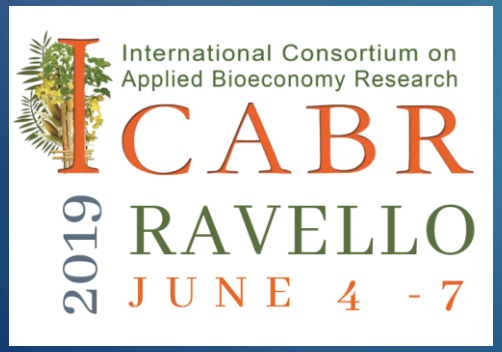
Measurement Considerations for Prioritizing Input Use among Smallholder Farmers:

Examples from Ethiopia and Tanzania



TRAVIS W. REYNOLDS[1], C. LEIGH ANDERSON[2], DIDIER ALIA[2],
PIERRE BISCAYE[3], JOSHUA MERFELD[4]

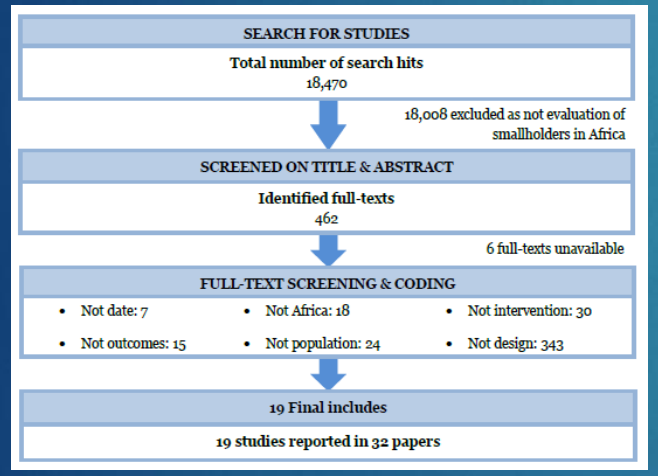
[1] UNIVERSITY OF VERMONT
[2] UNIVERSITY OF WASHINGTON
[3] UNIVERSITY OF CALIFORNIA – BERKELEY
[4] NEW YORK UNIVERSITY – WAGNER

Returns to Smallholder Input Use

- Many policies and programs seek to promote use of inputs (improved seed, fertilizer, and others) among smallholders in low-income countries
- Prioritizing inputs requires understanding each input's potential to boost production and overcome yield gaps (Sheahan & Barrett, 2017)
- To this end some recent research efforts have used **machine-learning / meta-analyses** to synthesize findings across multiple studies to draw conclusions about relative returns to input use

Sheahan M., & Barrett C.B. (2017). Ten striking facts about agricultural input use in Sub-Saharan Africa. *Food Policy*, *67*, 12-25.

Findings from Meta Analysis Methods



Stewart R., Langer L., Da Silva N. R., et al. (2015). The Effects of Training, Innovation and New Technology on African Smallholder Farmers' Wealth and Food Security: A Systematic Review. Campbell Systematic Reviews, 11(16).

- **Sileshi et al. (2008):** Estimates from 94 peer-reviewed publications from Sub Saharan Africa suggest positive returns to legume intercropping relative to unfertilized maize
- **Rusinamhodzi et al. (2011), Corbeels et al. (2014), & Himmelstein et al. (2016):** Estimated returns to conservation agriculture in small-holder farm systems vary depending on climate, soil quality, farm management, and cropping systems that vary across studies
- **Tonitto et al. (2016):** Published studies on sorghum in Sub Saharan Africa suggests a combination of fertilizer inputs and diversified rotations hold promise for yield gains

Researcher Measurement Decisions with Smallholder Consequences

- To what degree do measurement choices – including **variable construction** and **data cleaning choices** – impact estimates of smallholder productivity?
- How might measurement decisions affect estimated associations between agricultural interventions of interest, such as **seed** or **fertilizer use**, and smallholder productivity?
- Examples use plot- and crop-level microdata from the World Bank LSMS-ISA in Tanzania and Ethiopia (2015/16)
  - Replication codes: https://github.com/EvansSchoolPolicyAnalysisAndResearch/335_Agricultural-Indicator-Curation

Anderson C.L. & Reynolds T.W. (2019). In Bioversity International, *Agrobiodiversity Index Report 2019: Risk and Resilience*. Bioversity International, Rome, Italy. ISBN: 978-92-9255-125-4 https://hdl.handle.net/10568/100820.

Maize Area Cultivated (Hectares)

Construction Decision: ➡

Info. for Trimming/Replacing

Select: Season *or* Season(s)

LRS + SRS (ag2_01 + ag2_12)
12,471 LRS and SRS plots
? How to count multiple harvests on a single plot

LRS only (ag2_01)
9,157 LRS plots

Filter by:
Cultivated plots only (ag3a_03)
Maize plots only (ag3a_07)

Select: Area Planted *or* Area Harvested

Area Planted → Select Area Measure
4,413 with area planted
by farmer measure or GPS

Area Harvested: Farmer Report (ag4a_21)
N=4,138 ***Min: 0.004*** ***Max: 50.586***
Mean: 0.600 ***Median: 0.404***

