Economic Perspectives on Land Use and Leakage Effects of Agricultural Technology, Climate Impacts and Mitigation Policies

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Background

- There is a rich literature on land use change and leakage effects related to agriculture, including:
  - o Borlaug vs. Jevons: land sparing vs. land expanding impacts of technological change
  - o 'Feeding the world' in 2050: Is there enough land?
  - o iLUC consequences of biofuels
  - o Land-based climate mitigation
  - o Implications of climate change for land suitability and use
- Each of these issues has economic consequences that hinge a core set of responses:
  - o Extensive vs. intensive margins of supply response – both domestically and overseas
  - o Consumer response to food prices
  - o Extent of market integration through international trade
  - o General equilibrium considerations

Roadmap for this talk

Develop basic economic principles through series of successively more complex frameworks – as related to existing literature

- Start a unified global economy:
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  - Role of RoW supply response in determining the excess demand elasticity facing innovating region
  - Key role of relative yields, emissions efficiencies in determining extent of leakage and global environmental impacts
- Introduce market segmentation:
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1. Unified Global Economy: Theory

- Single global farm sector
  - produces all food, fiber and fuel from agriculture
  - employs land and variable inputs; the prices of the latter are exogenous to the farm sector in this long run analysis
  - cost minimization: entry/exit results in zero economic profits and aggregate constant returns to scale
- Three exogenous long run drivers
  - demand growth, includes food, fiber, fuel (Δ_D)
  - “trend” yield growth, alters derived demand for land (Δ_D^L)
  - Reductions in supply of agr land (e.g., urbanization) (Δ_S^L)
- Three margins of economic response (price elasticities)
  - demand (ε_D)
  - intensive margin of supply response ($\varepsilon_{S,I}$)
  - extensive margin of supply response ($\varepsilon_{S,X}$)

Source: Hertel, 2011

Theory: Long Run Land Use Change in Unified Model

- Long run equilibrium change in agricultural land use

$$q_L^* = [(\Delta_D + \Delta_S^L - \Delta_D^L) / (1 + \varepsilon_{S,I} / \varepsilon_{S,\mathrm{X}} + \varepsilon_D / \varepsilon_{S,\mathrm{X}})] - \Delta_S^L$$

- Key insights
  - **Purely biophysical analysis will overstate land use change** -- if intensive supply and demand elasticities = 0, simplifies to:

$$q_L^* = (\Delta_D - \Delta_D^L)$$

  - **Economic response is *shock absorber*** in the biophysical system:

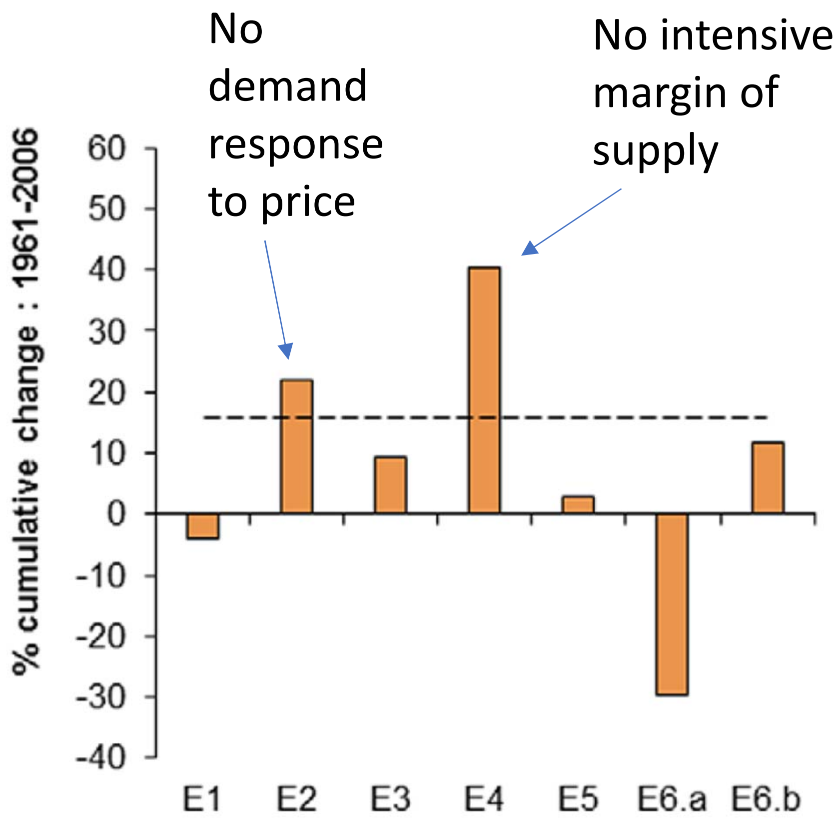
$$(1 + \varepsilon_{S,I} / \varepsilon_{S,\mathrm{X}} + \varepsilon_D / \varepsilon_{S,\mathrm{X}}) \geq 1$$

  - **Land use change *depends on relative size* of intensive/extensive margins**; if either the intensive or demand margins are omitted, will overstate resulting land use change (see above)

Source: Hertel, 2011

Application and insights: Why do IAMs overestimate global land use change?

- Many Integrated Assessment Models predict **massive land use expansion in 21st century** – despite slowdown in population growth & satiating food demands
- Indeed, predicted cropland expansion exceeds that in 20th century
- Coincidentally, they often **ignore the intensive and demand margins** of response to scarcity
- We asked how well these models would have performed over the 1961-2006 period
- **They would have predicted 3x too much historical cropland conversion**



Predicted historical cropland expansion: 1961-2006 under a range of restrictive assumptions – dashed line is observed change in cropland worldwide; closely mimicked by SIMPLE model

