Nutrition Demand, Subsistence Farming, and Agricultural Productivity

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Texas Christian University

SED 2024 Winter Meeting

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product choice $\neq$ comparative advantage

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agricultural productivity $\downarrow$

Preview

- **Data:**

▶ *literature*

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  - smallest farms focus on calories $\rightarrow$ specialize in staples

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    - smallest farmers gain the most

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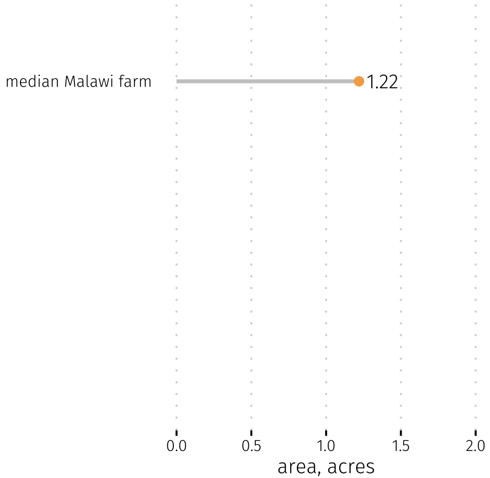
    ▶ *food* ▶ *output*
- Rescale HH kcal intake, output, income by HH kcal requirement

  $\rightarrow$ "per capita" measures, weighted by energy needs

Semi-Subsistence is Common



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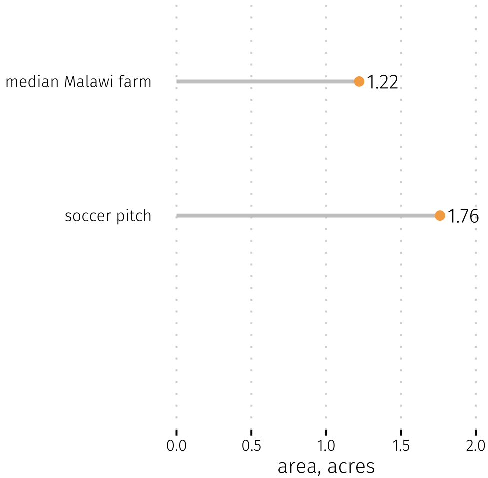

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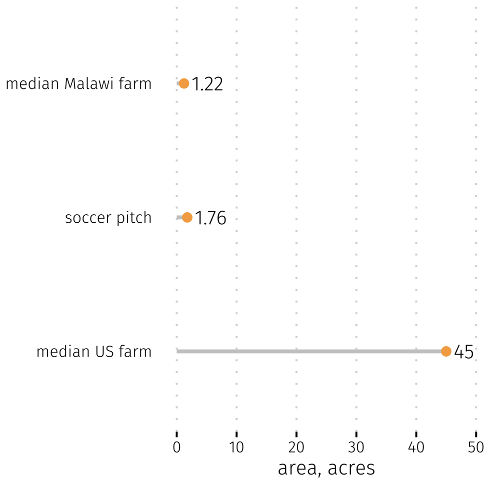

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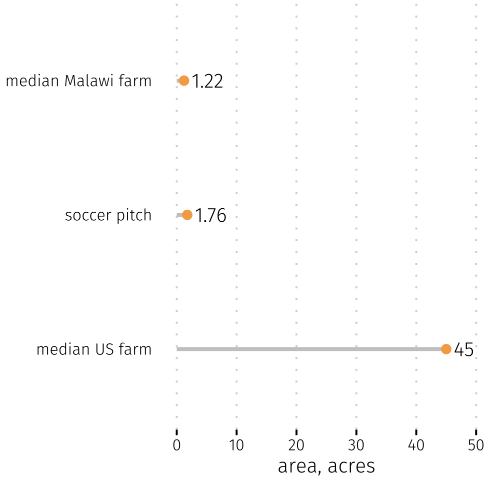

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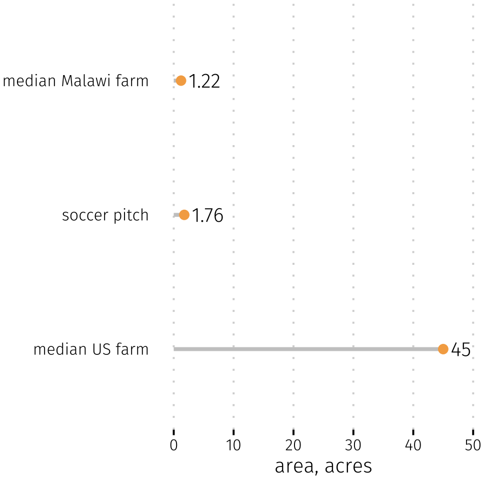

