Yield Growth Patterns for Food Commodities:

Insights and Challenges*

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Outline

- ***The context***
- ***<u>Objective 1</u>: Construct global, aggregate food production and yield indices***
- ***<u>Objective 2</u>: Estimate the long term yield growth rate***
- ***<u>Objective 3</u>: Test whether global yield growth has decelerated***
- ***Conclusions and future research***

Will there be enough food production to feed the world?

- Global population to approach 10 billion by 2050, up from 8.2 billion in 2024
- Higher income; diversion to biofuels; undernourishment
- By some accounts, global crop production must double by 2050 (from ~ 2015 levels) to meet global food requirements

ctions ☰ The Washington Post
Democracy Dies in Darkness

Economic Policy

This terrifying chart shows we're not growing enough food to feed the world

By **Brad Plumer**
July 1, 2013

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World may not have enough food by 2050: Report

PUBLISHED WED, OCT 15 2014 • 12:03 PM EDT | UPDATED WED, OCT 15 2014 • 6:32 PM EDT

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We can't grow enough food to feed the world according to the Food Guide

CBC Radio · Posted: Aug 18, 2018 12:00 PM ET | Last Updated: August 17, 2018

PNAS

Opinion: To feed the world in 2050 will require a global revolution

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feed humanity makes the prospe
for making the projected 9.7 billio
food-secure and healthy in 2050.

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Yield Trends Are Insufficient to Double Global Crop Production by 2050

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Food requirements can only be met through yield growth

- Given land constraints, future food requirements can be met from productivity (mostly yield) increases.
- Yield growth, however, may be slowing due to:
  - ➢ Climate change
  - ➢ Declining soil fertility due to erosion, salinization, nutrient depletion
  - ➢ Declining supplies of groundwater, in turn, limiting irrigation
  - ➢ Excessive pesticide and fertilizer application
  - ➢ Declining pollinators
  - ➢ Inadequate research funding

Summary of the iterature

- Most literature concludes that crop yield growth experienced declines or, at best, stagnation
  - Cassman (1999); Alston et al. (2009); Finger (2010); Lin and Huybers (2012); Ray et al. (2012) Ray et al. (2013); Michel and Makowski (2013); Iizumi et al. (2014); Wei et al. (2015); Li et al. (2016); Van Ittersum et al. (2016); Madhukar et al. (2020).
- The literature also reports a high degree heterogeneity in yield growth across crops & regions.
- But some papers take a more positive view
  - Alexandratos (1999); Ausubel et al. (2013); *Nature* (2020).

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A global yield index

- We compute the global calorie-based yield index as follows:

$$y_t = \frac{\sum_{i=1}^{N} w_i Q_{it}}{\sum_{i=1}^{N} L_{it}}$$

$i = 1, \dots, N$: individual commodities; $t = 1, \dots, T$: year

w_i: calorific content of i per weight unit; Q_{it}: total output of crop i at year t in weight unit

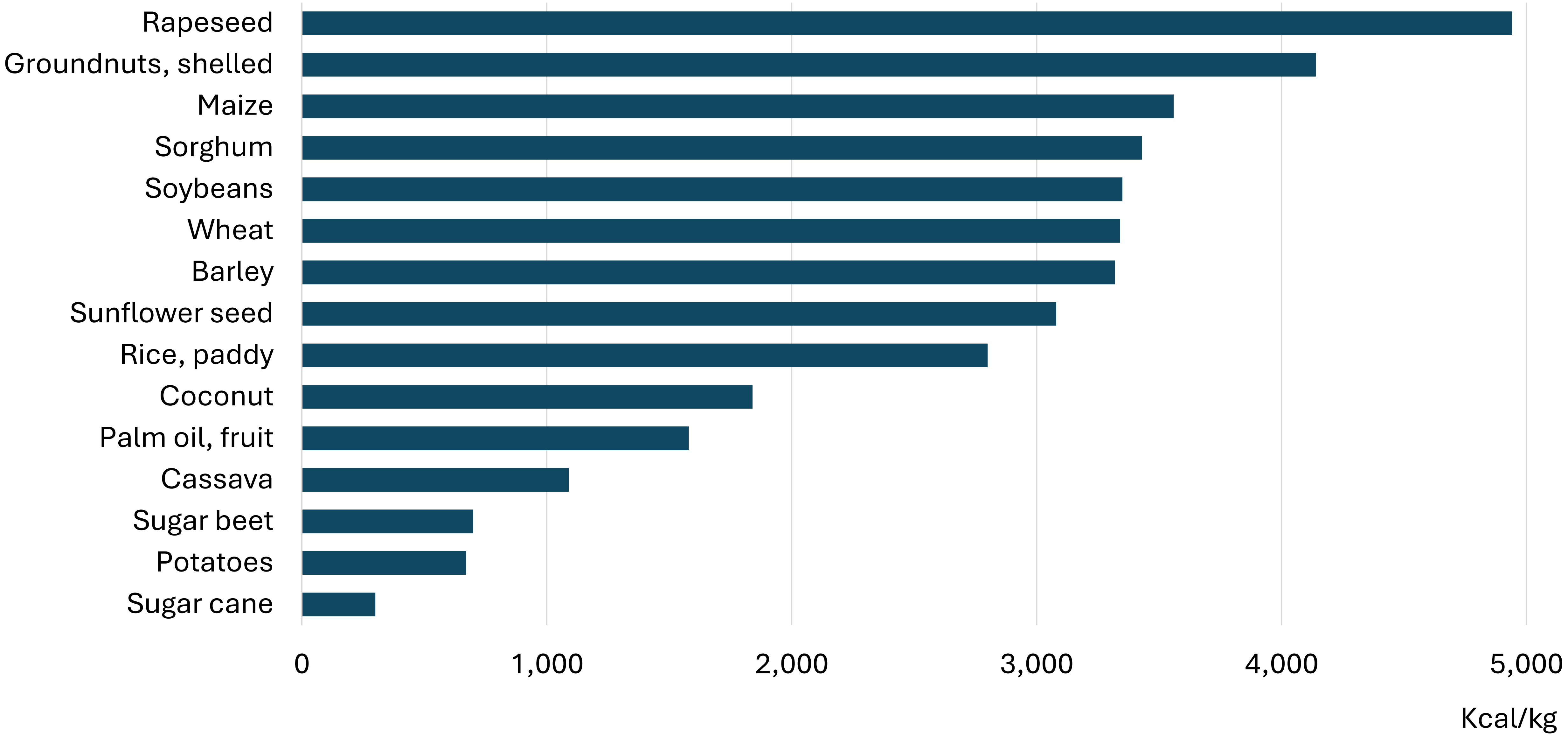
L_{it}: land allocated to commodity i at year t