Source: Baldos and Hertel, 2013

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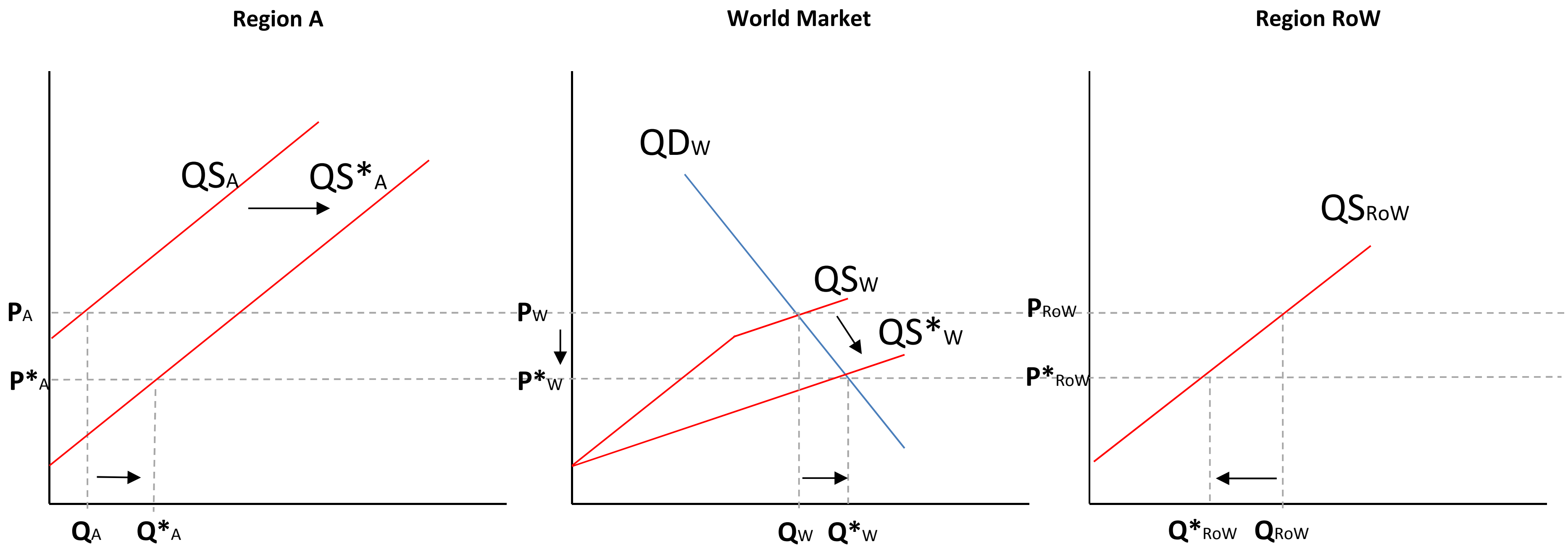
2. Two Region Model: Theory

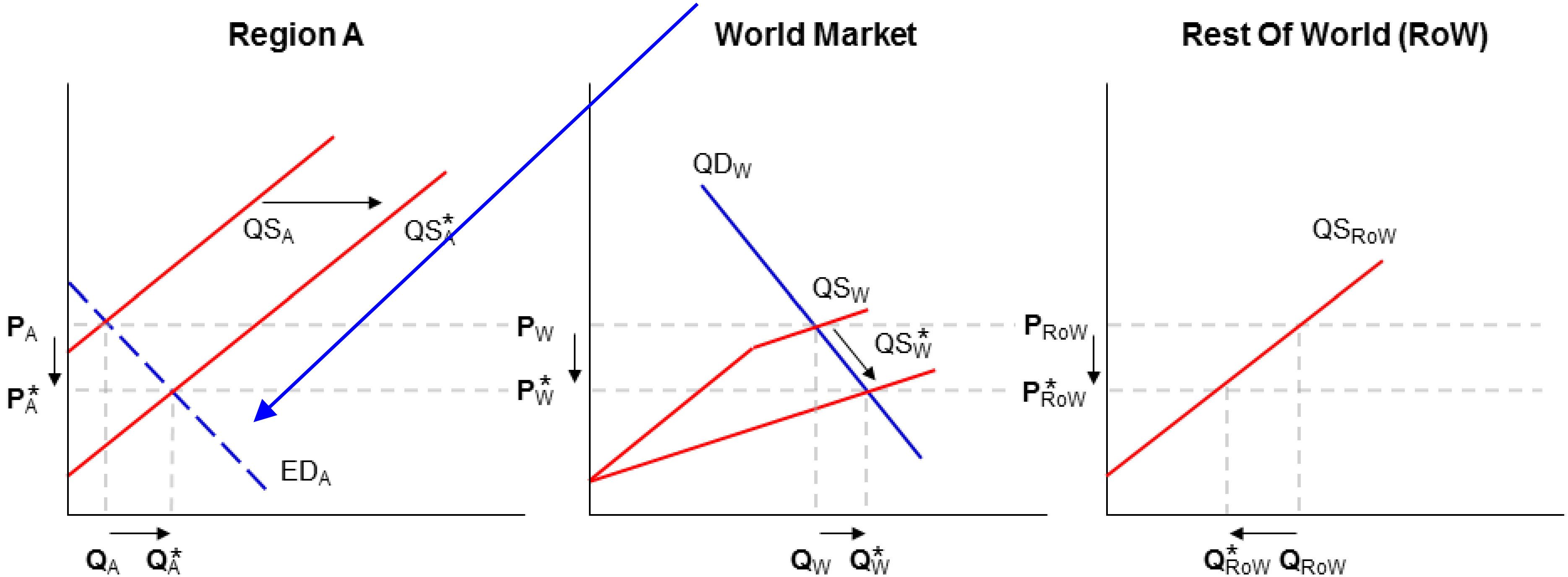
- Divide the world into two regions: One innovates (region A) and the other does not (Rest of World = RoW)
  - **Crop markets fully integrated through international trade**
  - Need only consider global demand for food
  - As before, production in each region based on land and nonland inputs
  - Intensive and extensive margins vary between the two regions
- Research Question: What is the impact of technological innovative in A on land use in region A, RoW and World Total?