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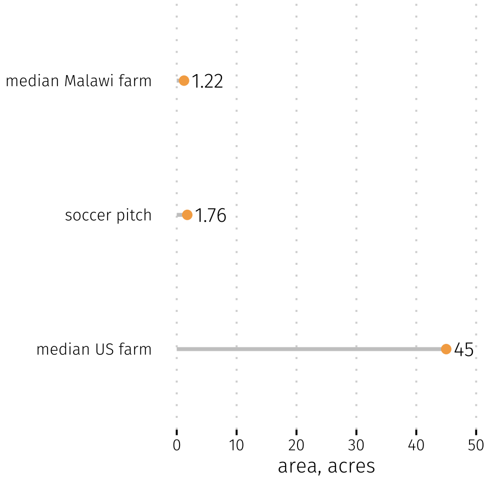

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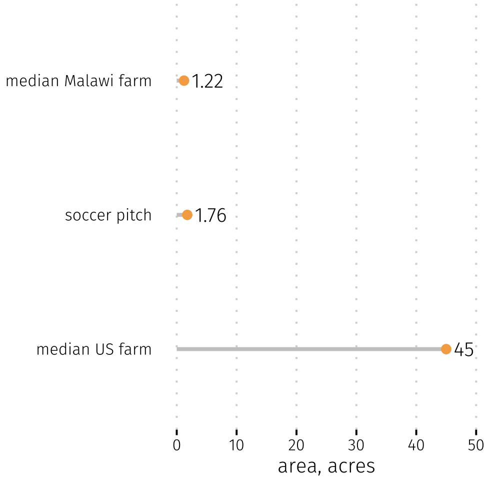

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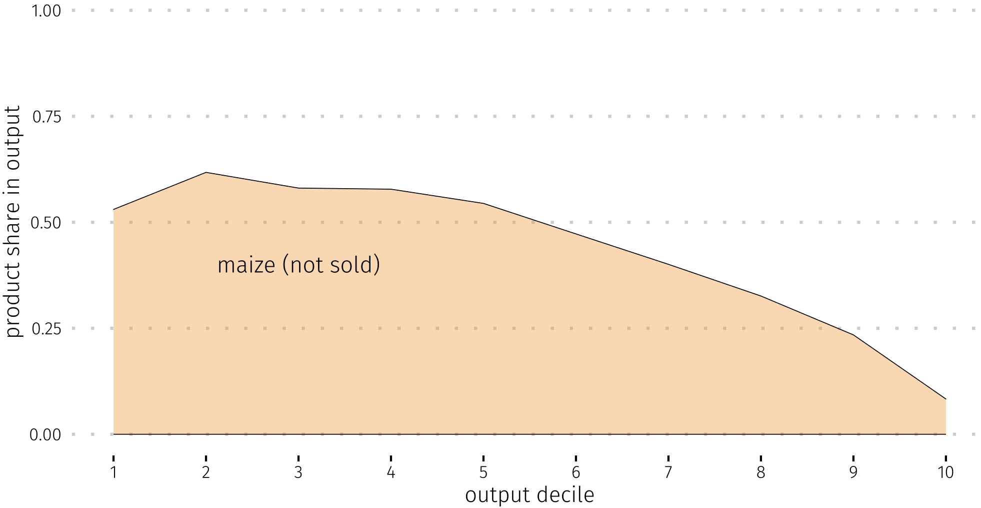
  - avg share of output sold: 16%

