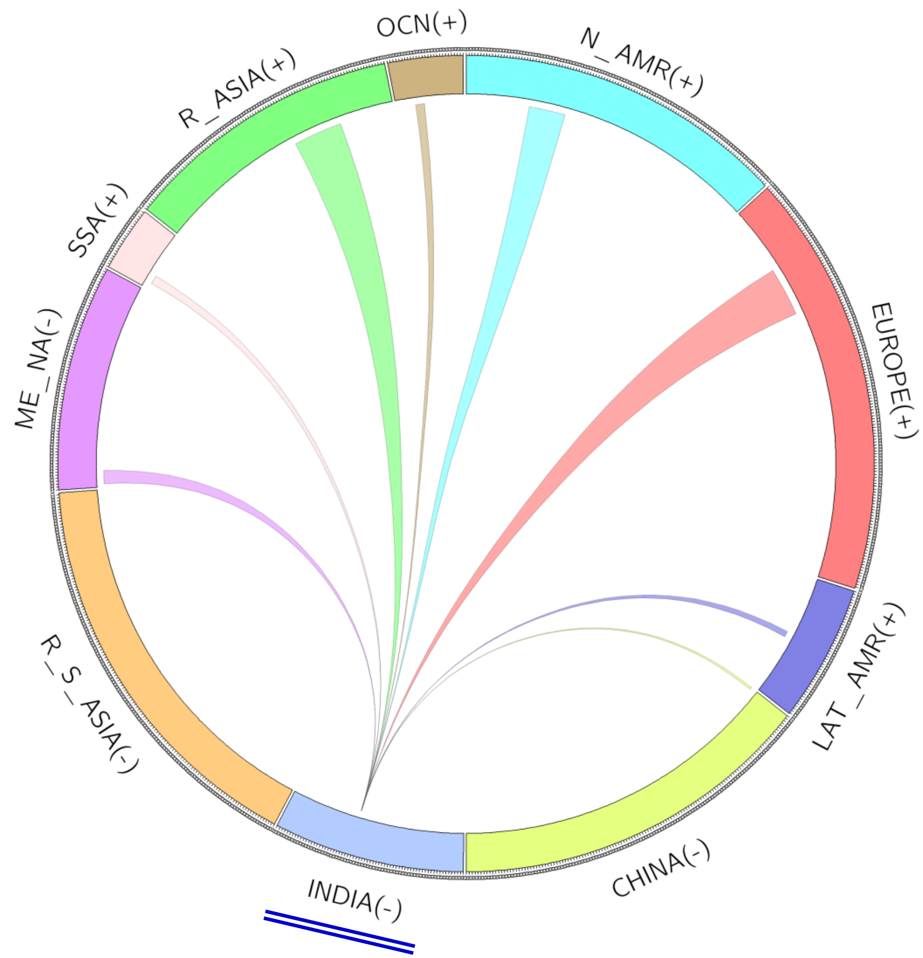


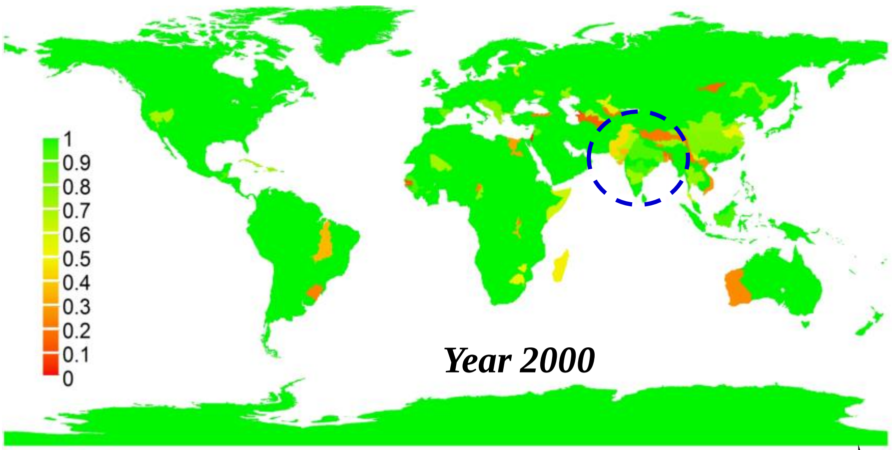
Source: Liu et al. (2013)



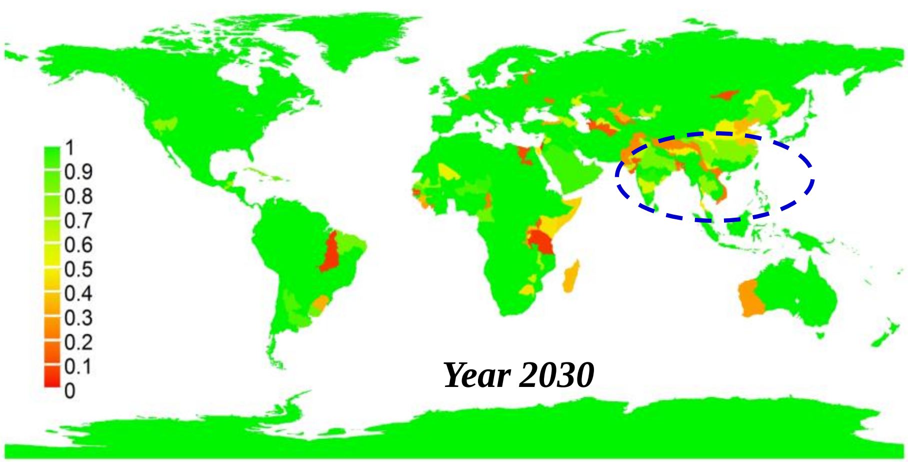
Regions facing the most severe water scarcity are most likely to increase net food imports