- Calorific-based indices have been widely used on the consumption side:
  - ➢ Bekaert (1991); Sibhatu and Qaim (2017).
- They have not been used on the production side as much, with some exceptions:
  - ➢ Williamson and Williamson (1942); Roberts and Schlenker (2009); D'Odorico et al. (2014); Bobenrieth, Bobenrieth, and Wright (2013); Cassidy et al. (2013).

Data

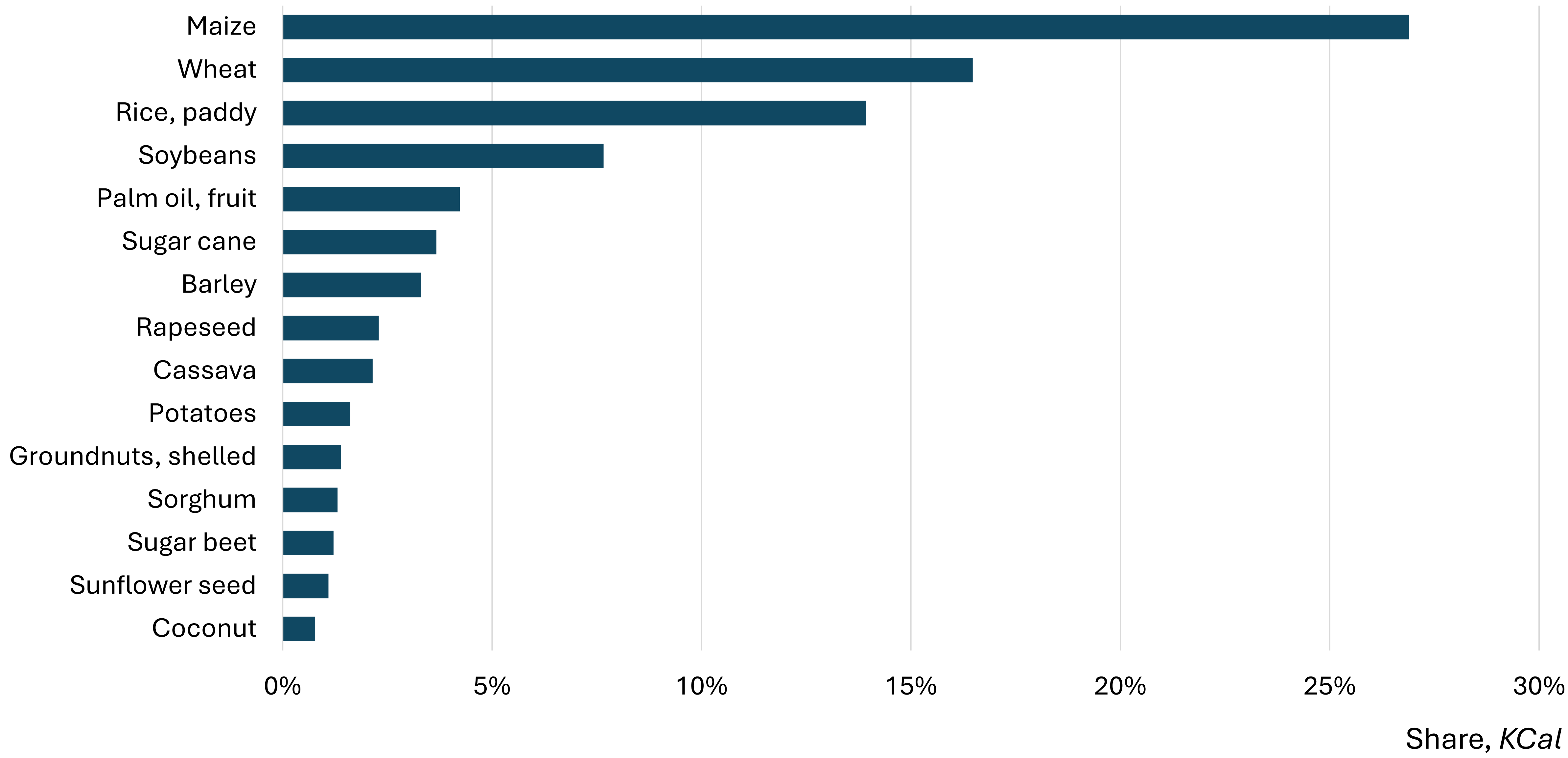
- Production and calorific content data for 144 major crops globally
  - Include cereals, oilseeds, vegetables, fruits, pulses, and other crops
  - Account for roughly 98% of total agricultural land and crop production
  - Data source: FAOSTAT, FAO food balance sheet, and USDA PS&D
- Sample period: 1961-2021
- We construct aggregate, regional, and commodity-specific yield indices