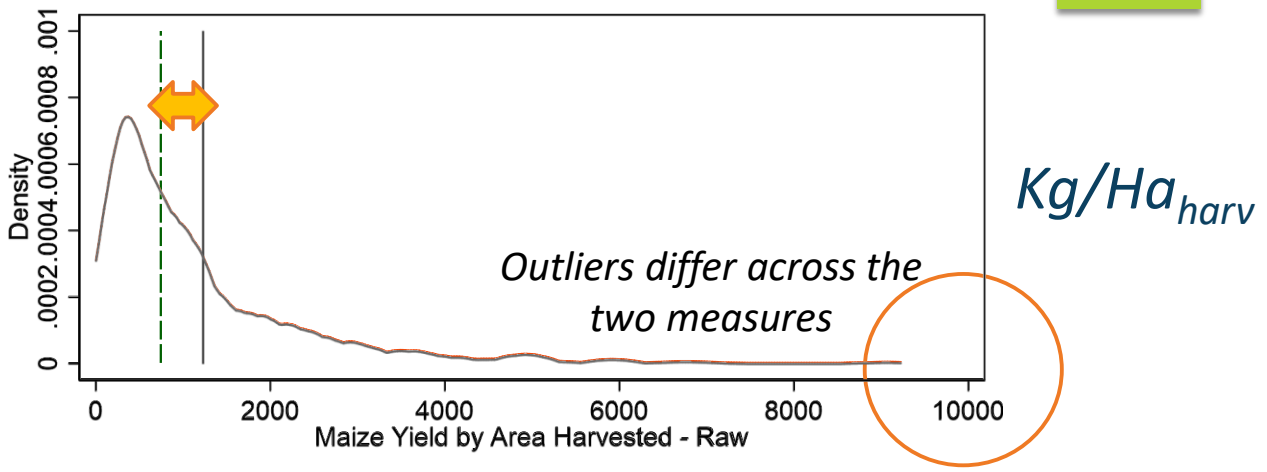
Large, uniform maize field

Smallholder maize plot, drought conditions

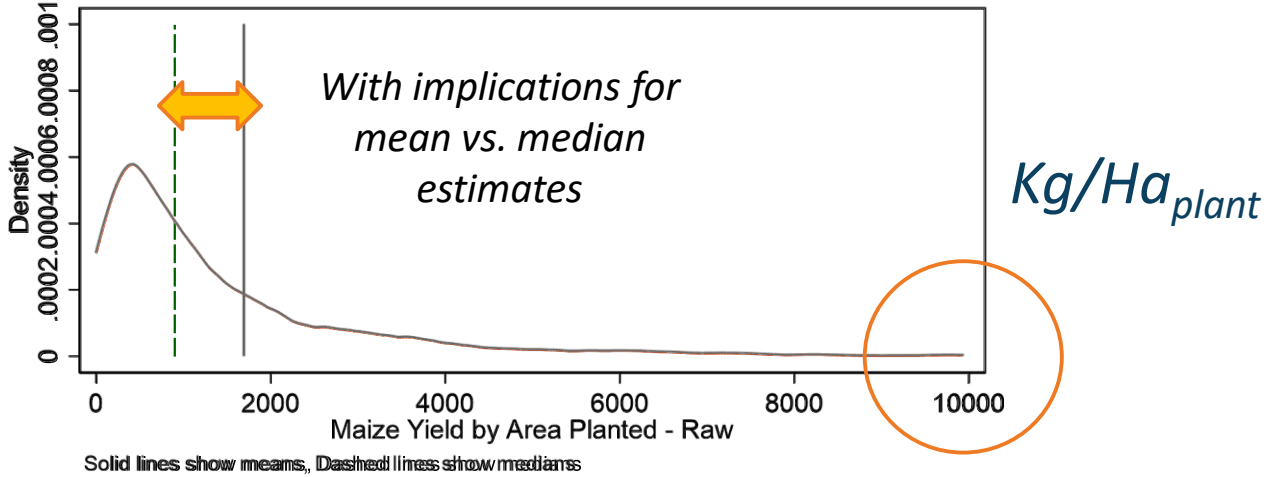
Area Planted

Area Planted

Distribution of Maize Yield (kg/ha) for Smallholders by Area Harvested or Area Planted: *Tanzania*

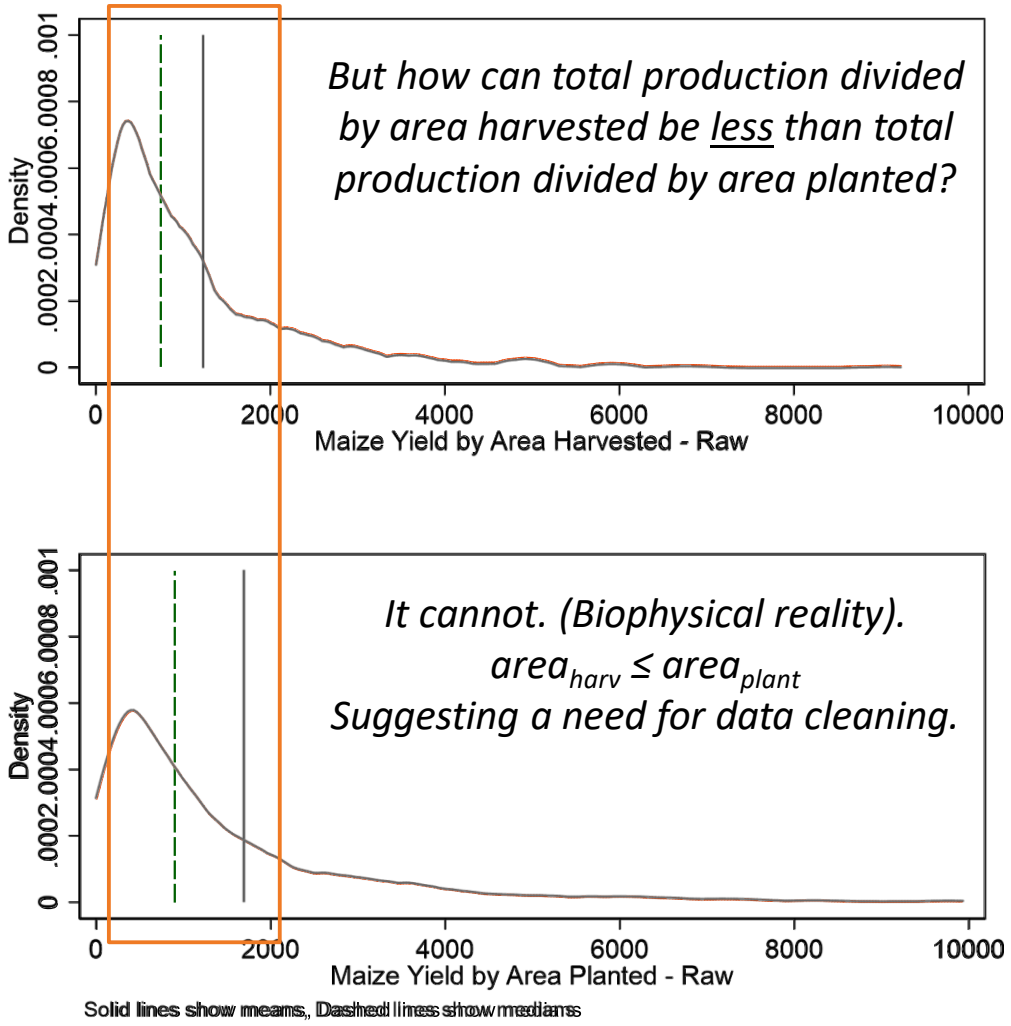


Kg/Ha_{harv}



Kg/Ha_{plant}

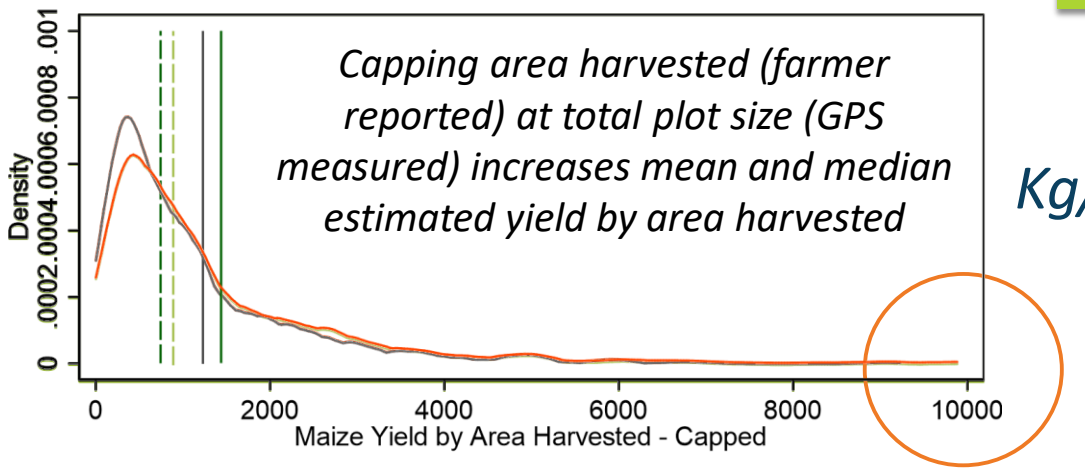
Distribution of Maize Yield (kg/ha) for Smallholders by Area Harvested or Area Planted: *Tanzania*