Global land use impacts of technological progress in region A: Theory



- 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
- ***Impact on cropland use in A is ambiguous due to efficiency gains***
- ***An increase in A does not mean a global rise in land use;*** faced by a lower world price, but unchanged technology, ***producers in the non-adapting rest of the world (RoW) contract production and cropland***

Land use impacts in innovating region A hinge on the *excess demand elasticity* facing A

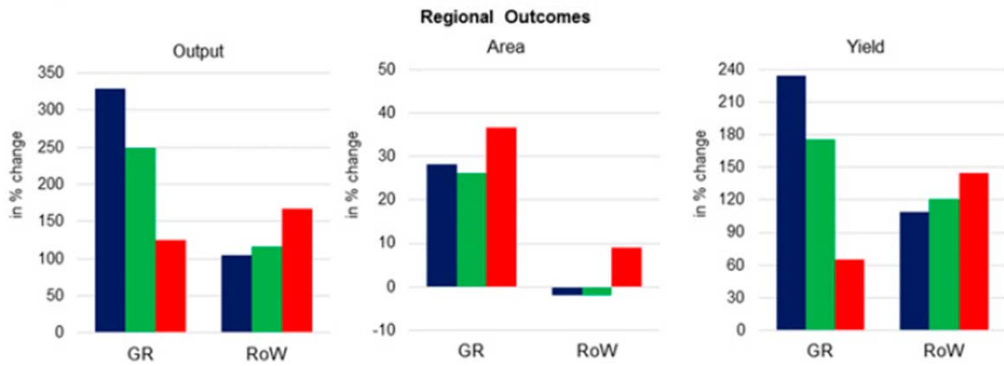


- *Land use in A will expand as long as excess demand elasticity > 1*
- *This can arise, even if global demand elasticity for food is zero*
- *Excess demand elasticity rises as global market share falls ($\alpha \rightarrow 0$)*

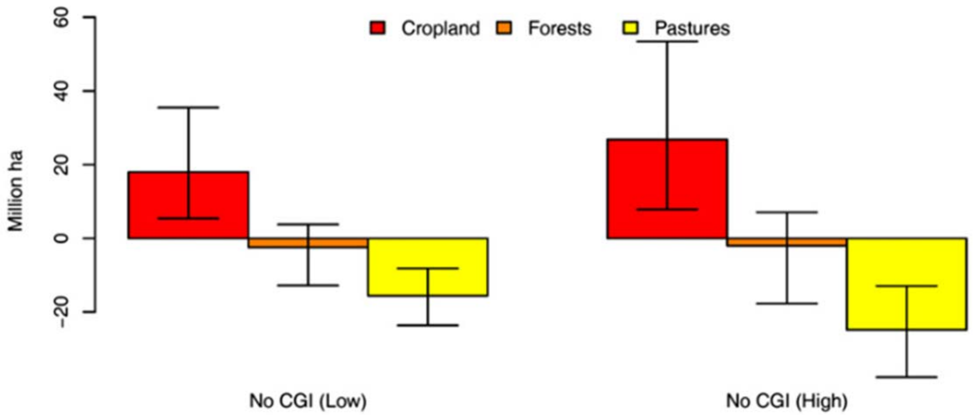
$$\varepsilon_D^A = (\varepsilon_D^W + (1-\alpha)(\varepsilon_{SI}^{RoW} + \varepsilon_{SX}^{RoW}]/\alpha$$

Application and Insights: Are Green Revolutions Land-Sparing?

- Borlaug argued forcefully that the Historical Green Revolution reduced cropland use and thereby spared natural ecosystems
- This was challenged by others who observed that cropland area was rising, even as yields were rising; yet other factors were also changing
- The **question cannot be answered without a counterfactual** experiment



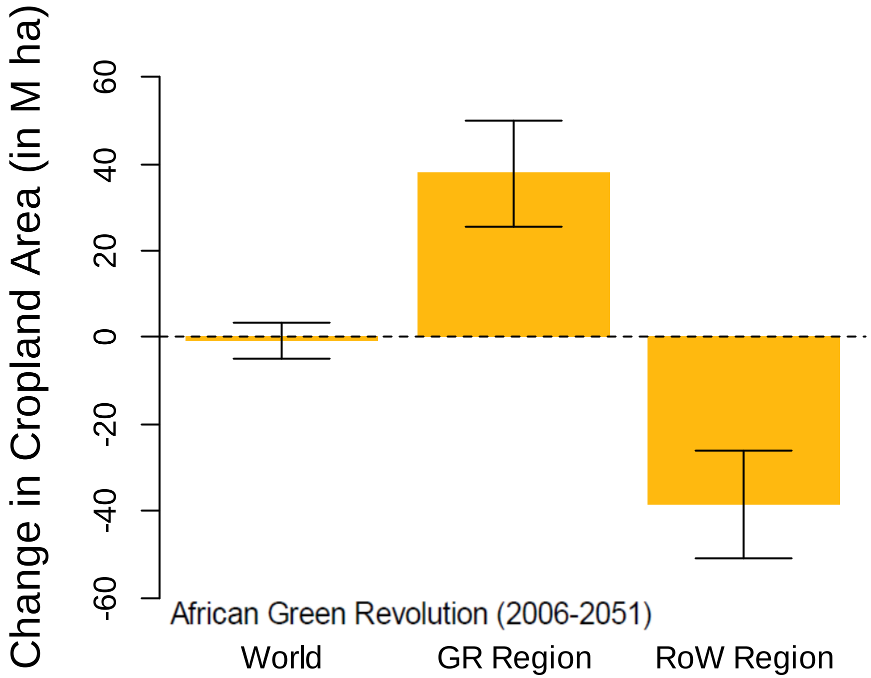
Actual (blue), model simulated (green), and counterfactual (red) changes in crop output, area, yield in the innovating (GR) and RoW regions: 1961-2006. The counterfactual shows an increase in cropland area in both the GR and RoW regions. Source: Hertel, Ramankutty and Baldos (2014).



Predicted global land cover change in the absence of the historical Green Revolution's Crop Germplasm Improvements (CGI). This shows that removal of the CGI contributions causes cropland to increase, while pasture and forest area declines. Source: Stevenson, Villoria et al., PNAS, 2013.

However, a *prospective* African GR may not be land-sparing….