Calorific content for selected commodities



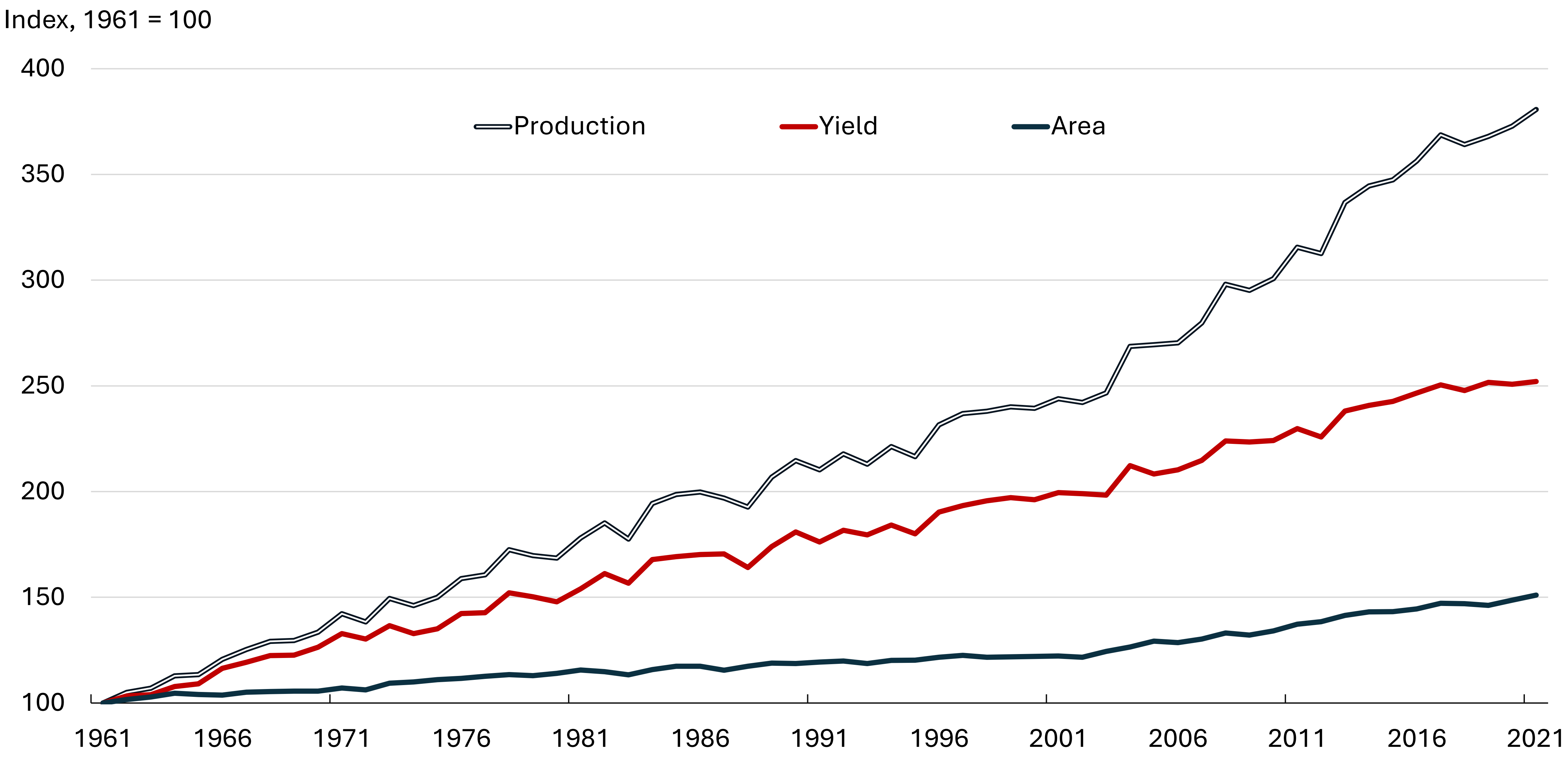
Sources: Authors calculation from FAO data