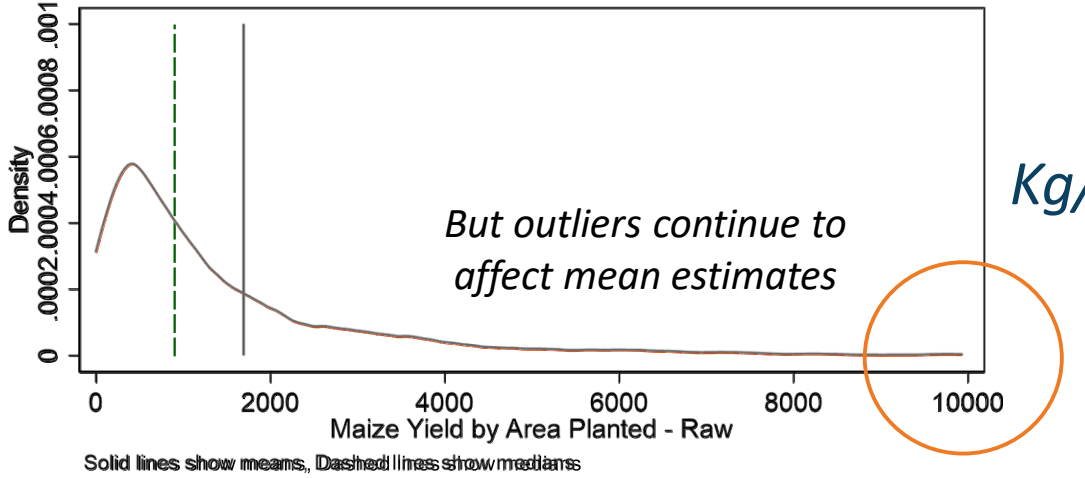
Kg/Ha_{harv}

Kg/Ha_{plant}

Distribution of Maize Yield (kg/ha) for Smallholders by Area Harvested or Area Planted, Capped: *Tanzania*

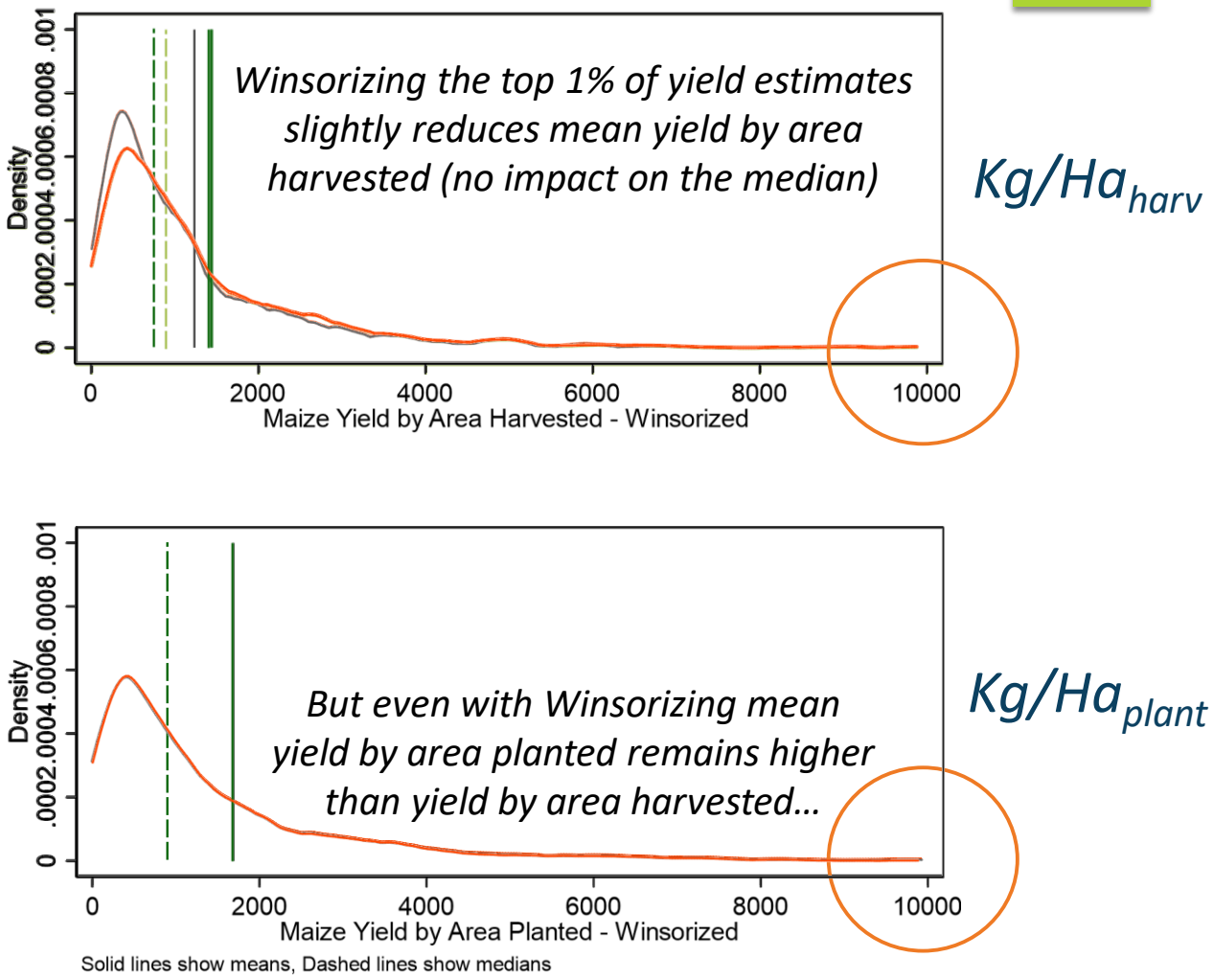


Kg/Ha$_{harv}$



Kg/Ha$_{plant}$

Distribution of Maize Yield (kg/ha) for Smallholders by Area Harvested or Area Planted, Capped, and Winsorized: *Tanzania*



Kg/Ha_{harv}

Kg/Ha_{plant}

Maize Area Cultivated (Hectares)

Construction Decision: ➡

Info. for Trimming/Replacing

Select: Season *or* Season(s)

LRS + SRS (ag2_01 + ag2_12)
12,471 LRS and SRS plots
? How to count multiple harvests on a single plot

LRS only (ag2_01)
9,157 LRS plots

Filter by:
Cultivated plots only (ag3a_03)
Maize plots only (ag3a_07)

Small, intercropped maize field

Further considerations

- Account for intercrops (ag4a_04)
- Account for trees
- Limitations to area planted categories reported in ag4b_02 (1/4, 1/2, 3/4)
- Accounting for multiple harvests on a single plot?