- Use the SIMPLE model to project to 2050 *assuming integrated markets*:
  - Baseline shocks to **pop, income growth, productivity growth**
  - **Counterfactual assumes faster productivity growth in GR regions** beginning in 2025
  - (GR – Baseline) shows higher yields, *little change in global cropland area*: **Unlikely that GR will be land-sparing**
- Why is this? *What are the key distinguishing characteristics of Africa?*



African Green Revolution (2006-2051)

Two Region Model: Theory Revisited

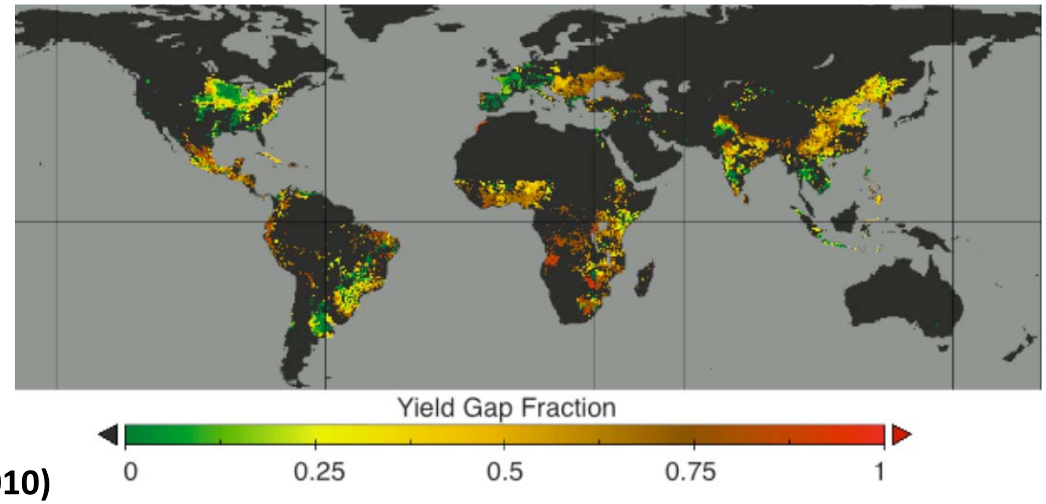
- *The condition for Jevons' paradox is relatively simple when supply response in both regions is equal and markets are fully integrated*:

$$\varepsilon_D^W > (Y^A / Y^W)(\varepsilon_S^W + 1) - \varepsilon_S^W$$

Source: Hertel, Ramankutty and Baldos (2014)

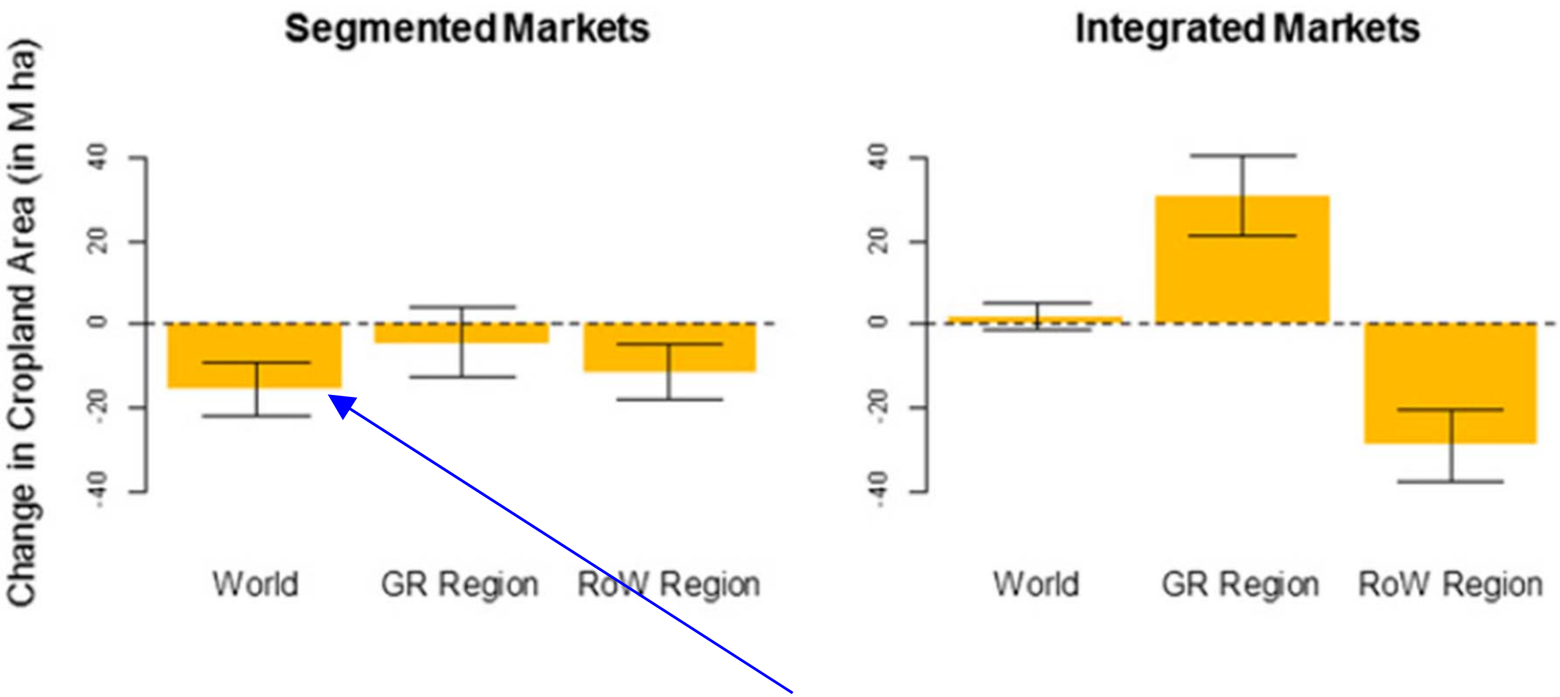
Ratio of yields in Africa / Global average yields is low

- Relative yields in Africa are low, making it more likely that GR will NOT be land-sparing



Source: Licker et al (2010)

But the outcome of an African Green Revolution depends on the extent of market segmentation vs. integration