Global food production shares for selected commodities, 2019-21



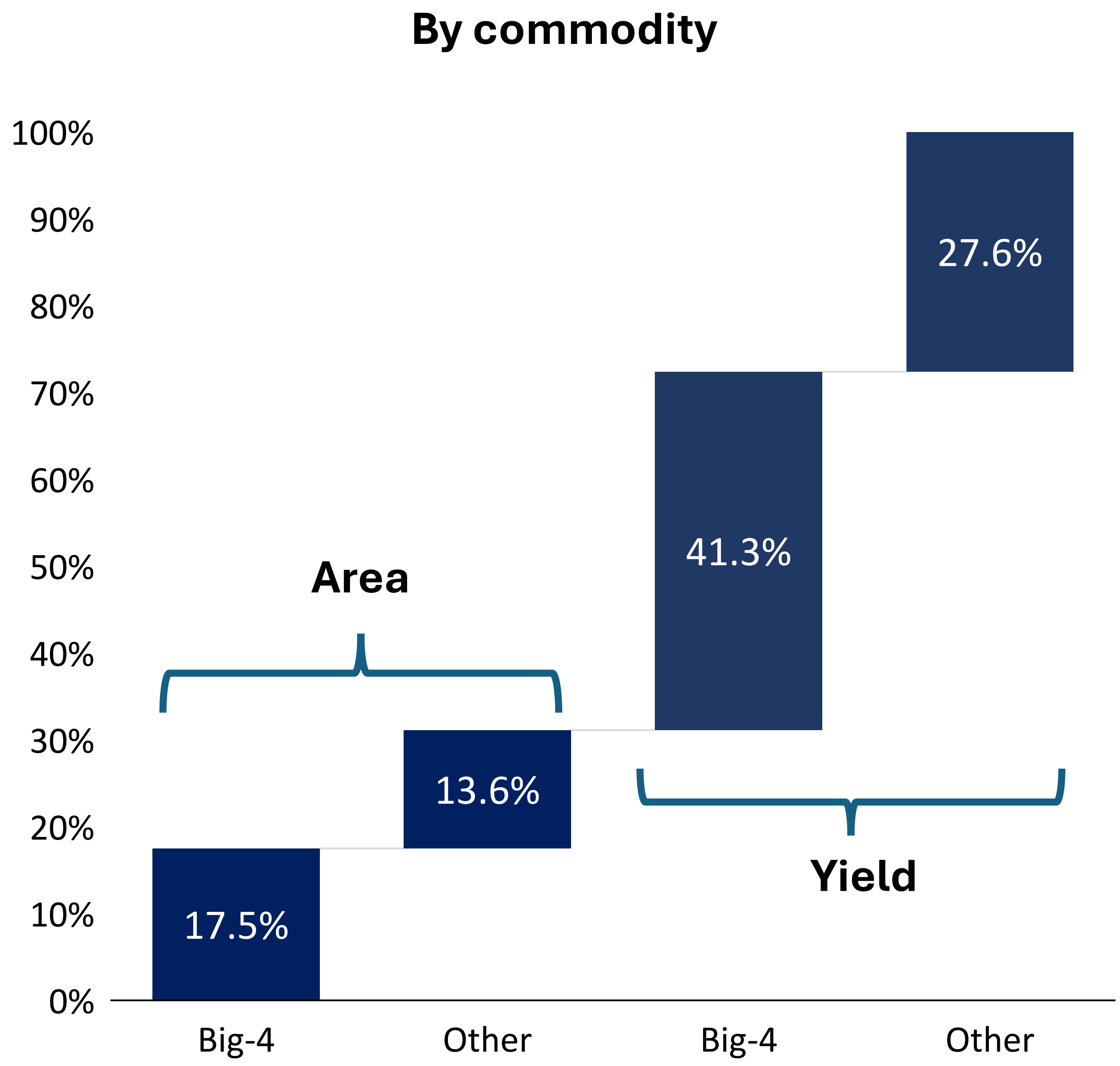
Sources: Authors calculation from FAO data