Select: Area Planted *or* Area Harvested

Area Planted → Select Area Measure
4,413 with area planted by farmer measure or GPS

Area Harvested: Farmer Report (ag4a_21)
N=4,138 ***Min: 0.004*** ***Max: 50.586***
Mean: 0.600 ***Median: 0.404***

Modify by:
Entire area (ag4a_01)
Partial area (ag4a_02)

Select: Area Measure or Measures

Area Planted: Farmer Report (ag2a_04)
N = 4,412 ***Min: 0.010*** ***Max: 28.328***
Mean: 0.791 ***Median: 0.405***

Area Planted: GPS (ag2a_09)
N = 3,736 ***Min: 0*** ***Max: 27.235***
Mean: 0.869 ***Median: 0.415***

Consider: By weather (ag2a_10, ag2b_10)

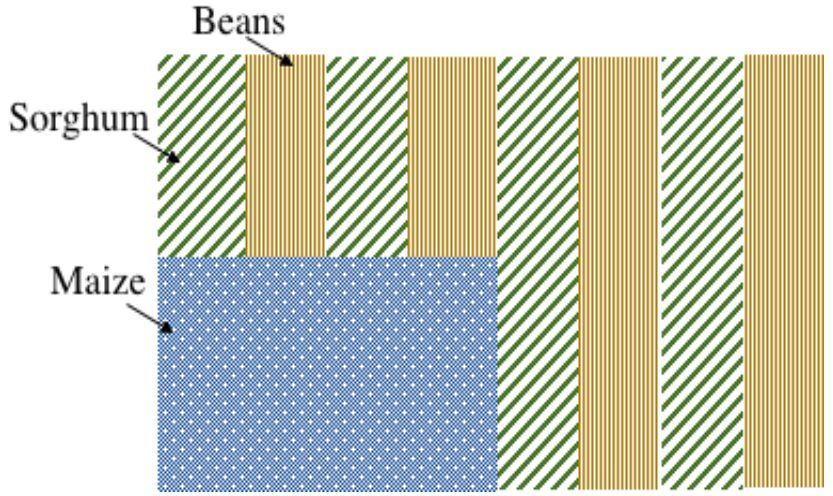
Accounting for Multiple Crops on a Single Plot

Wineman A., Anderson C.L., Reynolds, T.W., Biscaye, P. (2018) Crop yield measurement on intercropped plots. Evans School Policy Analysis and Research Group (EPAR) Technical Report No. 354

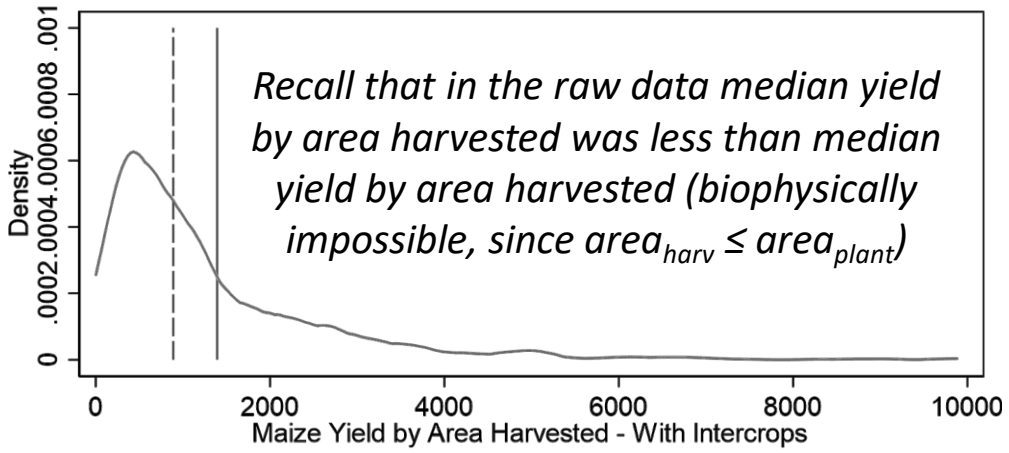
Example Area Calculations in the Presence of Multiple Crops (1 ha plot)

Wineman A., Anderson C.L., Reynolds, T.W., Biscaye, P. (2018) Crop yield measurement on intercropped plots. Evans School Policy Analysis and Research Group (EPAR) Technical Report No. 354

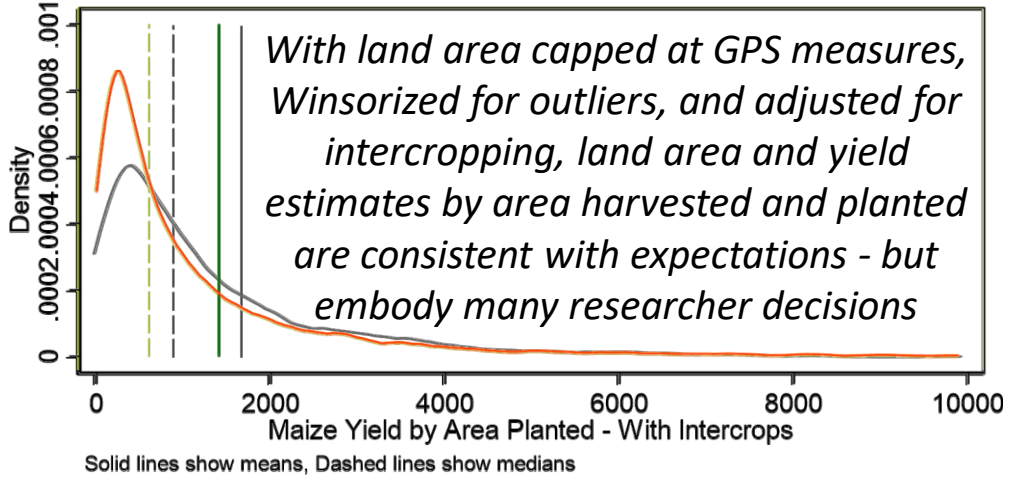
	Area under …		
	Maize	**Sorghum**	**Beans**
Method 1	1 ha	1 ha	1 ha
Method 2	0.25 ha	0.75 ha	0.75 ha
Method 3	0.33 ha	0.33 ha	0.33 ha
Method 4	0.25 ha	0.375 ha	0.375 ha



Distribution of Maize Yield (kg/ha) for Smallholders by Area Harvested or Area Planted, Capped, Winsorized, and Intercropped: *Tanzania*



Kg/Ha_{harv}



Kg/Ha_{plant}

Defining "Smallholders"

Alia D. (2018). Who is a smallholder farmer? Features and implications of alternative definitions with an application to household survey data in Nigeria, Tanzania, and Ethiopia. *Sustainability & Development Conference*. University of Michigan.

Biscaye P., Anderson C.L., Reynolds T.W. (2017). Tracking smallholder farm households. Evans School Policy Analysis and Research Group (EPAR) Technical Report No. 356.

Example Alternative Definitions of "Smallholder"

Alia D. (2018). Who is a smallholder farmer? Features and implications of alternative definitions with an application to household survey data in Nigeria, Tanzania, and Ethiopia. *Sustainability & Development Conference*. University of Michigan.