If agricultural markets remain segmented, **African GR is land-sparing** because this **reduces the excess demand elasticity** facing SSA

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3. Market segmentation reflects *incomplete access to world markets*

- Many consumers in Africa only have access to domestic commodities; producers cannot sell into world markets
- Limited access is reflected in small international crop shares in production and/or consumption and low international price transmission elasticities (0.19 in SSA)

- Regions which are more connected to world markets on supply and demand sides (e.g., EU) have much larger price transmission elasticity (0.64)

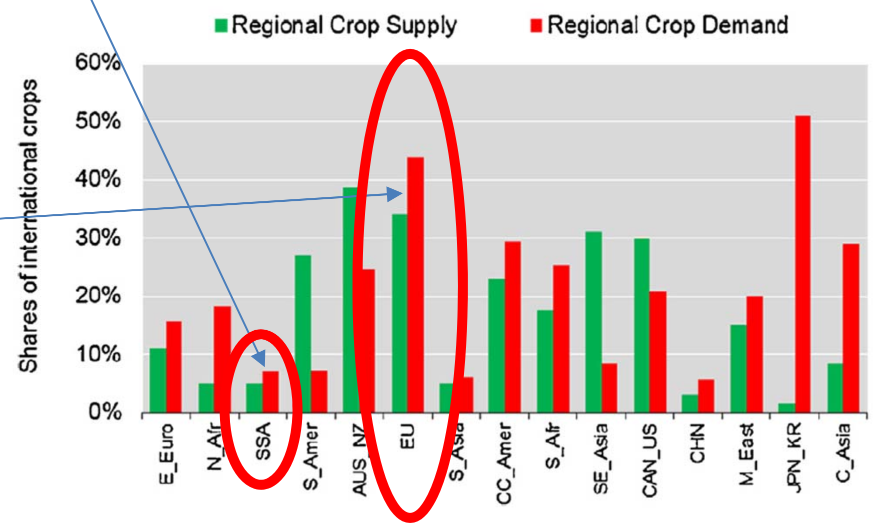
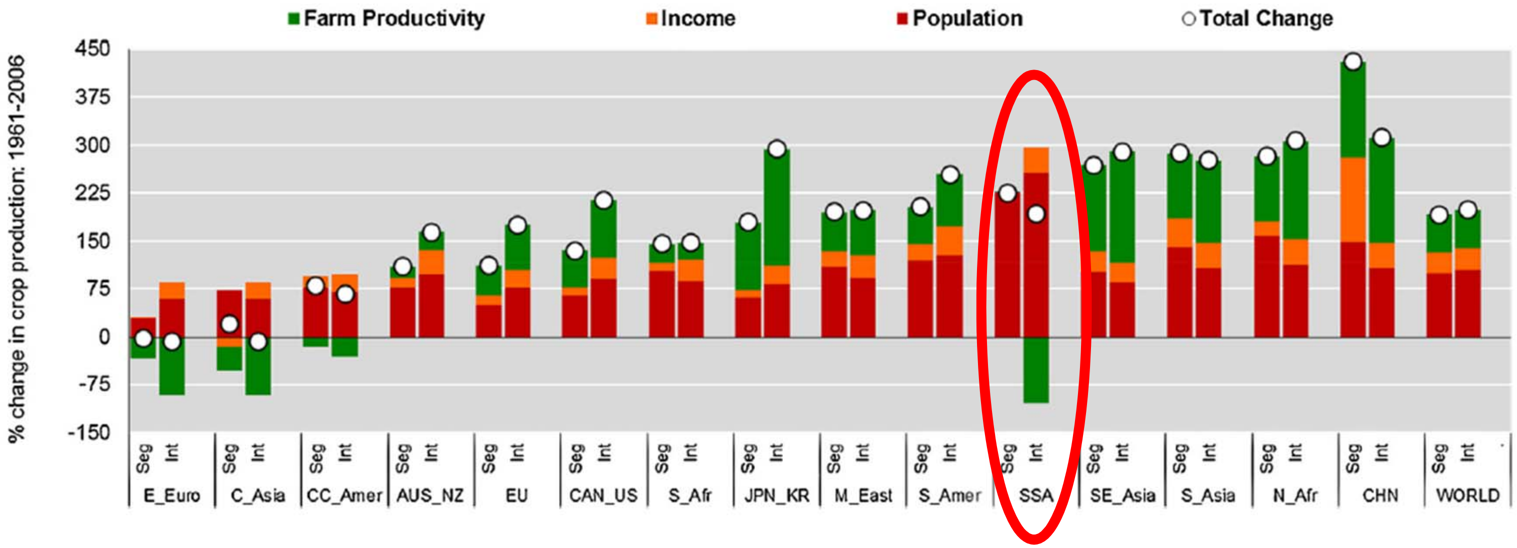


Fig. 1. Shares of international goods in the regional demand for (red) and supply of (green) crops in 2006. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Source: Hertel and Baldos, 2016

If historical markets had been fully integrated, pattern of regional crop output growth would have been different