Future water scarcity will also shape food trade

Index of irrigation water availability



Increasing water scarcity alters the geography of food trade



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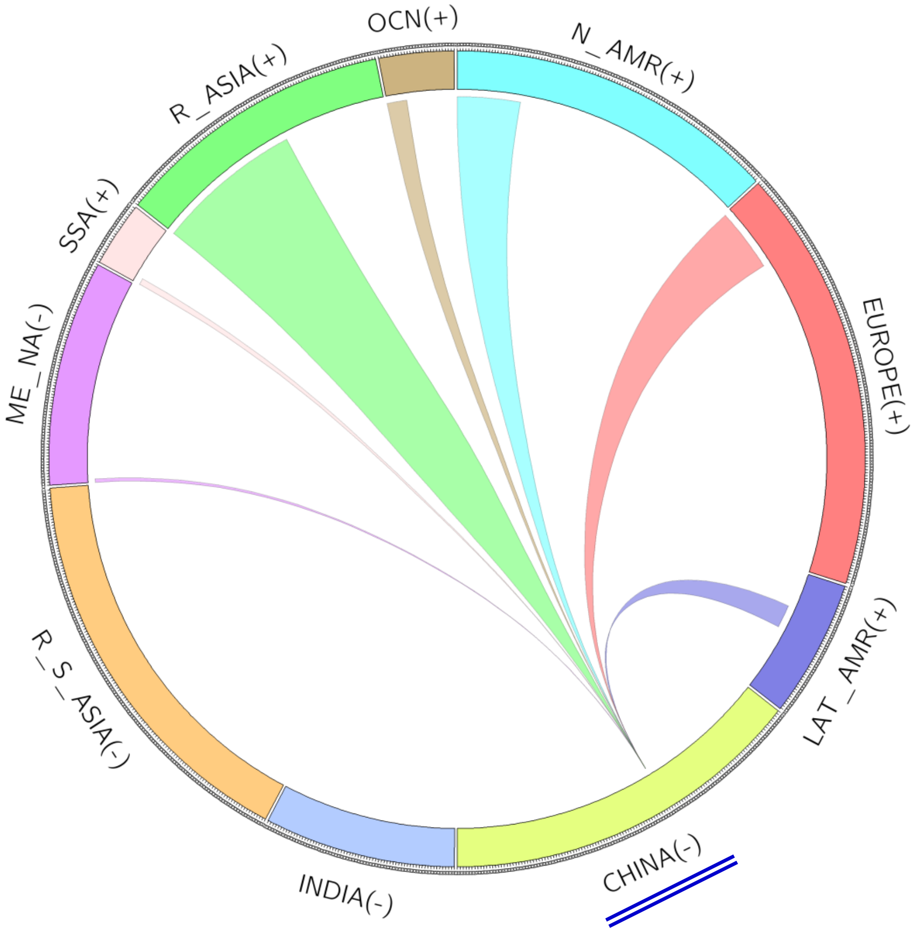

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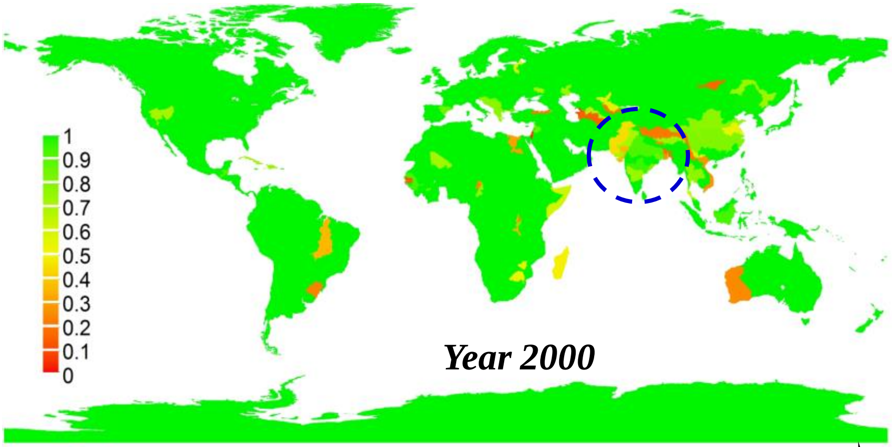