Smallholder Definitions

AGRA (2017) Smallholder Definitions

	Less than 33% of crop value sold	More than 33% of crop value sold
Less than 2ha farm size	Small Non-Commercial Farm	Small Commercial Farm
More than 2ha farm size	Large Commercial Farm	

Mellor & Malik (2016) Smallholder Definitions

	Less than 5% of crop value sold	Between 5% and 50% of crop value sold	More than 50% of crop value sold
Less than 33% of income from non-farm sources	Subsistence Farm	Pre-commercial Farm	Specializing Farm
More than 33% of income from non-farm sources	Transitioning Farm		Diversified Farm

Proportion of Rural Farmers Defined as Smallholders, by Definition

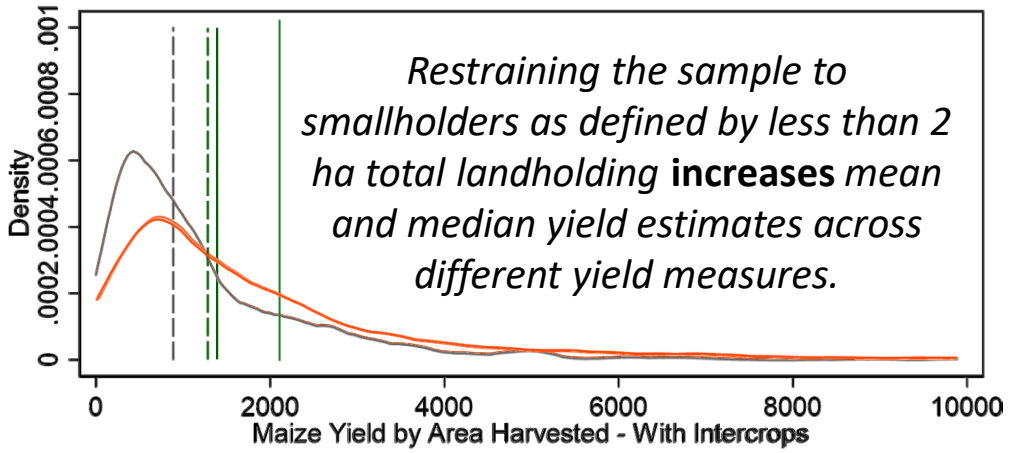
Share of Smallholders, by Definition

	Tanzania	Ethiopia
Farm Size less than 2ha	65%	75%
Farm Size less than 4ha	84%	93%
RuLIS Smallholder	13%	16%
AGRA Subsistence Farm	7%	26%
Mellor Small Non-Commercial Farm	32%	54%

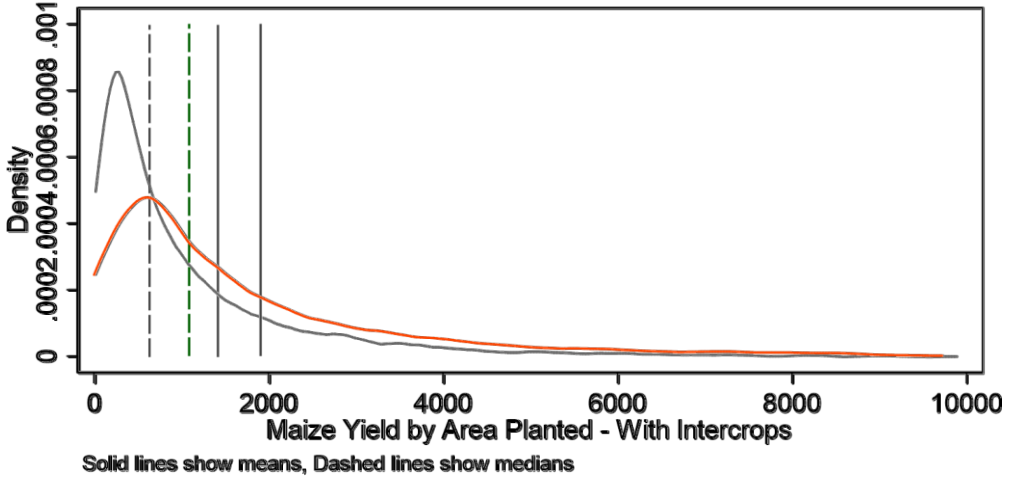
- The proportion of smallholders in the Tanzania and Ethiopia LSMS-ISA sample ranges from 7% to 93% of respondents, depending on the definition of "smallholder" used.

Alia D. (2018). Who is a smallholder farmer? Features and implications of alternative definitions with an application to household survey data in Nigeria, Tanzania, and Ethiopia. *Sustainability & Development Conference*. University of Michigan.

Distribution of Maize Yield (kg/ha) for Smallholders by Area Harvested or Area Planted, Capped, Winsorized, and Intercropped: *Tanzania*



Kg/Ha_{harv}



Kg/Ha_{plant}

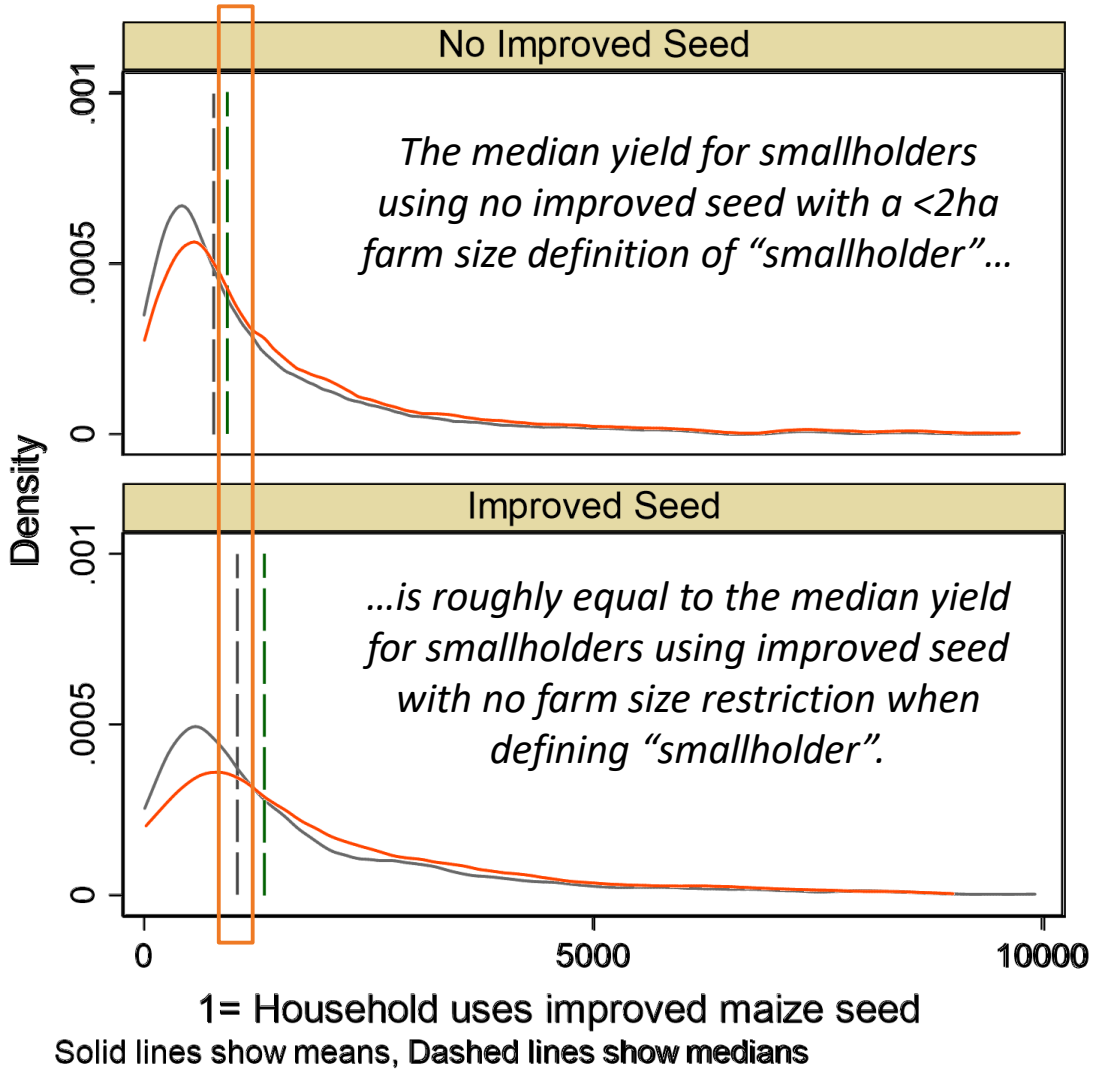
Data Cleaning, Measurement, and Returns to Input Use among Smallholder Farmers

- Many policies and programs seek to promote use of inputs (improved seed, fertilizer, and others) among smallholders in low-income countries.
- Prioritizing inputs requires understanding each input's potential to increase production and overcome yield gaps.