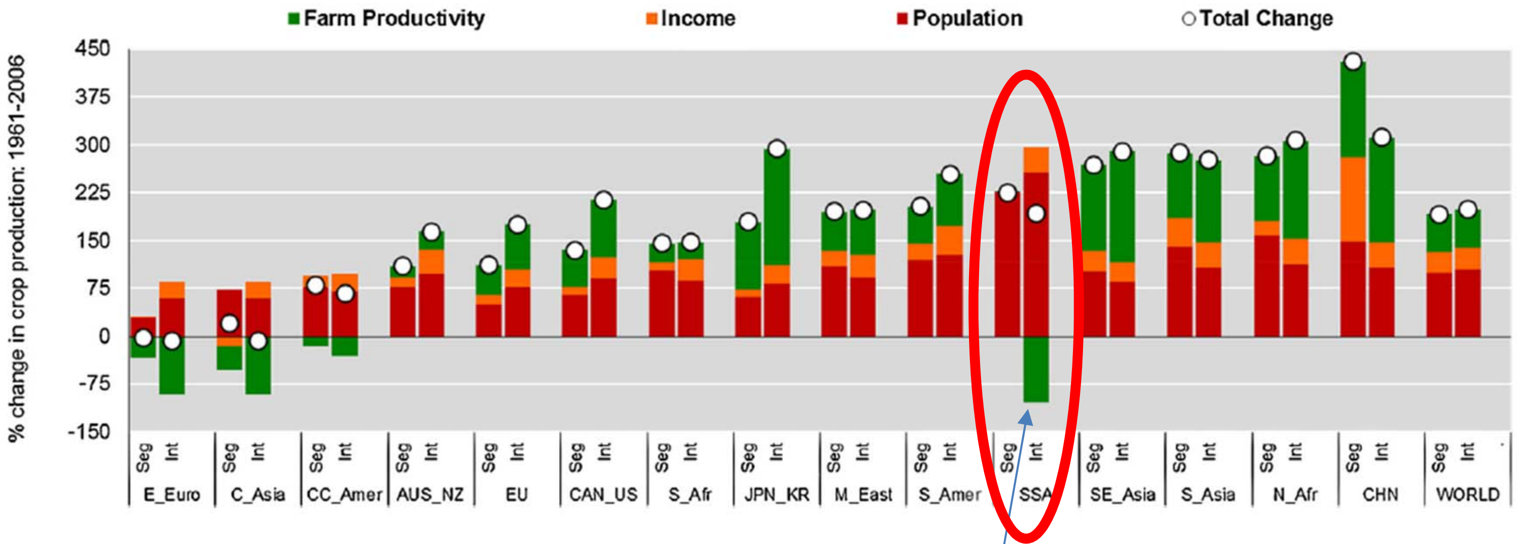


Sub-Saharan Africa:

- Historical growth in crop output was largely driven by population; productivity played a minor role in the region
- However, under integrated markets, income growth in the world economy would have been a driver
- But the low relative rate of productivity growth (green bar) would have been a drag on production

Source: Hertel and Baldos, 2016

Market segmentation is critical to understanding the historical pattern of crop production



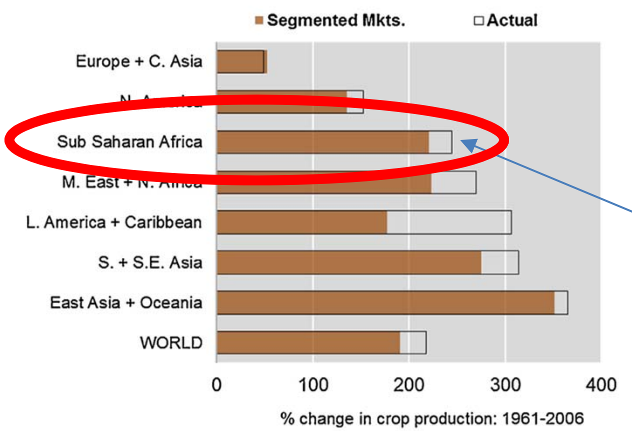


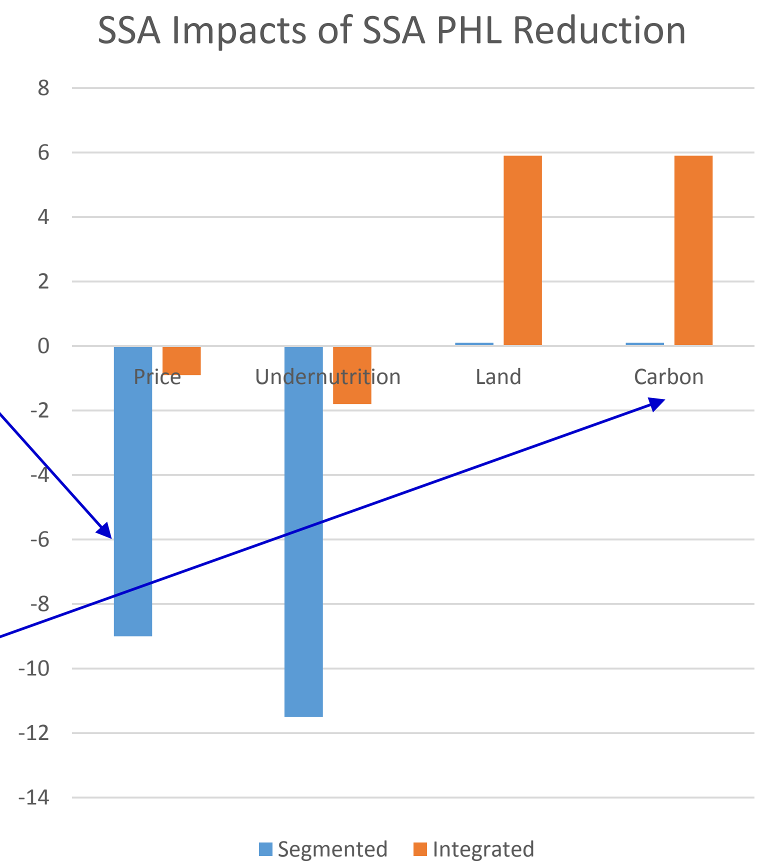
Fig. 2. Regional changes in output from 1961 to 2006 (% change): Observed vs. predicted.

Given its slow productivity growth, it is *not possible to explain SSA crop output expansion in presence of integrated markets*. *Under market segmentation*, the growth in output and land use in SSA is much closer to observation; *local population growth drives local production*

Source: Hertel and Baldos, 2016

Market segmentation also alters our view of many policies: Impacts of reducing post-harvest losses in Africa

- Under *segmented markets* SSA prices fall sharply following PHL reduction, so non-farm under-nutrition drops and cropland area shrinks
- However, with *integrated markets* there are few nutritional gains and environmental losses



Highlights the critical interplay between globalization and the food and environmental security implications of technological innovations

Source: Hertel and Baldos, 2016

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4. Rigidity in bilateral trade: Theory