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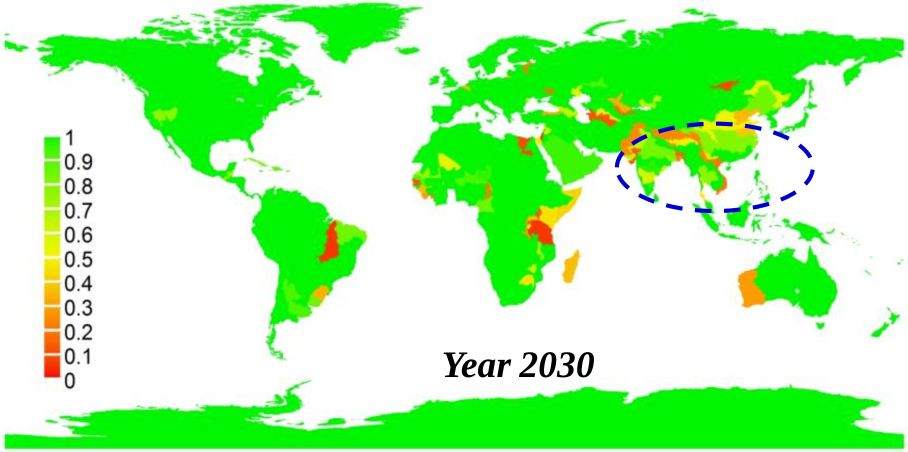
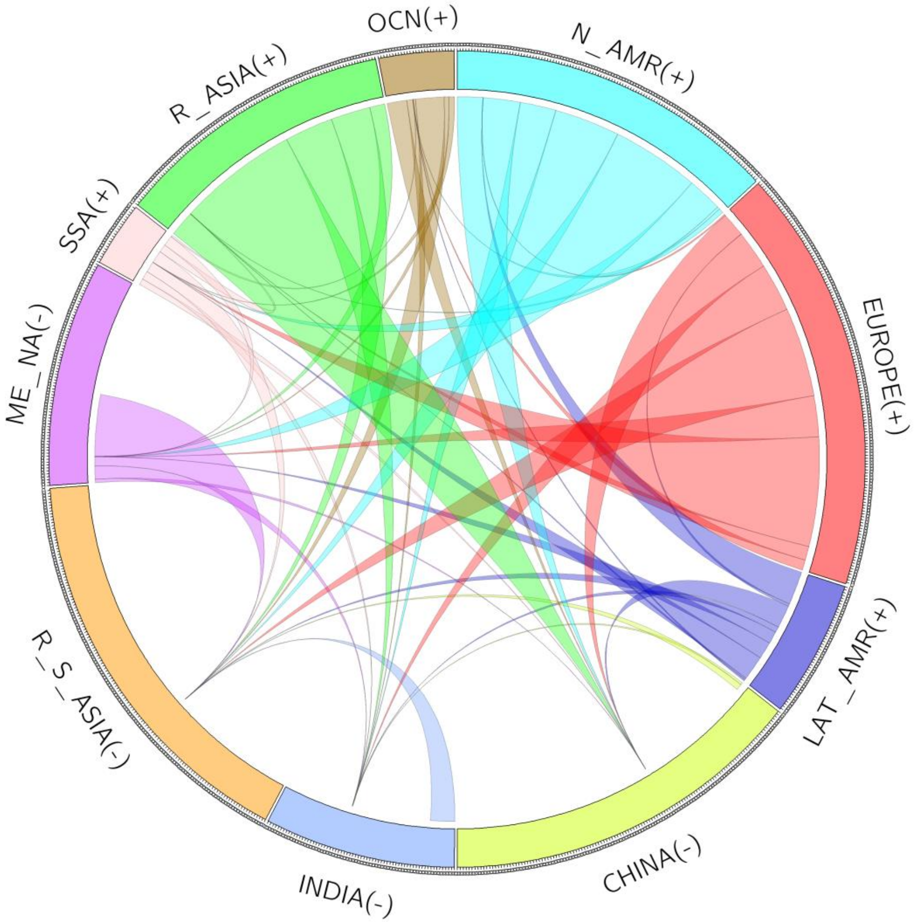
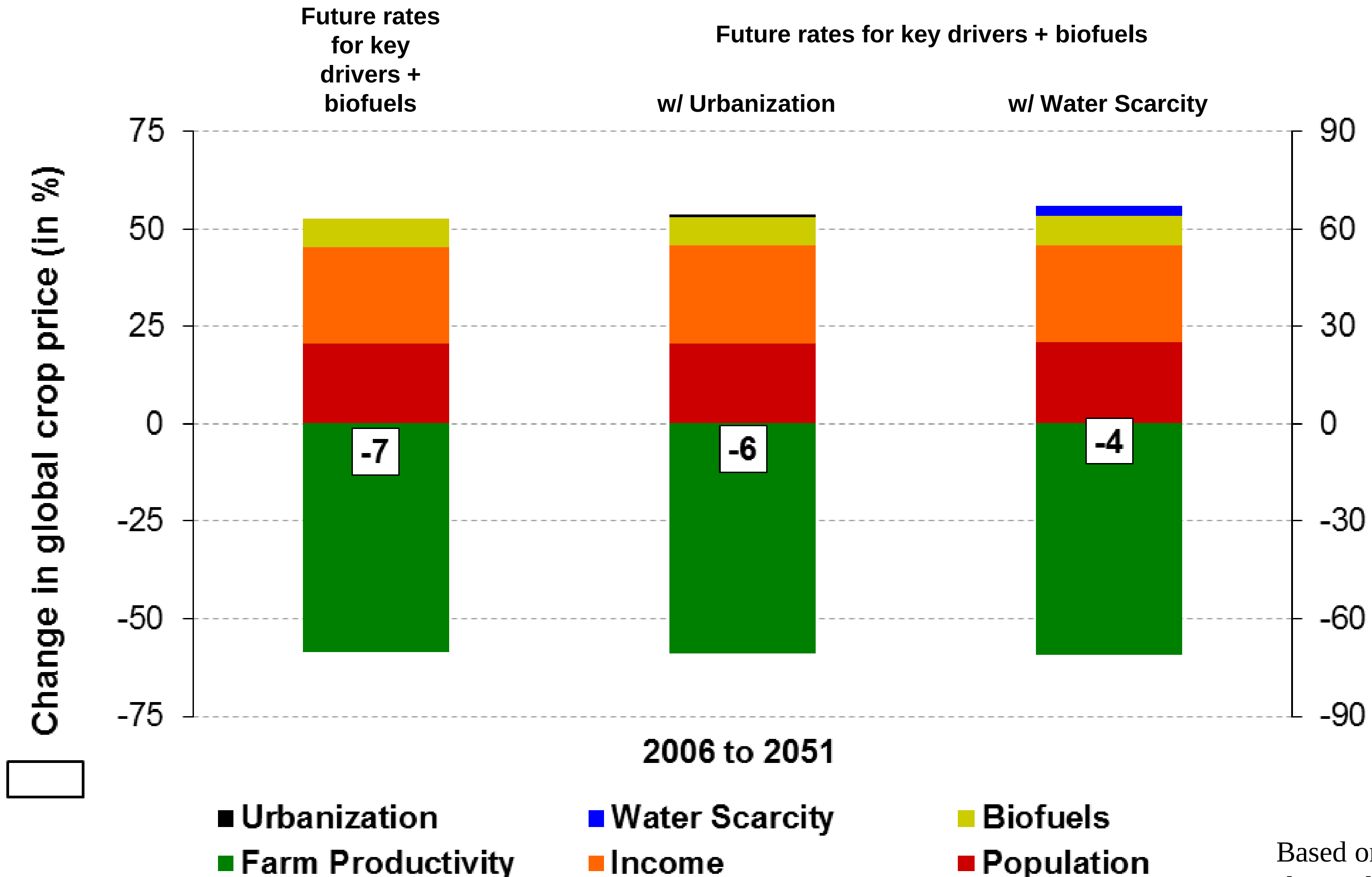




Source: Liu et al. (2013)

Regions facing the most severe water scarcity are most likely to increase net food imports

Urbanization and water scarcity are likely to have minor impacts on the global price trajectory