Farm Size ↑ → Shift Farm From Maize to Diversity, Commercialize



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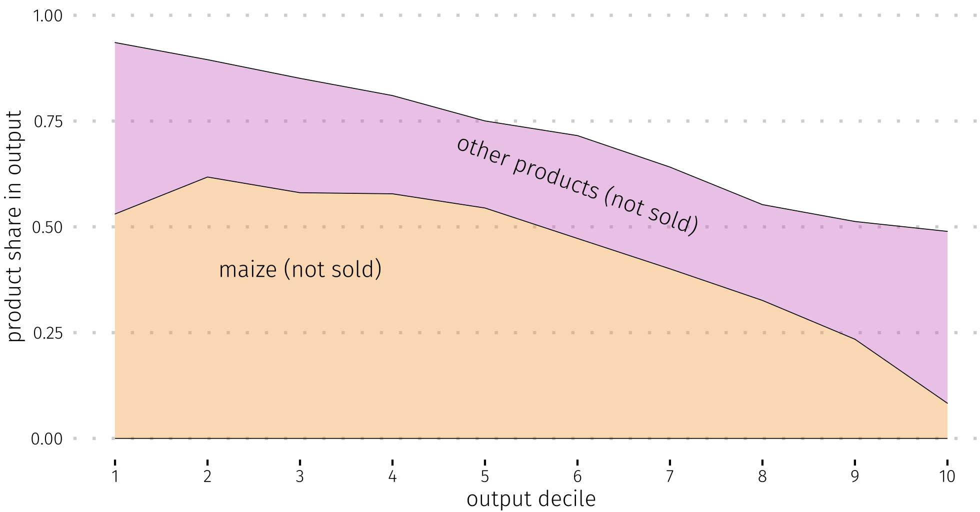

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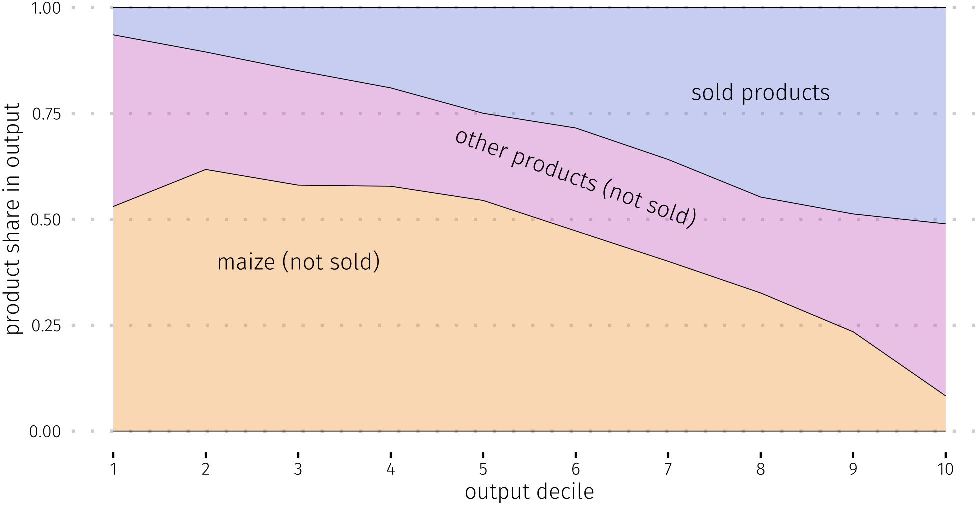

Model

Model: HH Problem

- heterogeneous households and agricultural products, solve GE ▶ *details*
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- foods differ in kcal content k_i

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- foods differ in kcal content k_i
- HH prefers $\underbrace{\sum_{i=1}^{n} c_{h,i} k_i}_{\text{caloric intake}} \approx \underbrace{K_{req,h}}_{\text{caloric requirement}}$

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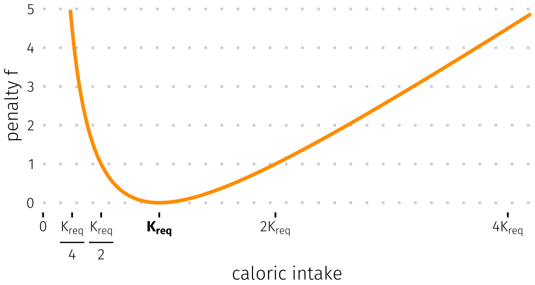
▶ *details*

Caloric Deviation Penalty f

- caloric deviation penalty fn (▶ *properties*):

$$f\left(\sum_i c_{h,i}k_i, K_{req,h}\right) = \psi\left(\frac{\sum_i c_{h,i}k_i - K_{req,h}}{K_{req,h}}\right)^2 \frac{K_{req,h}}{\sum_i c_{h,i}k_i}$$



Farm Behavior in Model and Data

Farm Size ↑ ⟶ Shift From Dietary Energy to Diversity: Model & Data

	log kcal intake	food diversity ▶ *def* ▶ *nutrients*
log output		
log non-farm income		
N		
Adj. R^2		