- In the late 1960's while working at the IMF, Paul Armington (1969) noted that bilateral trade linkages were remarkably rigid:
  - Responsive to price changes, but trade patterns do not change radically when one exporter's prices rise, as would have predicted
  - Proposed a 'theory of demand for products distinguished by place'
- Possible reasons include:
  - Geographic characteristics of the products (think wine!)
  - Colonial/language/political ties
  - Presence of national firms with internationally differentiated products (e.g., Toyota)
- Virtually all trade models now rely on some form of product differentiation linked to country of origin to explain bilateral trade flows
- This results in a matrix of bilateral trade ties that has important implications for land use and leakage impacts

Armington's theory tested and illustrated in iLUC context

- Villoria and Hertel estimate an Armington model of land use change and *reject the null hypothesis of integrated markets*
- *Consequences for iLUC are significant* – Fully integrated markets model predicts more land conversion and double the terrestrial GHG emissions in response to a rise in the US corn price

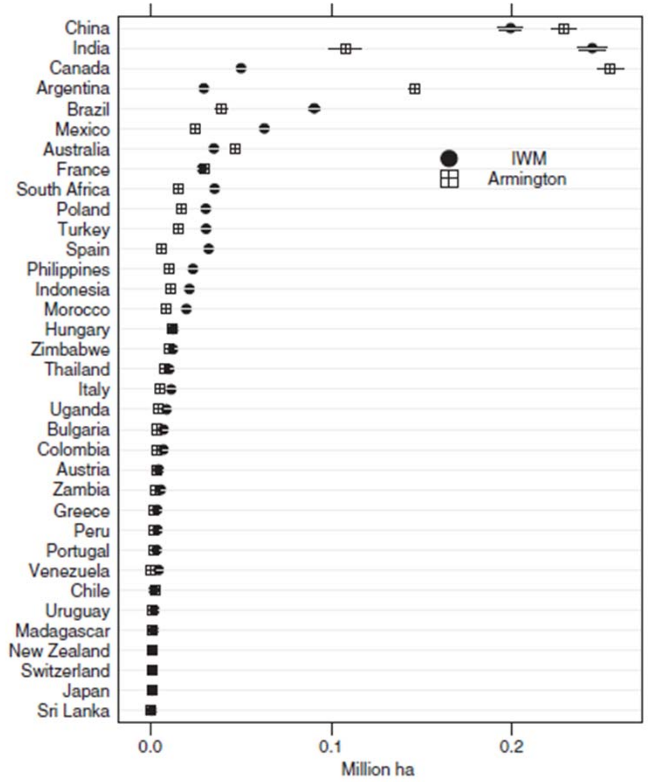

Figure 3. Bootstrapped confidence intervals (95%) for the differences between the mean changes in harvested areas predicted by the IWM and the Armington models, by country

Implications for regional crop land of a 15% price rise in crop prices in the US.

Source: Villoria and Hertel (2011)

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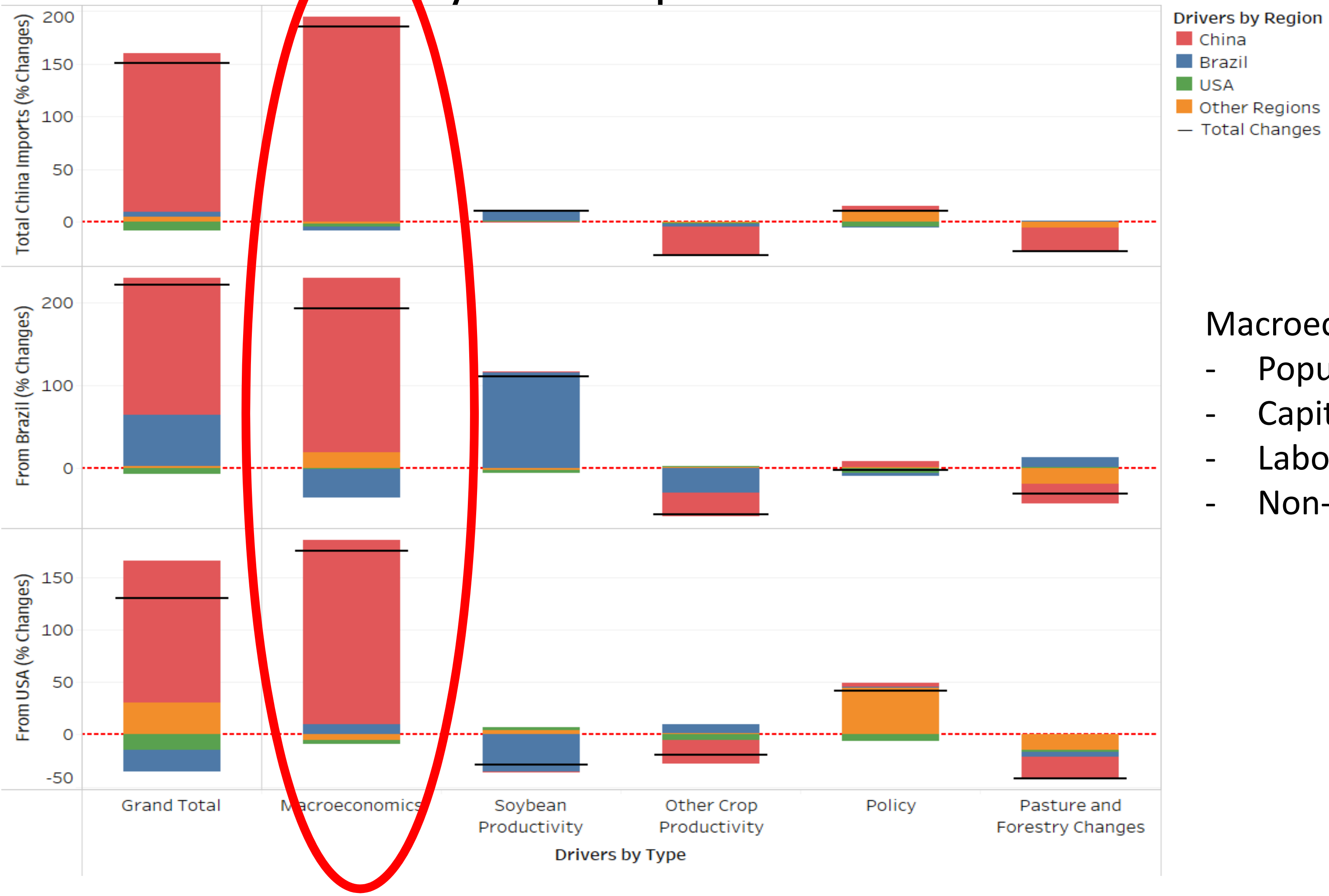
General equilibrium analysis of land use change