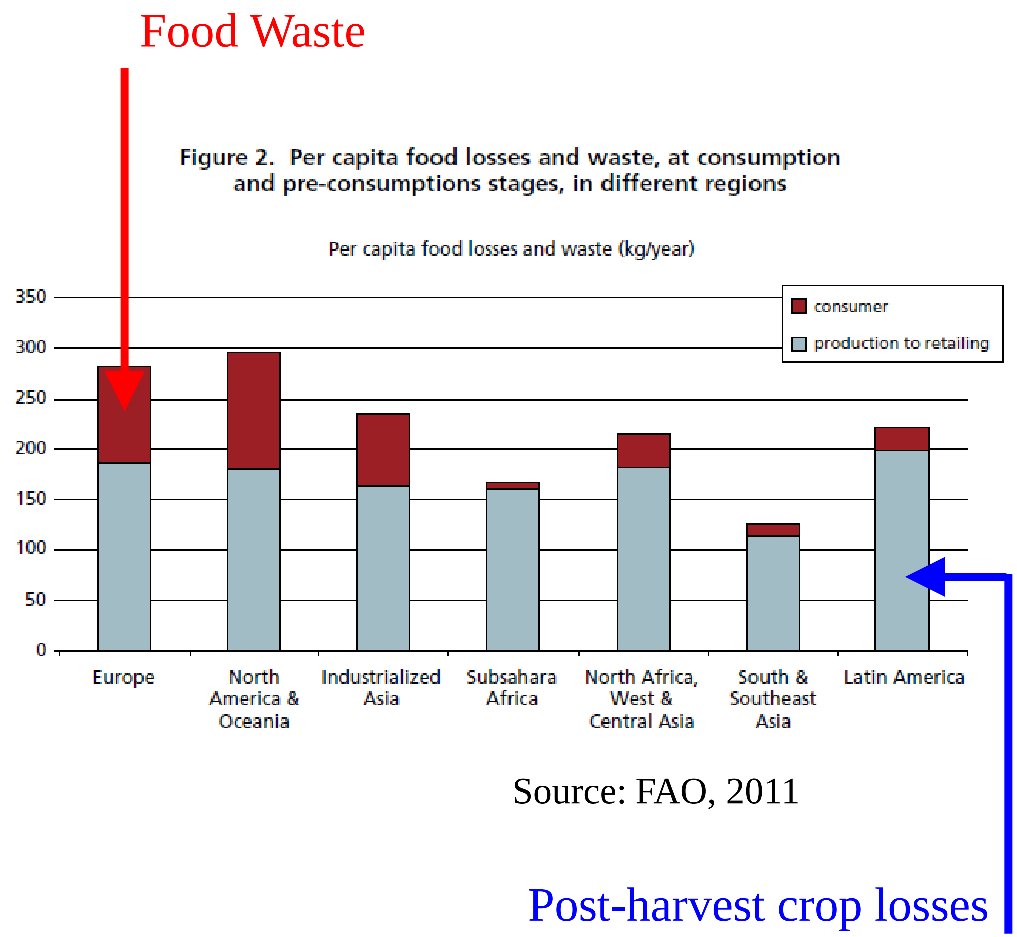


Based on Baldos and Hertel (2014a)

…but will likely have significant impacts on local economies

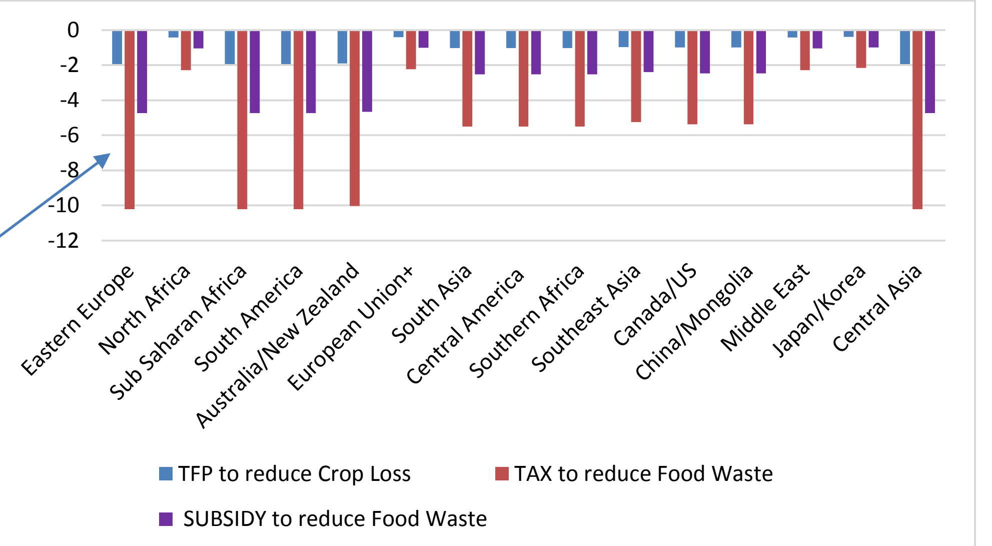
Food waste and post-harvest losses are another source of food 'supply'

- Food "waste" *mainly related to consumer behavior* in medium & high-income countries
- "Post-harvest crop losses" are main source of food loss in low-income countries
- However, requires investment and innovations

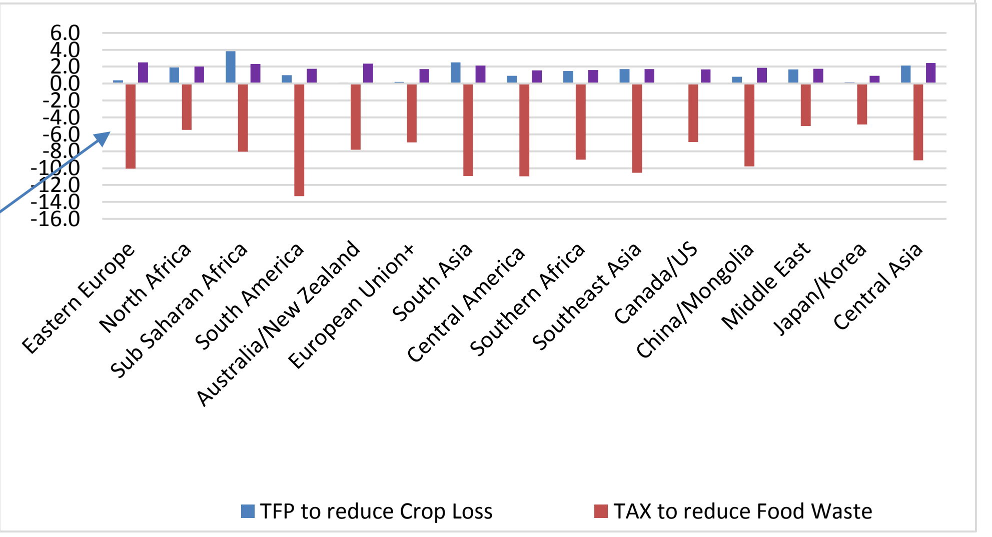


Impacts on cropland and caloric consumption due alternately to *1/3 reductions in postharvest losses or food waste*, using 3 different policy instruments

- **Postharvest productivity improvements, food tax and waste reduction subsidy all lower global crop land conversion and GHG emissions**