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Farm Size ↑ → Shift From Dietary Energy to Diversity: Model & Data

	log kcal intake	food diversity ▶ *def* ▶ *nutrients*
	model: CES-only	
log output	0.810	
	(0.001)	
log non-farm income	0.216	
	(0.001)	
N	71,040	
Adj. R^2	0.951	

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

- CES-only ($\psi = 0$): relative consumptions invariant to size/income
  - kcal intake ↑ proportionally to total shadow income, diversity constant

Farm Size ↑ → Shift From Dietary Energy to Diversity: Model & Data

	log kcal intake	food diversity ▶ *def* ▶ *nutrients*
	model: CES-only	model: CES-only
log output	0.810 (0.001)	−0.058 (0.001)
log non-farm income	0.216 (0.001)	0.012 (0.001)
N	71,040	71,040
Adj. R^2	0.951	0.036

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Farm Size ↑ → Shift From Dietary Energy to Diversity: Model & Data

	log kcal intake		food diversity ▶ *def* ▶ *nutrients*
	model: CES-only	**model**: benchmark	**model**: CES-only
log output	0.810 (0.001)	0.109 (0.001)	-0.058 (0.001)
log non-farm income	0.216 (0.001)	0.089 (0.001)	0.012 (0.001)
N	71,040	70,750	71,040
Adj. R^2	0.951	0.395	0.036

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- CES-only ($\psi = 0$): relative consumptions invariant to size/income
  - kcal intake ↑ proportionally to total shadow income, diversity constant
- $\psi > 0$ (benchmark): reallocate resources from calories to diversity as size/income ↑
  - **small**: focus consumption on obtaining calories to reduce caloric deviation penalty

Farm Size ↑ → Shift From Dietary Energy to Diversity: Model & Data

	log kcal intake		food diversity ▶ *def* ▶ *nutrients*	
	model: CES-only	model: benchmark	model: CES-only	model: benchmark
log output	0.810	0.109	-0.058	0.445
	(0.001)	(0.001)	(0.001)	(0.001)
log non-farm income	0.216	0.089	0.012	0.425
	(0.001)	(0.001)	(0.001)	(0.002)
N	71,040	70,750	71,040	70,750
Adj. R^2	0.951	0.395	0.036	0.758

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  - kcal intake ↑ proportionally to total shadow income, diversity constant
- $\psi > 0$ (benchmark): reallocate resources from calories to diversity as size/income ↑
  - **small**: focus consumption on obtaining calories to reduce caloric deviation penalty
  - **large**: caloric requirement largely satisfied → diversify diet
  - ▶ *details* ▶ *comparison to Stone-Geary*

Farm Size ↑ → Shift From Dietary Energy to Diversity: Model & Data

	log kcal intake			food diversity ▶ *def* ▶ *nutrients*	
	model: CES-only	model: benchmark	data	model: CES-only	model: benchmark
log output	0.810 (0.001)	0.109 (0.001)	0.091*** (0.005)	-0.058 (0.001)	0.445 (0.001)
log non-farm income	0.216 (0.001)	0.089 (0.001)	0.063*** (0.004)	0.012 (0.001)	0.425 (0.002)
N	71,040	70,750	8,674	71,040	70,750
Adj. R^2	0.951	0.395	0.063	0.036	0.758

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  - **large**: caloric requirement largely satisfied → diversify diet

  ▶ *details* ▶ *comparison to Stone-Geary*

Farm Size ↑ → Shift From Dietary Energy to Diversity: Model & Data

	log kcal intake			food diversity ▶ *def* ▶ *nutrients*		
	model: CES-only	model: benchmark	data	model: CES-only	model: benchmark	data
log output	0.810	0.109	0.091***	-0.058	0.445	0.395***
	(0.001)	(0.001)	(0.005)	(0.001)	(0.001)	(0.034)
log non-farm income	0.216	0.089	0.063***	0.012	0.425	0.857***
	(0.001)	(0.001)	(0.004)	(0.001)	(0.002)	(0.033)
N	71,040	70,750	8,674	71,040	70,750	8,675
Adj. R^2	0.951	0.395	0.063	0.036	0.758	0.131

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Large Farms Are More Active Sellers ▶ *details*

- Model & Data: farm size $\uparrow\ \rightarrow$ sell bigger fraction of output
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Selling Behavior: Model & Data