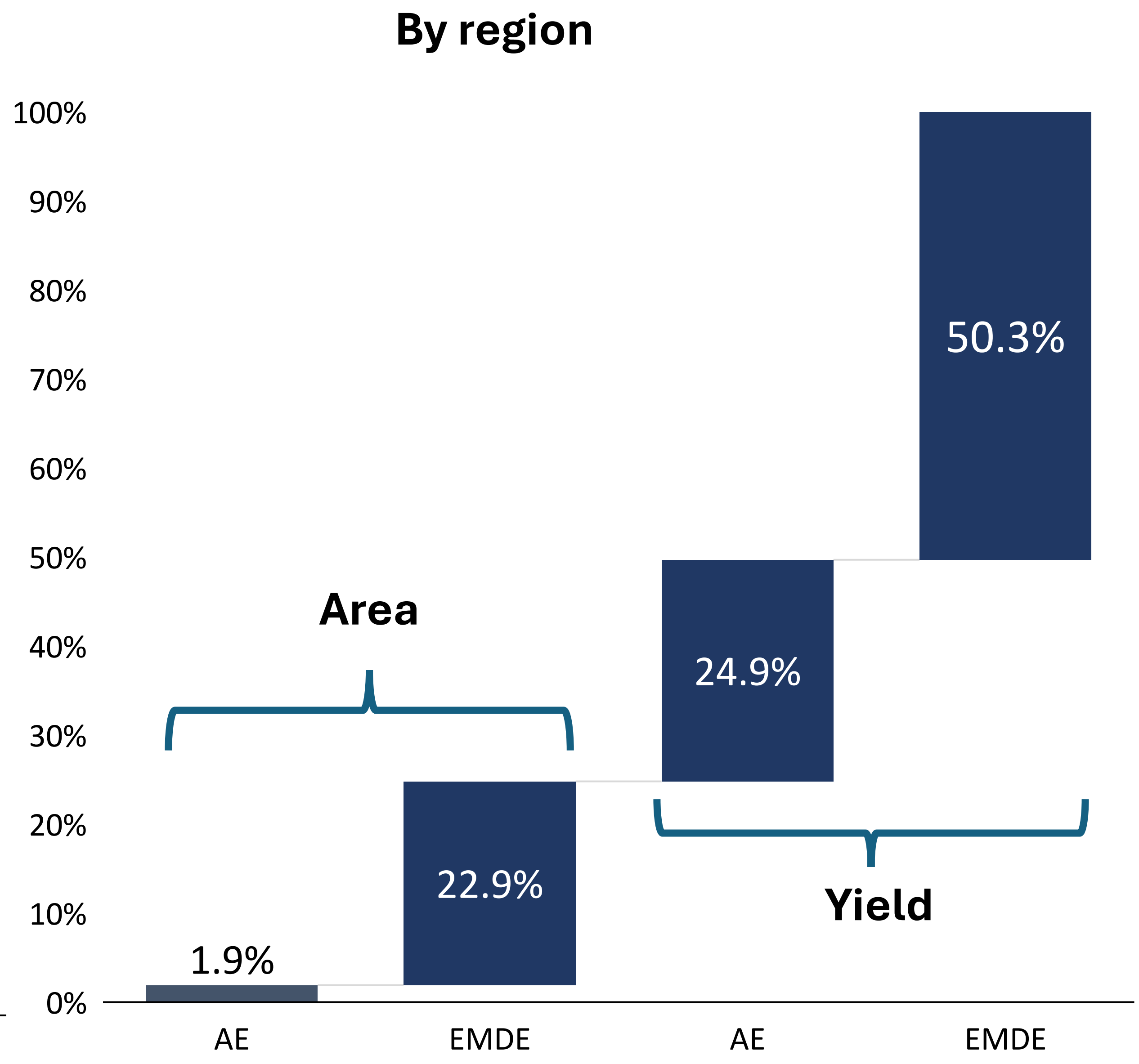
Global production, yield, and area



Sources: Authors calculation from FAO data

Contribution to production growth from 1961-63 to 2019-21