- **However, the food tax has an adverse impact on caloric intake**



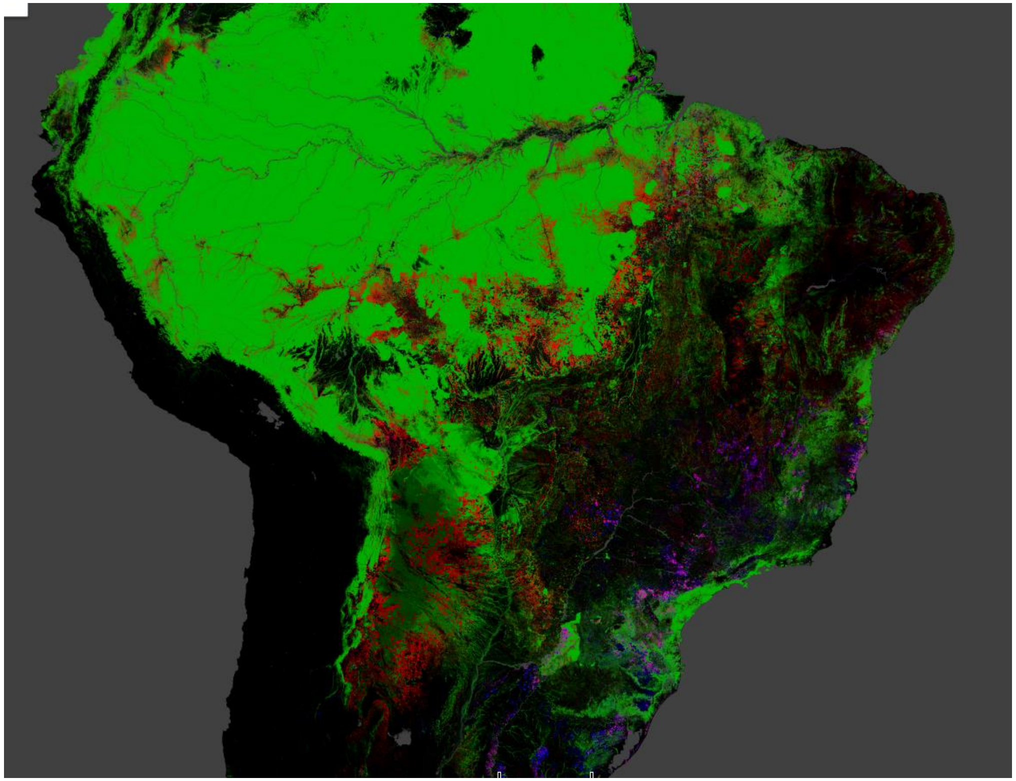
Source: Irfanoglu et al., 2014

Climate regulation: Pricing carbon will change the way we manage the world's resources

- **When the world decides to move ahead on climate policy carbon pricing could significantly alter global land use**
- **Land based mitigation (forestry and agr) could provide up to 50% of efficient GHG abatement at $27/ton CO2 (Golub et al.)**
- **Carbon vs. commercial timber: Brent Sohngen estimates that, at $5-$15 per ton CO2, the *value of carbon in most forests is greater than the value of timber;* therefore, the management of carbon stocks can play a large role in carbon sequestration**
- **And presently less than 500million of the 3.5 billion hectares of global forests are actively managed; this could change**

Leading to more intense competition between food, fuel and environmental services from land

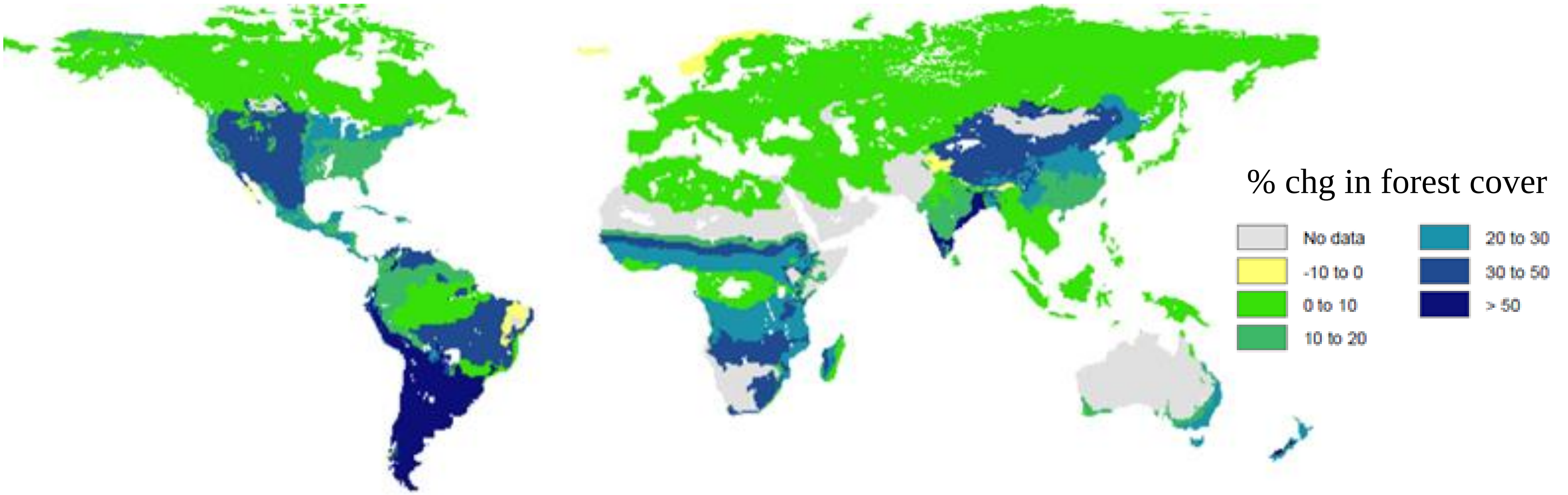
Amazon Deforestation: 2000-2012



Source: Hansen et al., Science, November 15, 2013

- Golub et al (2012) explore implications of implementing REDD+ worldwide in conjunction with Annex I emissions taxes ($27/tCO2e) on fossils fuels combustion as well as non-CO2 gases
  - Carbon incentive payments limit further deforestration
  - Encourage afforestation increased carbon intensity