- *However the results of **data cleaning and variable choices** may have substantial impacts on estimated productivity.*

Returns to Smallholder Input Use

- Improved Seed in Tanzania, Smallholders < 2ha



Among smallholders (<2ha) in the Tanzania data improved seed use is associated with higher yields, with a median yield of 827 kg/ha with improved seed versus 565 kg/ha without

+ 262 kg/ha

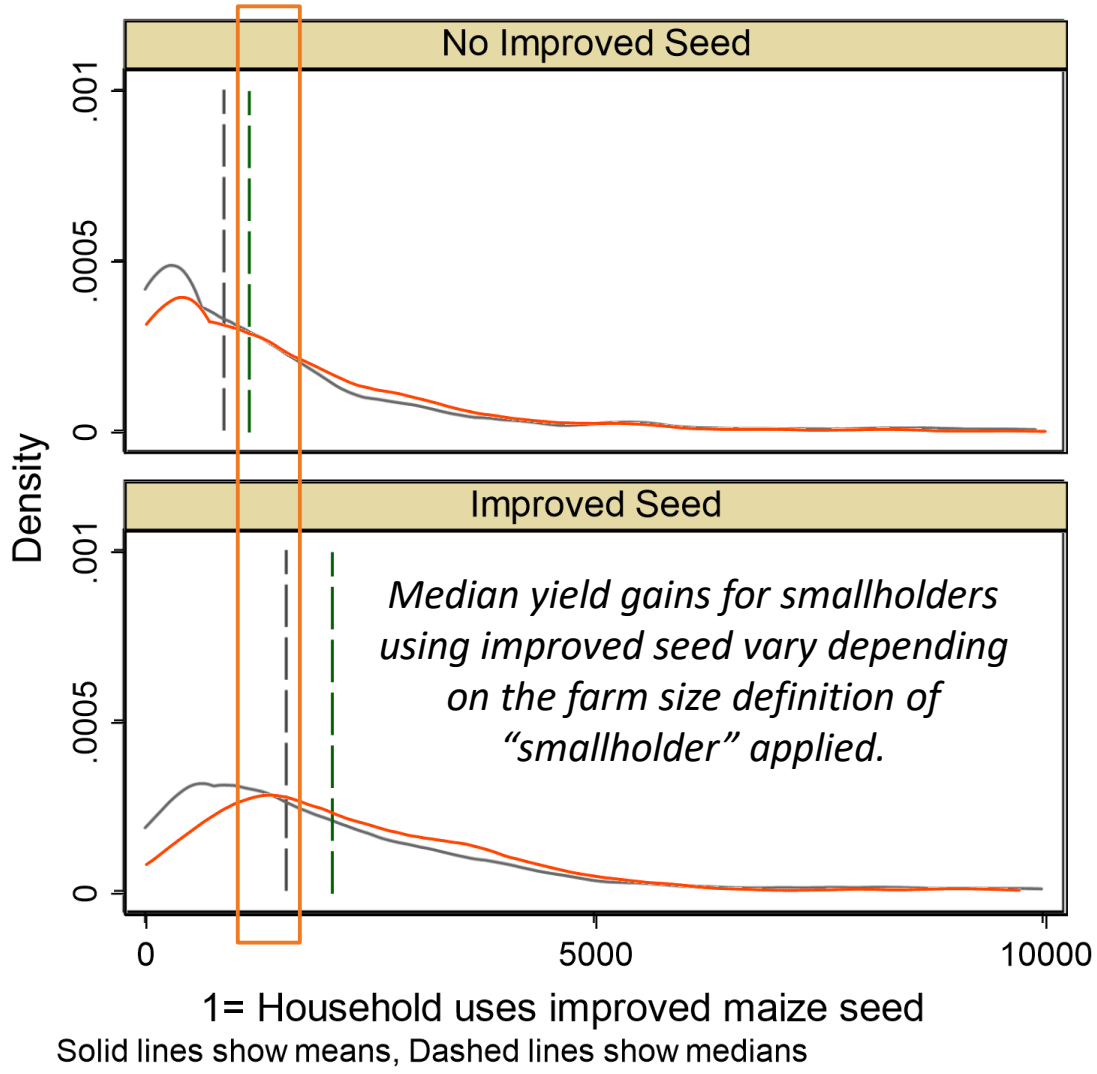
Median Intercropped and Pure Stand Maize Yield (kg/ha) for Smallholders (by Area Planted): *Tanzania*

Yield of Smallholders, by Definition

	Intercropped			Pure Stand
	Method 2	Method 3	Method 4	
Farm Size < 2 ha	549	827	896	808
Farm Size < 4 ha	509	778	865	737
RuLIS Smallholder	494	706	712	974
AGRA Subsistence Farm	577	577	751	297
Mellor Small Non-Commercial Farm	431	593	624	627

Returns to Smallholder Input Use

- Improved Seed in Ethiopia, **Smallholders < 2ha**



Among smallholders (<2ha) in the Ethiopia data improved seed is associated with much higher yields, with a median yield of 2,004 kg/ha with improved seed versus 1,044 kg/ha without

+ 960 kg/ha

Median Intercropped and Pure Stand Maize Yield (kg/ha) for Smallholders (by Area Planted): *Ethiopia*

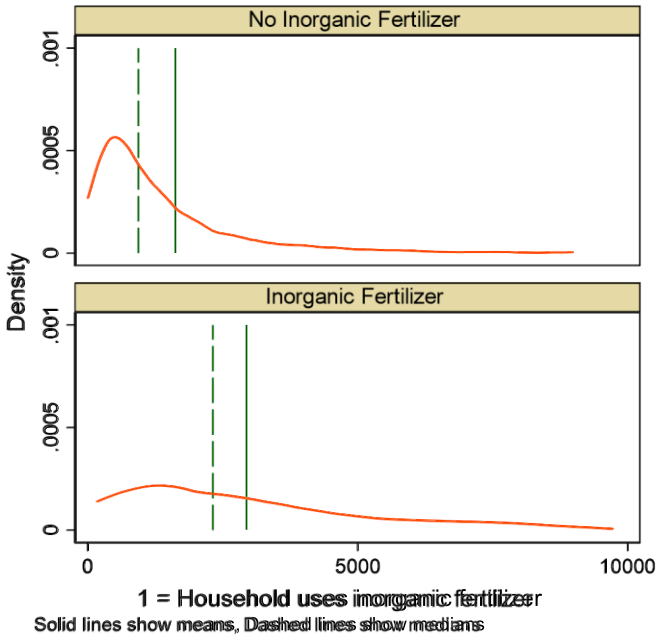
Yield of Smallholders, by Definition

	Intercropped			Pure Stand
	Method 2	Method 3	Method 4	
Farm Size < 2 ha	1957	2628	1957	1299
Farm Size < 4 ha	1679	1919	1668	1485
RuLIS Smallholder	1568	1840	1579	1558
AGRA Subsistence Farm	1325	1424	1325	1413
Mellor Small Non-Commercial Farm	1983	2628	1983	1459