- CGE literature adds general equilibrium determinants of trade, production and land use change. Of particular relevance here are:
  - Productivity growth in the rest of the economy
  - Internal equilibrium: factor market clearing
  - External equilibrium: Balance of payments equilibrium
- These *can be as important as land-based productivity growth* for telecoupling and land use changes:
  - Strong productivity growth in the rest of the economy can shift comparative advantage – encouraging more land-based imports
  - In rapidly developing economies such as China, the high savings rate and rapid growth of capital stock encourages expansion of capital-intensive sectors. This draws labor into manufacturing and out of agriculture (Rybcynski Effect)
  - When manufacturing growth generates increased exports (as with China), the exchange rate must appreciate to restore external balance, leading to cheaper imports of land-based commodities

General Equilibrium decomposition of the drivers behind China's soybean imports: 2004-2011

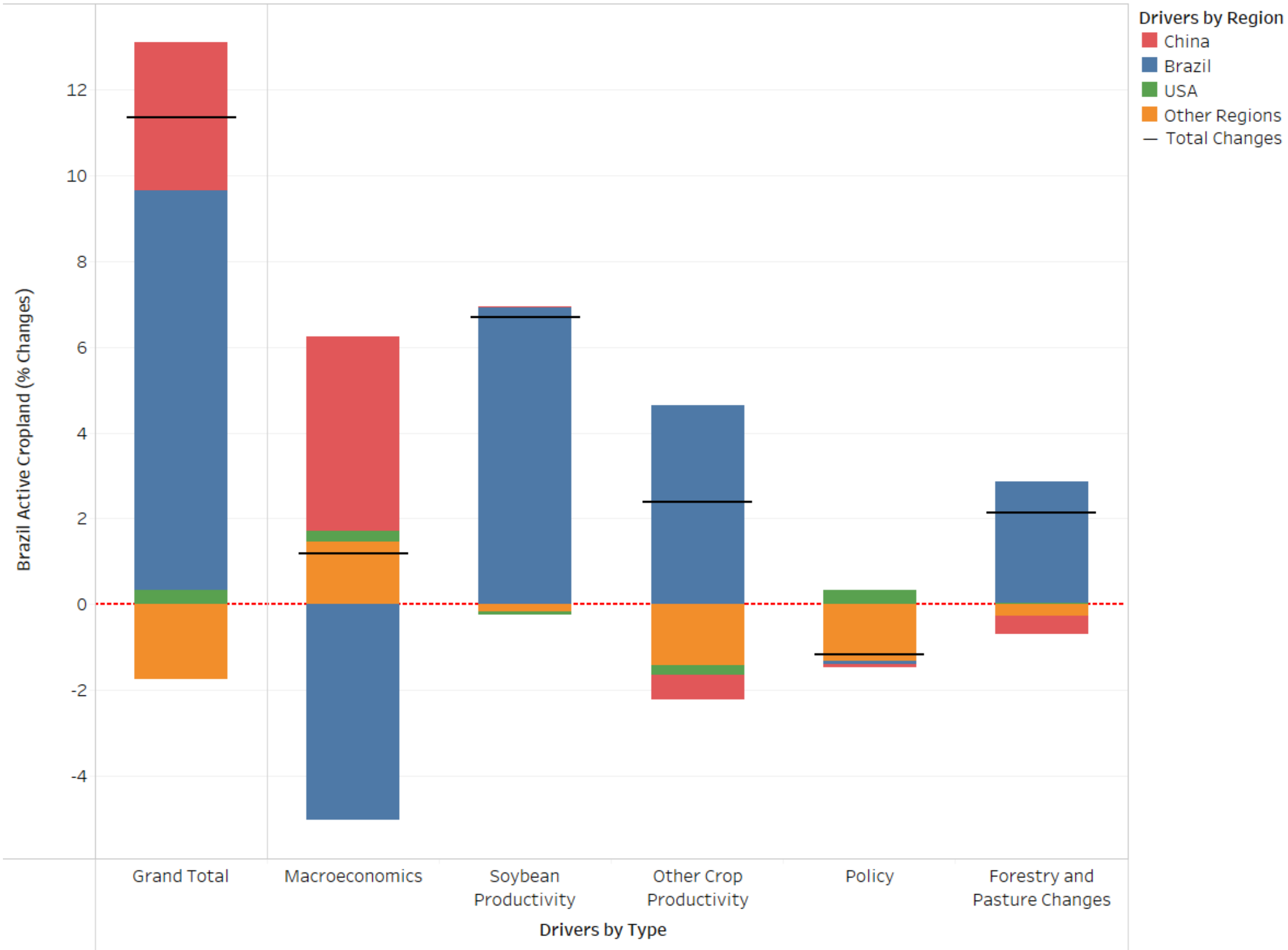


Macroeconomic factors:
- Population growth
- Capital accumulation
- Labor force growth
- Non-agr productivity

Growth in trade was driven by macroeconomic factors, including:
- Population growth, capital accumulation, labor force growth and non-agr productivity

Source: Yao, Hertel and Taheripour, in review

General Equilibrium decomposition of the drivers behind Brazil's cropland expansion: 2004-2011



Macro-economic factors cancel out here.. Agricultural productivity growth dominates net change

Source: Yao, Hertel and Taheripour, in review

Conclusions: Economic considerations are critical to land use/leakage debate

- Ignoring the intensive and demand margins leads to overstatement of land use change
- Ignoring supply response in RoW can lead to erroneous conclusions about both local and global land use and environmental change; biases results against Jevons' paradox
- Ignoring market segmentation leads to inaccurate predictions of land use change; biases results in favor of Jevons' paradox
- Geography of trade is critical to land use/leakage
- Ignoring GE constraints may lead to understatement of trade growth (e.g., China's soy imports)

Selected references

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