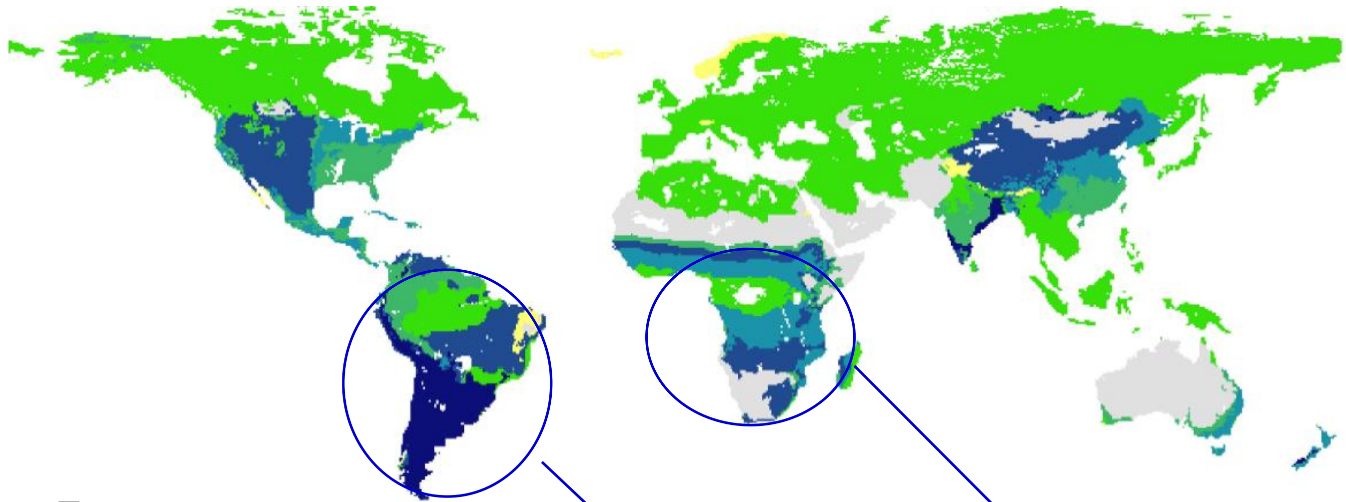
Global carbon sequestration incentives have a big impact on future *forest land*



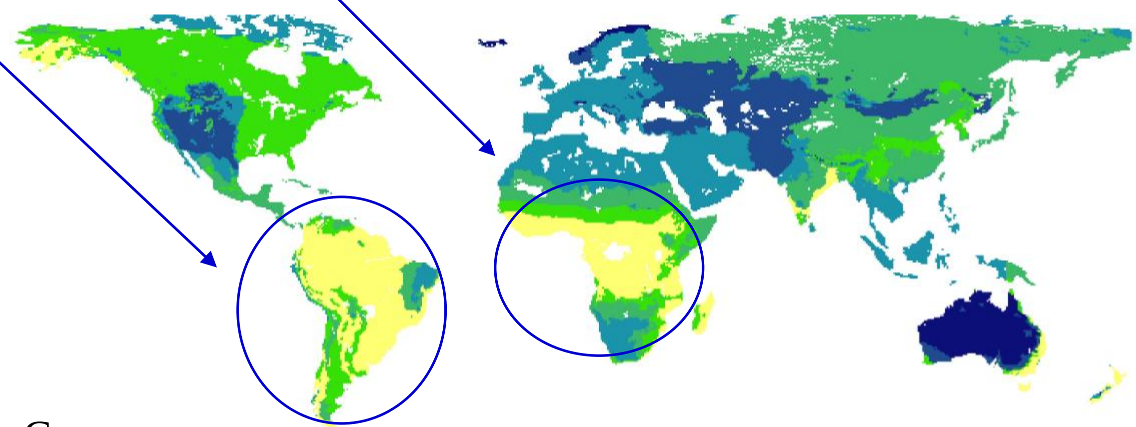
Forest cover expands in nearly all regions, relative to baseline!!

Source: Golub et al., PNAS 2012

REDD+ has could also have a big impact on cropland after 20 years of implementation



drives change in…



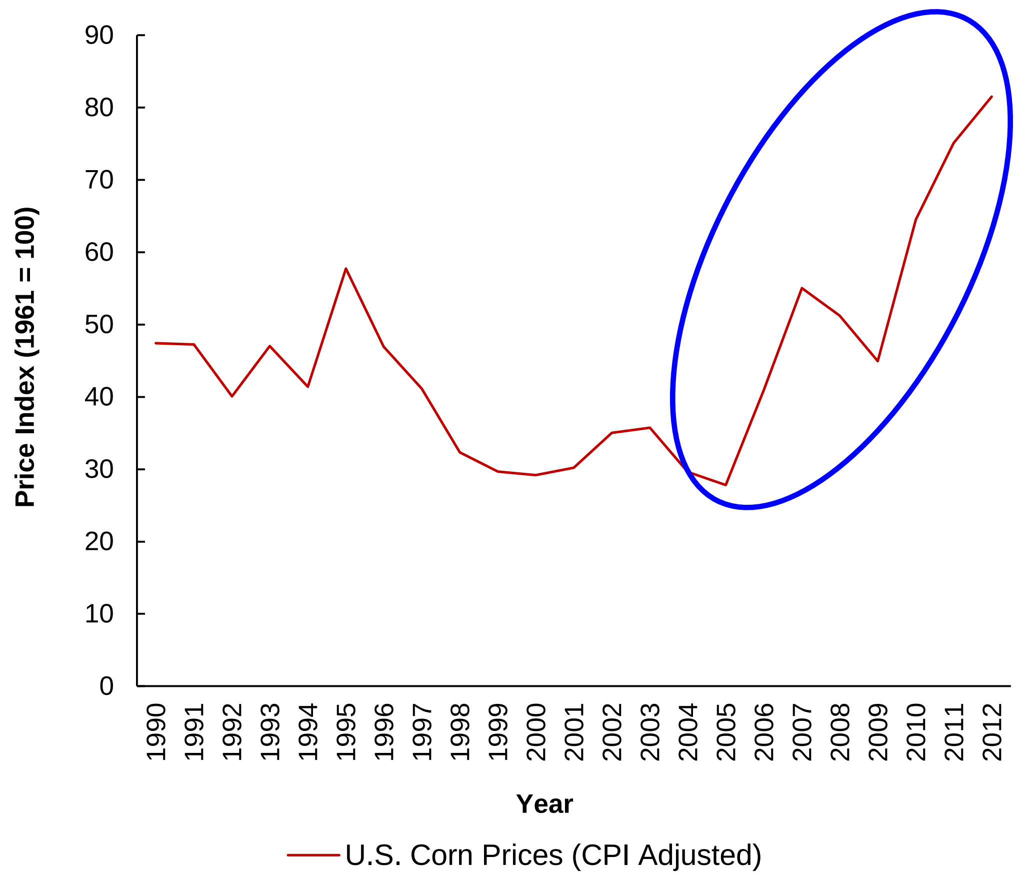
Source: Golub et al., PNAS 2012

Overview of the talk

- Demand-side drivers:
  - Changing relative importance of pop and income
  - Energy prices are the wildcard
- Supply-side:
  - Prospects for closing yield gaps
  - Technological progress is key to food security
- Emerging issues:
  - Urbanization
  - Water scarcity
  - Food waste/loss as new source of supplies
  - Climate regulation
- **How does it all add up?**