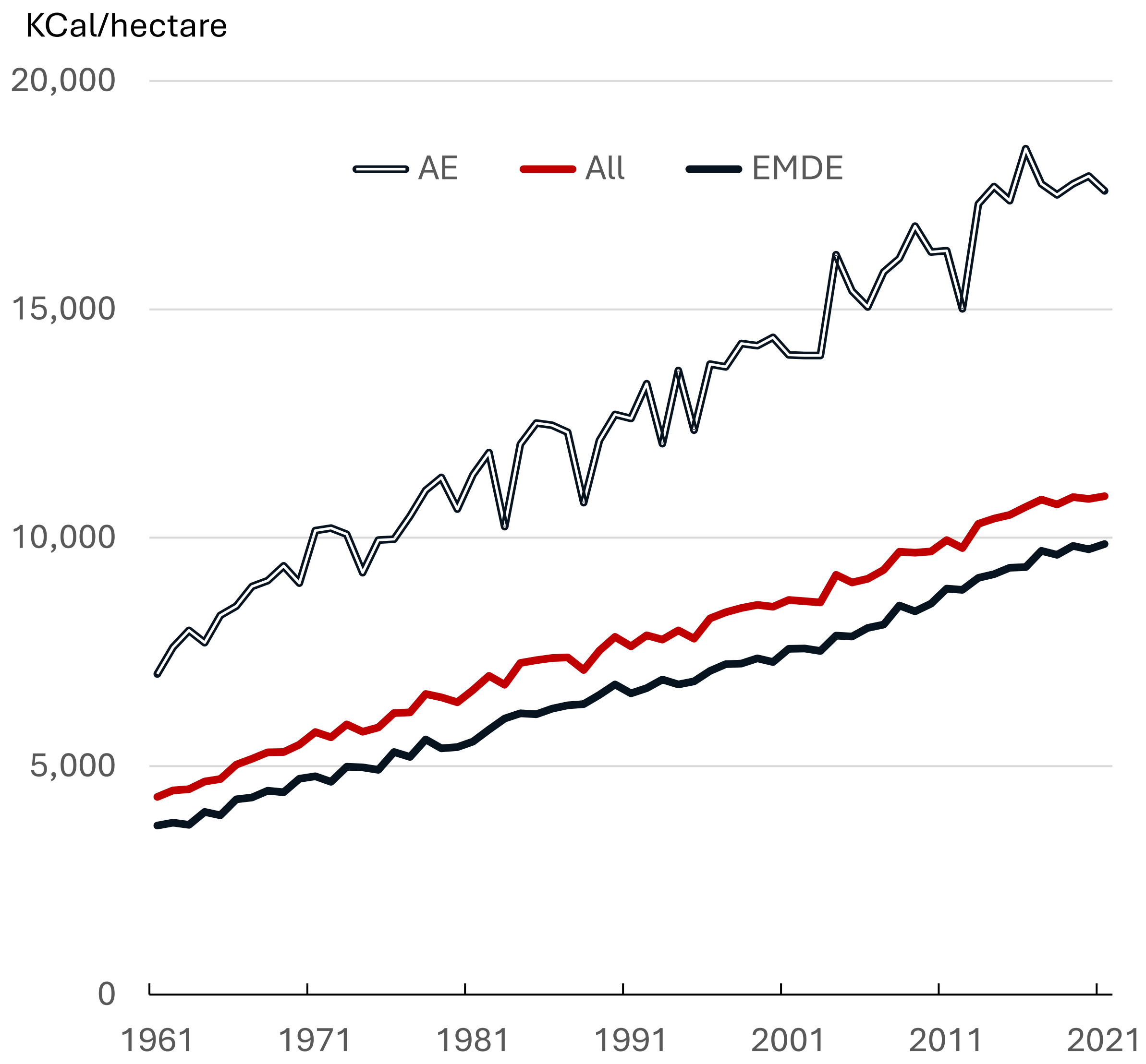




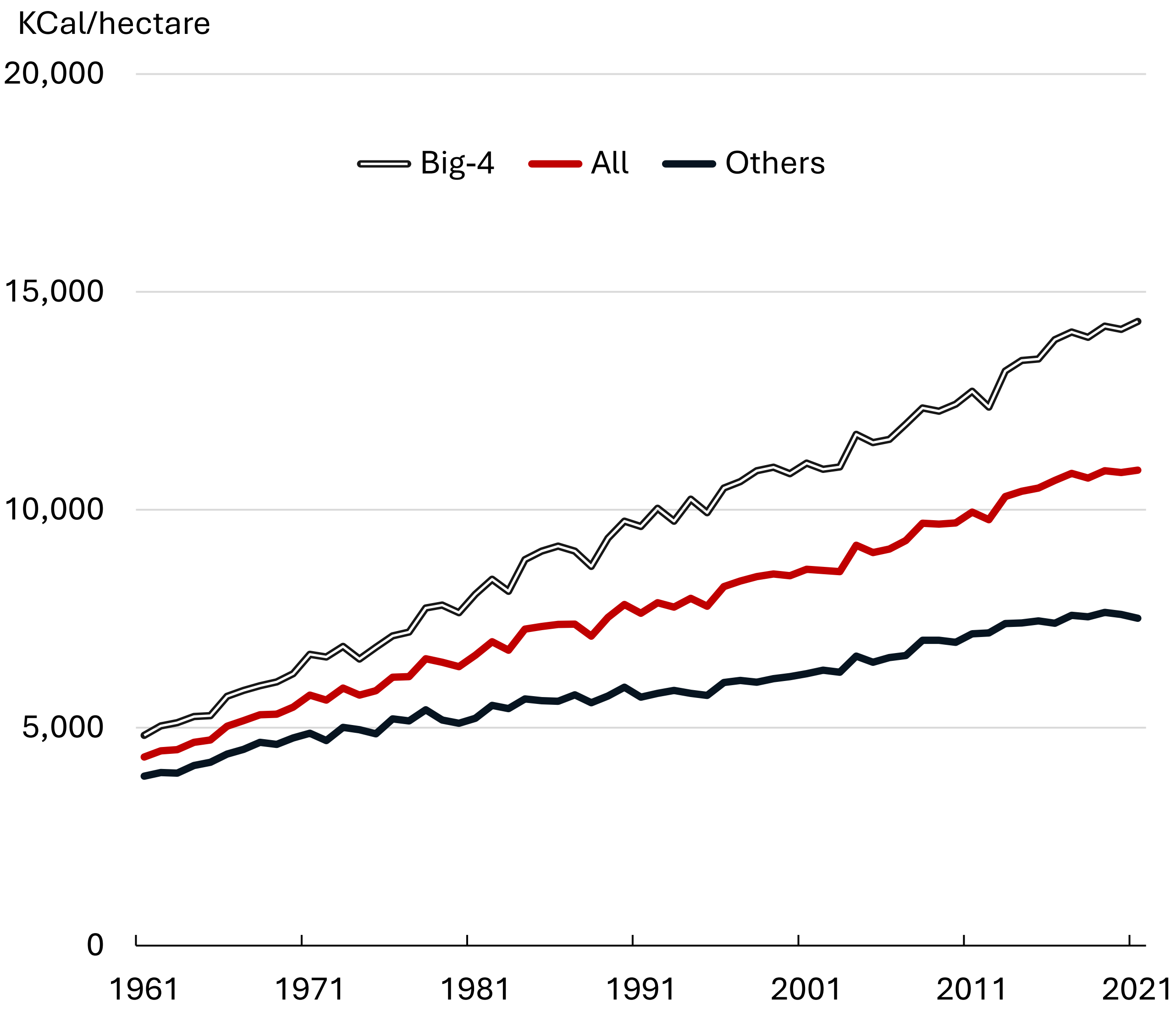
Notes: AEs= Advanced Economies; EMDEs = Emerging Markets and Developing Economies; Big-4 includes maize, wheat, rice, and soybeans.