Returns to Smallholder Input Use

- Fertilizer, in aggregate

Returns to Fertilizer Use (Y/N)

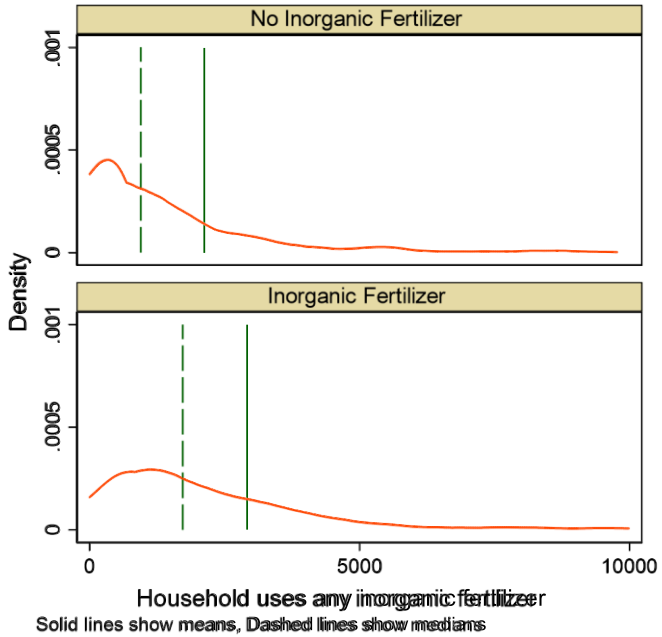


Tanzania:

Median maize yields among smallholder farmers are 1,472 kg/ha with fertilizer use vs. 593 kg/ha without

Ethiopia:

Median maize yields among smallholder farmers are 1,601 kg/ha with fertilizer use vs. 857 kg/ha without



Returns to Smallholder Input Use

- Fertilizer, by unit (kg/ha)

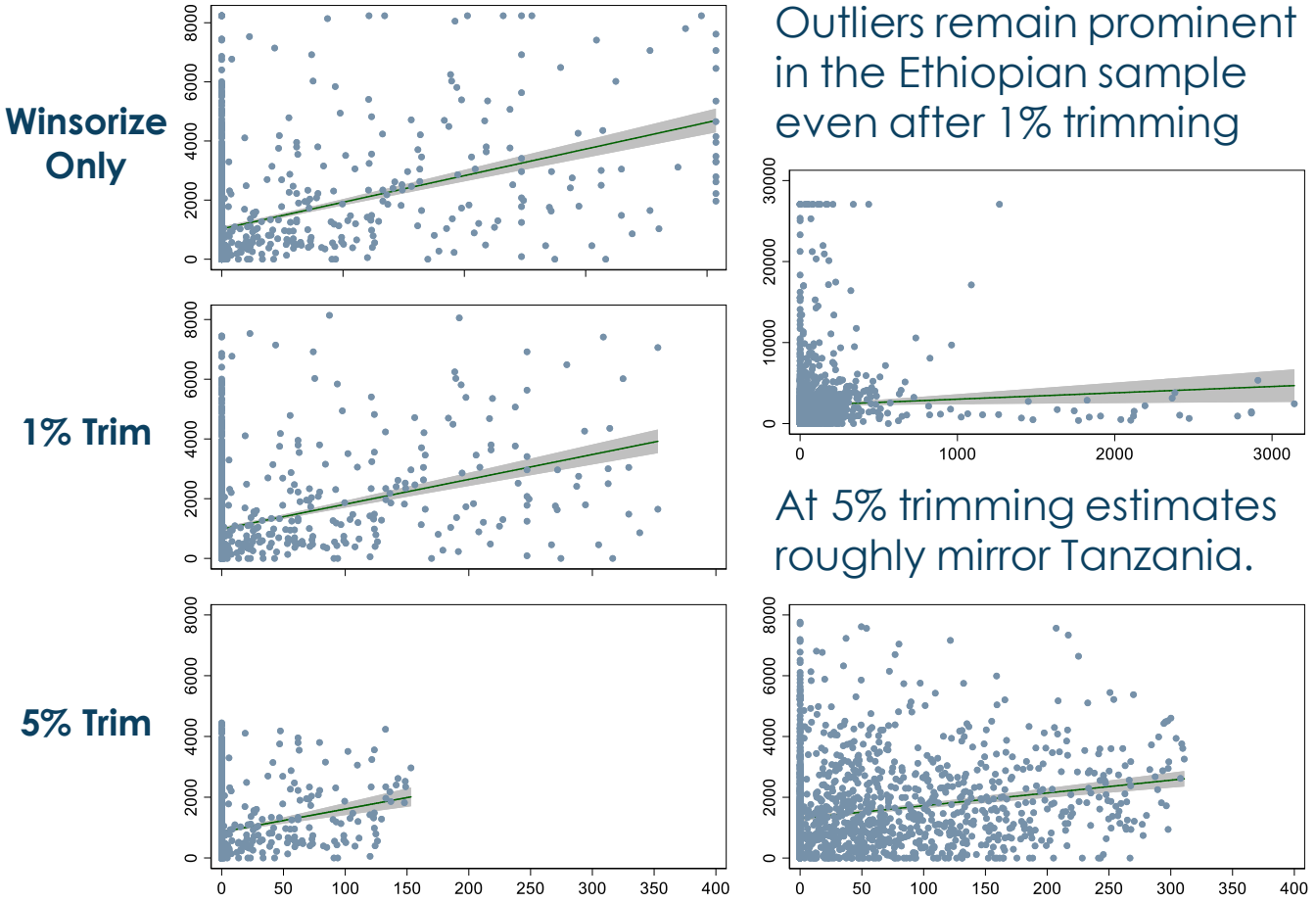
Returns to Fertilizer Use (By Trimming)

Tanzania:

Ethiopia:

Outliers remain prominent in the Ethiopian sample even after 1% trimming

At 5% trimming estimates roughly mirror Tanzania.