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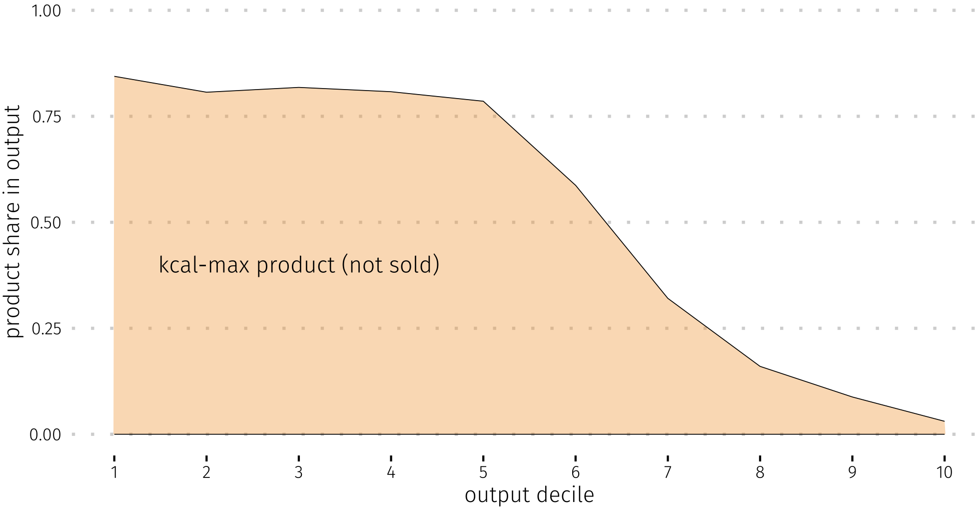
Sales Are Specialized ▶ *details*

- Model & Data: sales are specialized compared to overall production
- **model mechanism**: sell only the most revenue-productive good, but can produce others for own consumption

Small Specialize, Medium Diversify, Large Commercialize: Model



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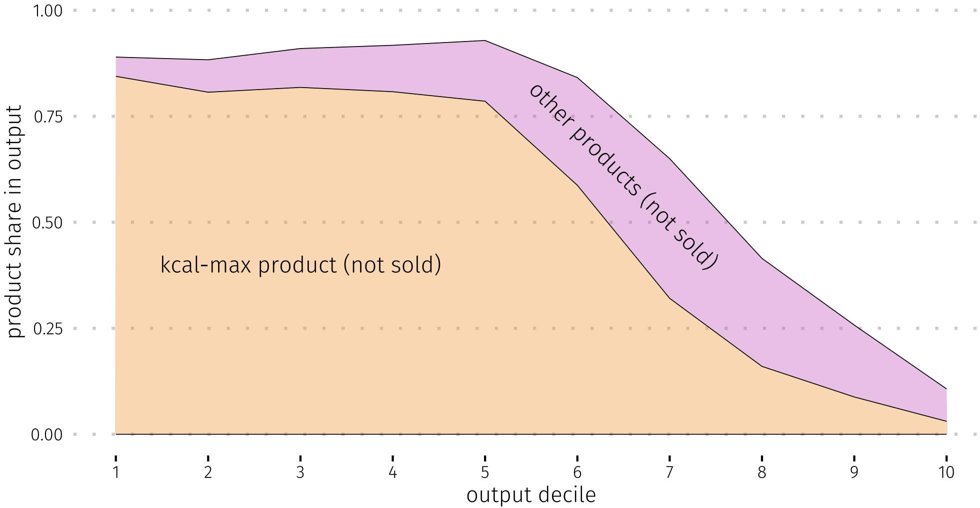