Yield growth by country and commodity grouping

Country grouping



Commodity grouping



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Sources: Authors calculation from FAO data

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Defining and estimating growth rates

- In a two-period context, growth rate typically calculated as the percentage change

$$\rho = (y_1 - y_0)/y_0.$$

- Because $(y_1 - y_0)/y_0 \neq (y_0 - y_1)/y_1$, often growth rate reported as logarithm of the ratio,

$$\rho = \log\left(\frac{y_1}{y_0}\right).$$

- For multiple periods, the following regression model is estimated,

$$log(y_t) = \beta_0 + \beta_1 t + \varepsilon_t$$

  - growth rate is calculated as:

$$\rho = exp(\beta_1) - 1$$

  - growth rate is often reported as estimate of β_1 rather than ρ, since for small growth rates $\beta_1 \approx \rho$

The "problem" with the logarithmic regression

An important issue with logarithmic regression is that the results are sensitive to the "base effect".

- Maize yields grew at 2.6 percent per annum during 1961-71and 1.7 percent during 2011-21.
- However, maize yields grew at 203 *KCal* and 324 *KCal* annually during these two periods.
- Conclusion—yield growth for maize:
  - **decelerated** by one-third (based on the logarithmic specification)
  - but **accelerated** by more than 50 percent (based on the linear specification).

Choosing the right model

We utilize the following Box-Cox transformation:

$$y(\lambda) = \begin{cases} (y^{\lambda} - 1)/\lambda & \lambda \neq 0 \\ log(y) & \lambda = 0 \end{cases}$$

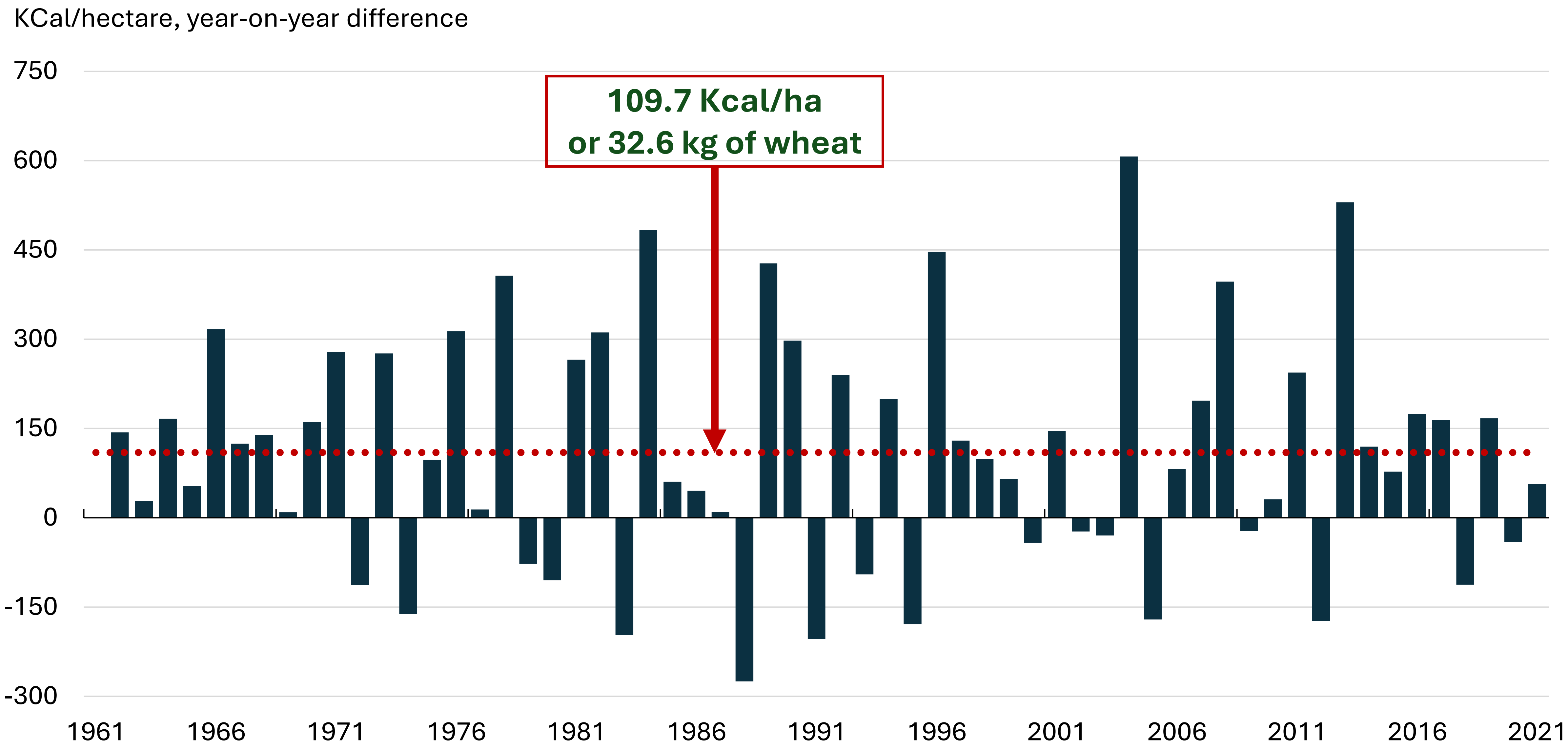
which embeds linear ($\lambda = 1,\ y_t = \beta_0 + \beta_1 t + \varepsilon_t$) and logarithmic ($\lambda = 0$, see earlier slide) transformation of the dependent variable.