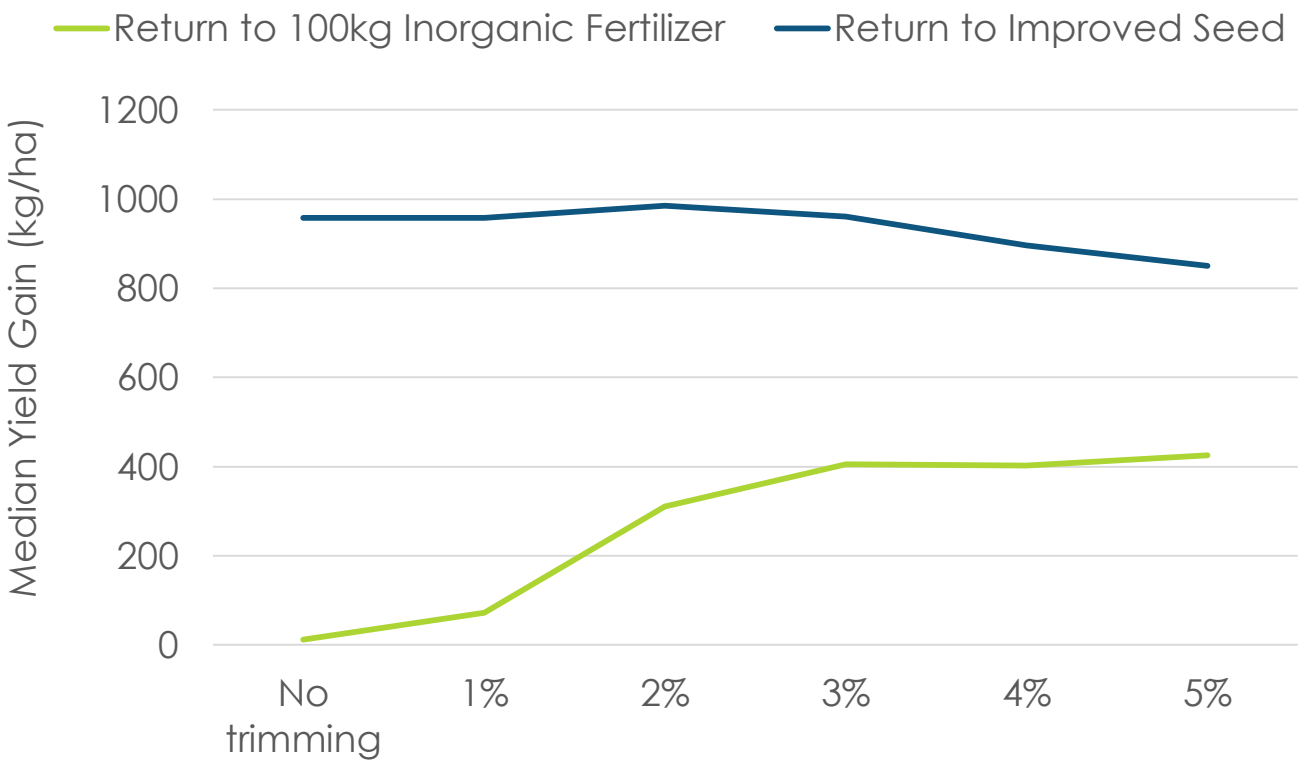


Returns to Smallholder Input Use

- Estimated returns to seed versus fertilizer further vary depending on trimming decisions

Returns to Fertilizer Use (By Trimming)

Quantile Regression Estimates for Median Maize Yield Gain from Fertilizer Use or Improved Seed Under Different Trimming Rules in Ethiopia



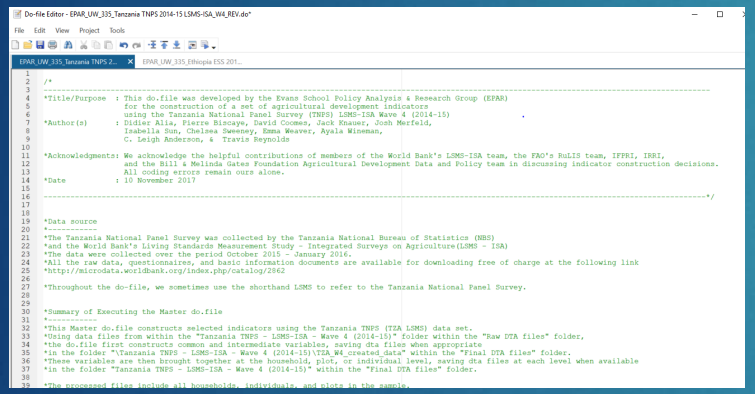
Discussion:
"Measurement with Consequences"

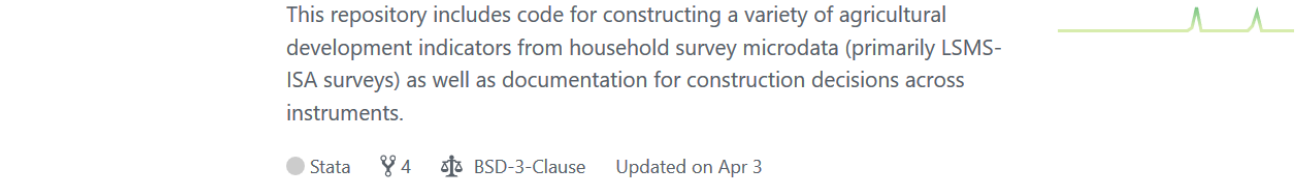
- The results of **data cleaning and variable choices** may have substantial impacts on estimated productivity – in some cases exceeding the estimated effects of productivity-enhancing interventions.
- Meta-analyses and machine learning approaches can provide valuable insights, but may also amplify the effects of researcher decisions.
- More detailed reporting of researcher choices in variable construction and data cleaning – alongside public access to data and analysis code – can help address these challenges.

Anderson C.L. & Reynolds T.W. (2019). In Bioversity International, *Agrobiodiversity Index Report 2019: Risk and Resilience*. Bioversity International, Rome, Italy. ISBN: 978-92-9255-125-4 https://hdl.handle.net/10568/100820.

Public Data *and* Analysis

- *… alongside public access to data and analysis code…*





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UNIVERSITY of WASHINGTON
Evans School Policy Analysis and Research (EPAR)

Thank you.

We thank David Coomes, Terry Fletcher, Isabella Sun and Emma Weaver for their excellent research assistance.

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Stata .do files used in the analysis are available for download and use from the Evans School Policy Analysis and Research Group (EPAR) at https://evans.uw.edu/policy-impact/epar

World Bank Living Standards Measurement Study (LSMS) datasets and documentation are available at http://surveys.worldbank.org/lsms

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Biscaye, P., Anderson, C.L., Reynolds, T.W. (2017). Tracking smallholder farm households. Evans School Policy Analysis and Research Group (EPAR) Technical Report No. 356.

Bravo-Ureta B.E., Solís D., López V.H.M., Maripani J.F., Thiam A., & Rivas T. (2007). Technical efficiency in farming: a meta-regression analysis. *Journal of Productivity Analysis*, 27(1), 57-72.

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Himmelstein J., Ares A., Gallagher D., & Myers J. (2017). A meta-analysis of intercropping in Africa: impacts on crop yield, farmer income, and integrated pest management effects. *International Journal of Agricultural Sustainability*, *15*(1), 1-10.

Sheahan M., & Barrett C.B. (2017). Ten striking facts about agricultural input use in Sub-Saharan Africa. *Food Policy*, 67, 12-25.

Sileshi G., Akinnifesi F.K., Ajayi O.C., & Place, F. (2008). Meta-analysis of maize yield response to woody and herbaceous legumes in sub-Saharan Africa. *Plant and Soil*, 307(1-2), 1-19.

Tonitto C. & Ricker-Gilbert J. E. (2016). Nutrient management in African sorghum cropping systems: applying meta-analysis to assess yield and profitability. *Agronomy for Sustainable Development*, 36(1), 10-19.

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