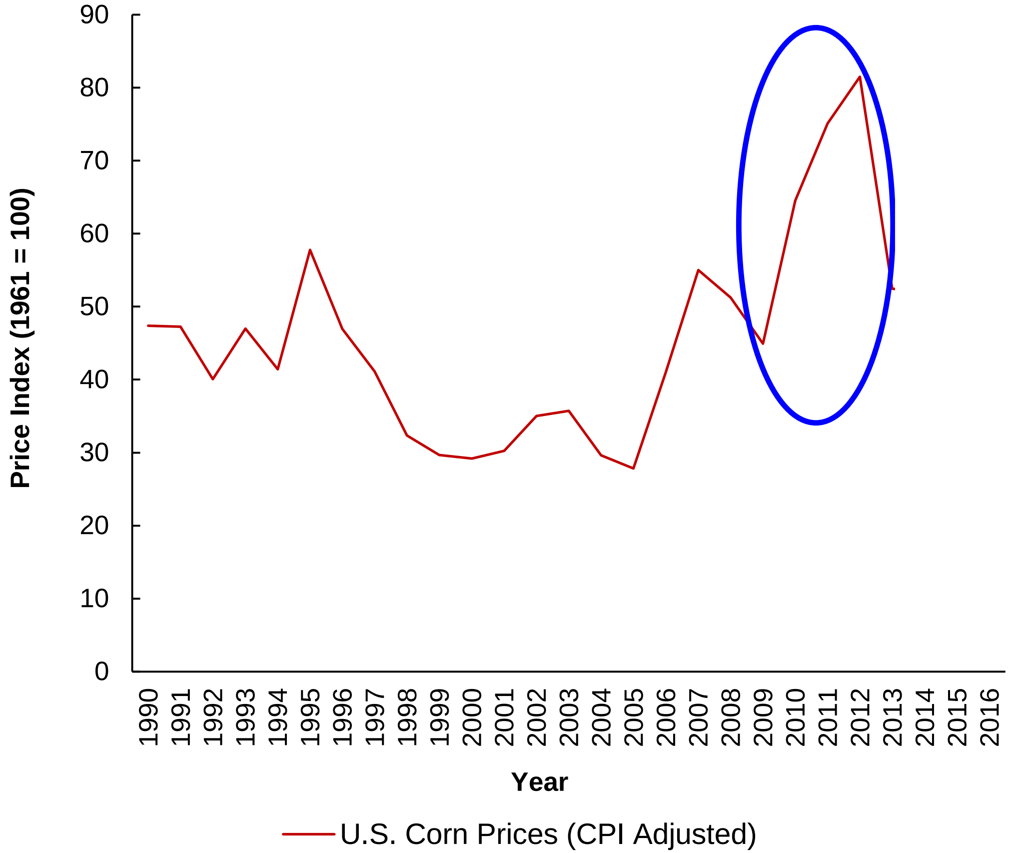
As recently as 2013: there was apparent consensus that were in a 'new normal'

- **World Bank (2013)** ***"...high and volatile food prices have become the "new normal"..."***
- **FAO (2013) noted that the** ***long-term trend in declining food prices has been reversed***
- **OECD-FAO (2013) projects** ***"Higher priced agricultural products over the coming ten years..."***



Data Sources: CPI data from Federal Reserve Bank of Minneapolis (2014)
Historical corn prices from USDA ERS (2014)

However, commodity prices have subsequently dropped … where is the new equilibrium? Will they bounce back? Was this just a bubble?



Data Sources: CPI data from Federal Reserve Bank of Minneapolis (2014)
Historical corn prices from USDA ERS (2014)

The ‘Scarcity Syndrome’:

“Pessimism has arisen about the ability of the Earth to feed its people …. [Due to]

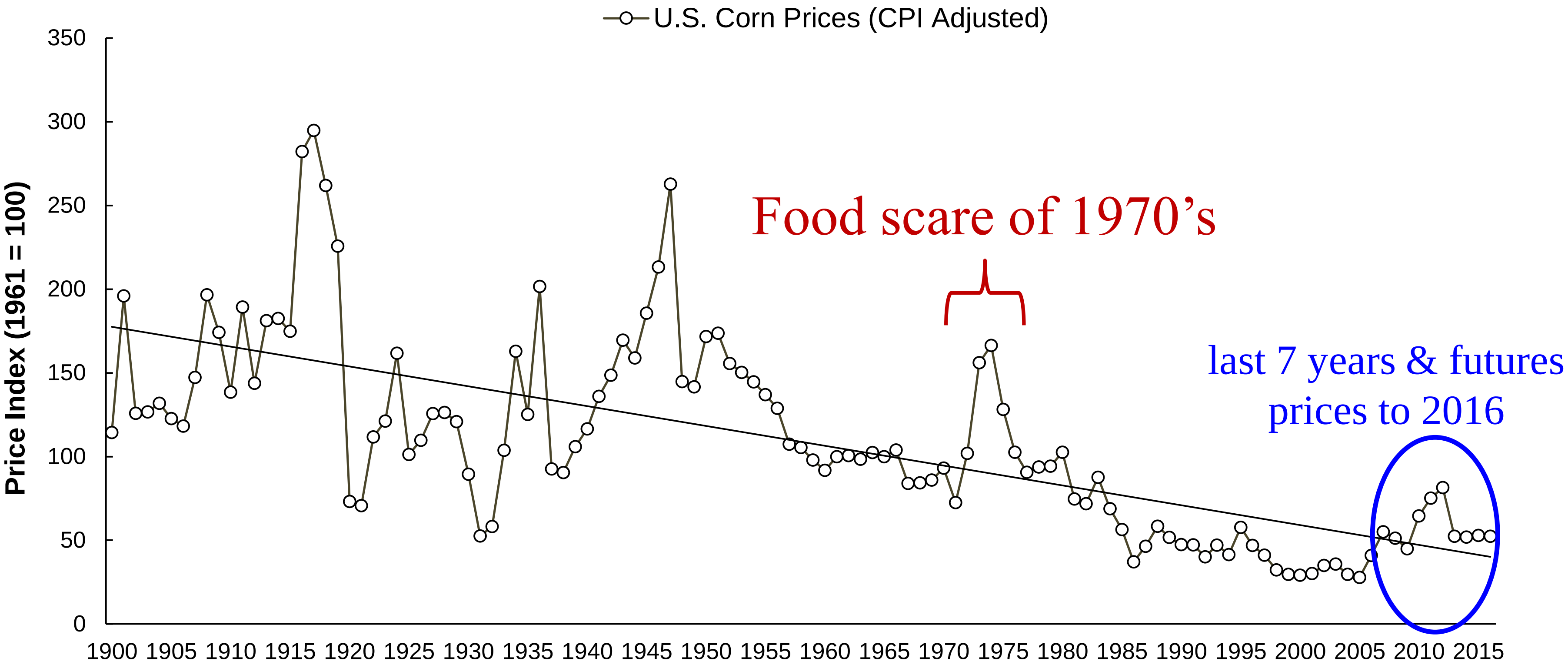
- **Burgeoning *population growth*…**
- **Doubts about the adequacy of the agricultural resource base…**
- **Misgivings about *weather* in the years ahead..”**