- Based on the Box-Cox test, we conclude that data generation process for global yield growth is better represented by linear specification.
- We use linear model to (i) estimate growth rate; (ii) test for structural break.

Parameter estimates of yield growth

	All	Big-4	Other	AE	EMDE
Constant	4332.75*** (41.08)	4691.98*** (47.48)	4020.06*** (50.27)	7401.90*** (131.02)	3526.23*** (34.60)
Trend	108.98*** (1.33)	158.05*** (1.62)	59.12*** (1.41)	175.71*** (4.20)	102.05*** (1.43)
PP test	-5.47***	-6.14***	-3.81***	-7.33***	-4.28***
AIC	803.07	836.07	795.83	955.25	796.18

Yield growth



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Testing for non-linearities

Based on the linear specification we tested for two types of non-linearities:

- First, we introduced a time-square term to determine if the yield growth pattern has changed throughout the sample period:

$$y_t = \beta_0 + \beta_1 t + \beta_2 t^2 + \varepsilon_t$$

where β_1 approximates the growth rate and β_2 denotes the rate at which growth decelerates (when negative) or accelerates (when positive).

- Second, we tested for structural break:

$$y_t = \beta_0 + \beta_1 t + \beta_2 (t - \tilde{\tau}) D + \varepsilon_t,$$

where $\tilde{\tau}$ is the estimated break year, D is a dummy variable taking the value of one for the years after the break and zero otherwise. We used the QRL procedure to determine the break date (Andrews 1993; Andrews and Ploberger 1994)

Parameter estimates of yield growth w/ $Trend^2$

	All	Big-4	Other	AE	EMDE
Constant	4367.41^{***} (68.35)	4705.00^{***} (55.38)	4077.56^{***} (97.15)	7548.26^{***} (196.21)	3688.04^{***} (59.54)
Trend	105.67^{***} (5.65)	156.81^{***} (5.85)	53.64^{***} (6.85)	161.77^{***} (16.22)	86.64^{***} (5.00)
$Trend^2$	0.05 (0.09)	0.02 (0.10)	0.09 (0.10)	0.22 (0.27)	0.25^{***} (0.08)
PP test	-5.52^{***}	-6.15^{***}	-3.93^{***}	-7.49^{***}	-5.01^{***}
AIC	804.60	838.03	796.37	956.56	785.64

Parameter estimates of yield growth w/ structural break in 1993

	All	Big-4	Other	AE	EMDE
Constant	4366.77*** (55.31)	4679.28*** (45.70)	4091.72*** (82.58)	7574.11*** (166.17)	3640.02*** (41.18)
Trend_before	106.85*** (2.80)	158.84*** (2.82)	54.64*** (3.60)	164.95*** (8.07)	94.94*** (2.41)
Trend_after	4.47 (5.40)	-1.67 (6.47)	9.42 (5.85)	22.64 (16.58)	14.96*** (4.77)
PP test	-5.54***	-6.15***	-4.07***	-7.67***	-4.93***
AIC	804.24	838.00	793.57	955.48	786.86

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Conclusion

- We find that, contrary to the commonly held view, there is no evidence of deceleration in global yield growth (in fact, there is weak evidence of acceleration),
- This suggests that while certain regions, commodities, or countries may experience stagnation or slower growth in yields, these are balanced by yield acceleration in other areas.
- On a global scale, yields have consistently increased from 1961 to 2021 at a rate equivalent to 109 KCal/ha per year, which translates to an additional 32.6 kilograms of wheat per hectare annually.

Further discussions

- Challenges:
  - Increasing frequency and intensity of adverse weather patterns, exacerbated by climate change
  - Distorting trade polices that restrict food availability in regions experiencing food deficits
  - Equitable access to food across income groups
- The aggregate approach proposed useful for future research
  - Assessment of environmental strain: water usage, chemical input use
  - Identifying patterns of production or yield variability
  - Understand susceptibility of commodities and regions to changes in weather patterns and climate phenomena