— 1981 USDA Yearbook of Agriculture: “Will there be enough food?”

From the opening paragraph of Don Paarlberg’s chapter:

“Enough Food? Sure, If We Don’t Play it Dumb.”

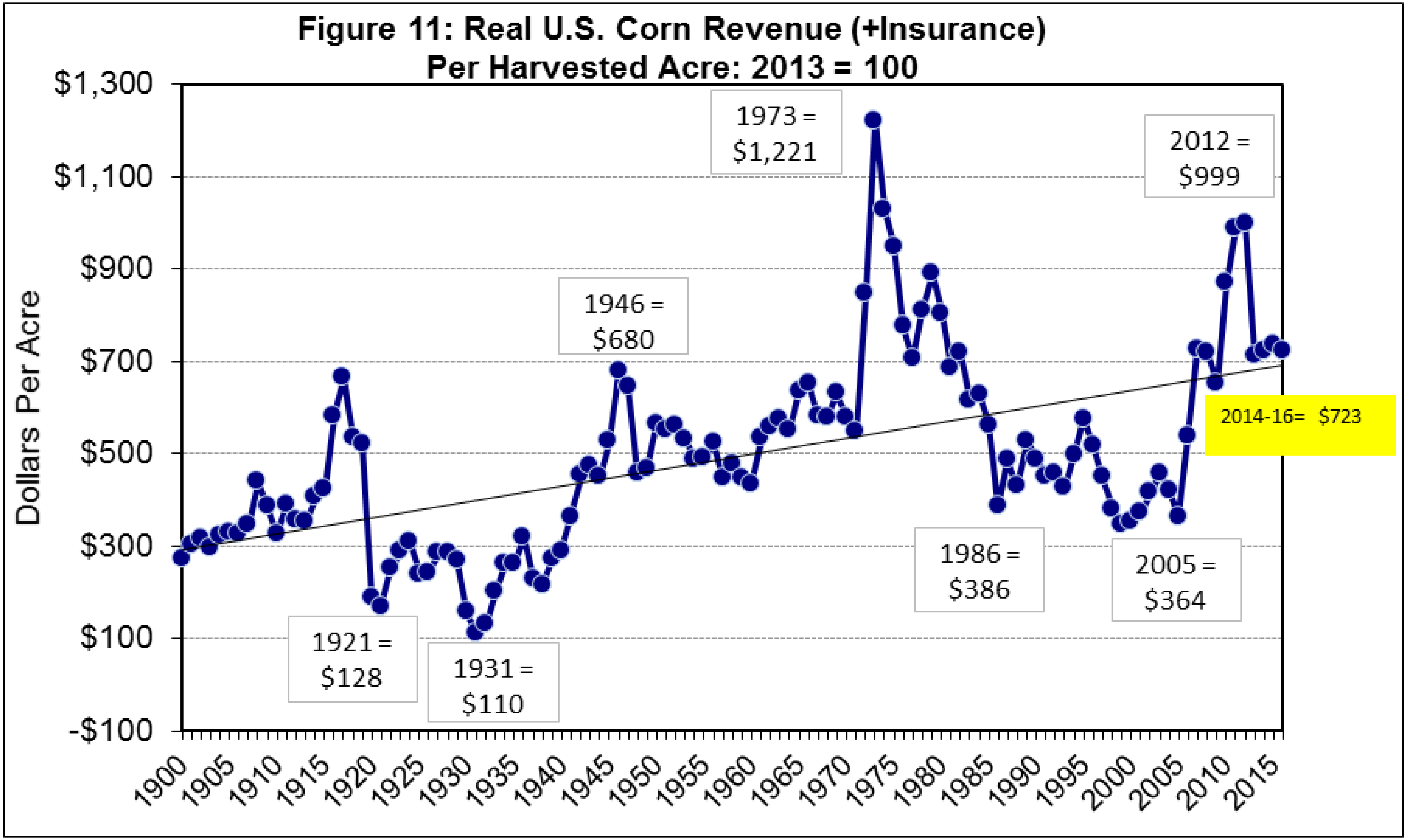
Where are we headed?



Data Sources: CPI data from Federal Reserve Bank of Minneapolis (2014)
Historical corn prices from USDA ERS (2014)
Hurt (2014) *personal communication*

- But we believe that this "consensus" is misguided and is heavily influenced by the 2007/08 and 2010/11 spikes in commodity prices
- ***We argue that long-run global crop prices will "likely resume their historical pattern of decline"***

But lower prices do not mean lower returns



Source: Abbott, Hurt and Tyner 2011; updated by Chris Hurt (2014)

Conclusions

- **Population and income drivers are changing**
- **Energy prices remain a wildcard**
- **Technological progress is key for food security**
- **Food waste/loss offers additional source of ‘supply’**
- **Water scarcity and urbanization will have local/regional impacts and shape future trade**
- **Climate mitigation policies will change the way we manage the world’s land resources and could have significant impacts on agricultural land and prices**
- **Recent price rise seems to be a repeat of 70’s; the long term price trajectory is likely to continue downwards – albeit more slowly**

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Thank you to my collaborators!








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