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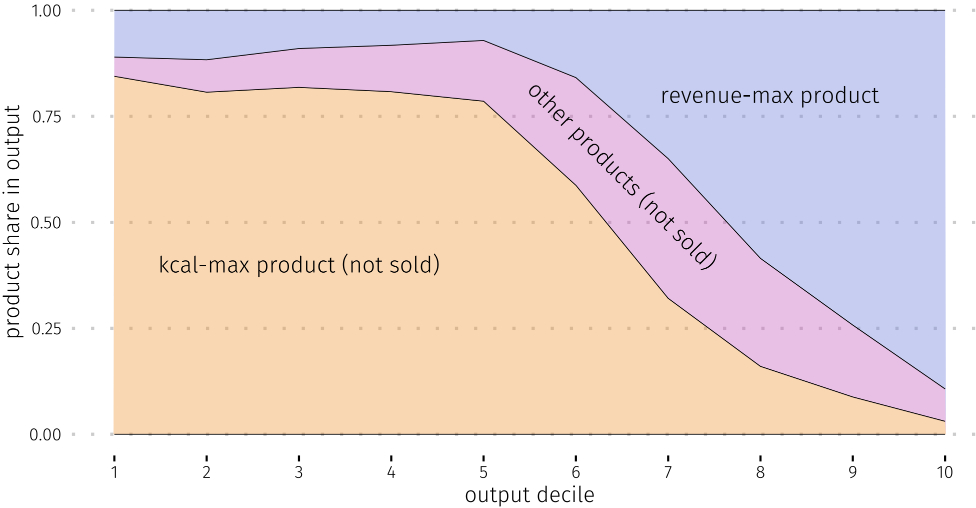

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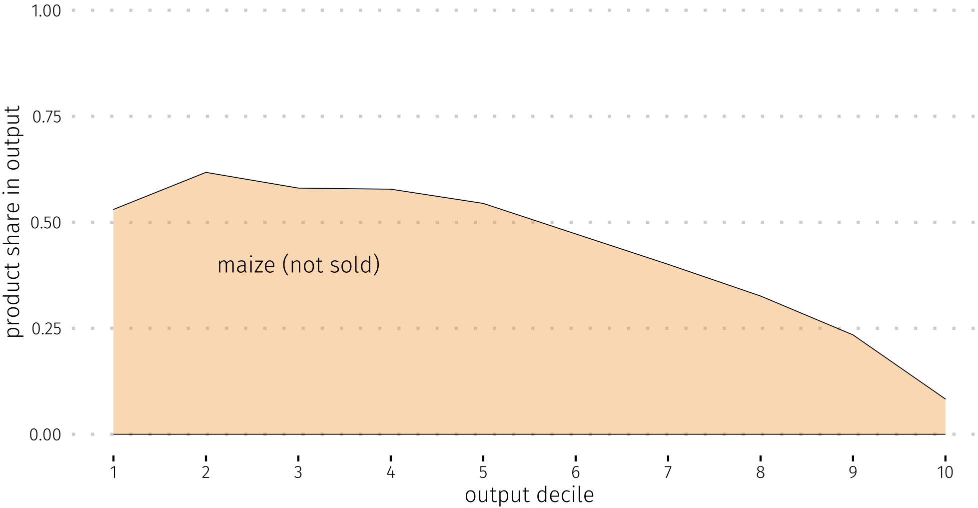

▶ *diversity* ▶ *product frequency*

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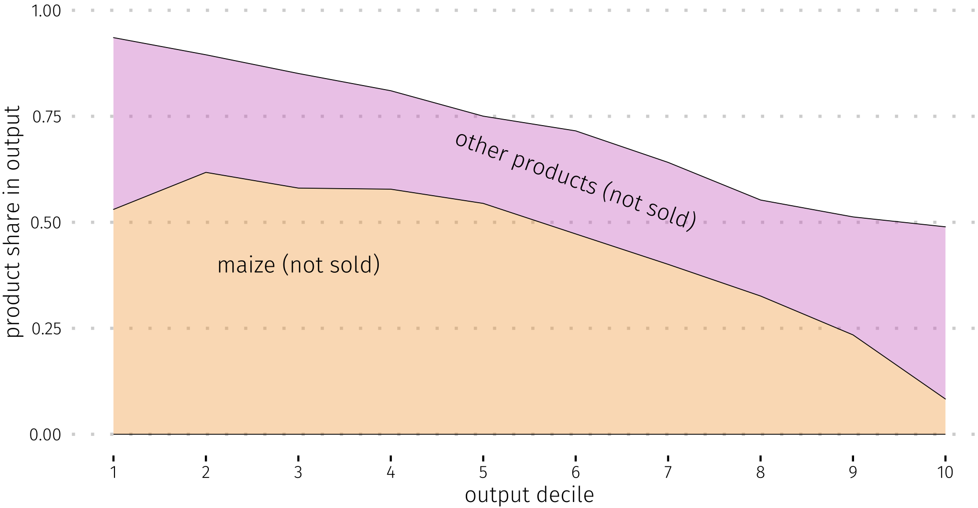

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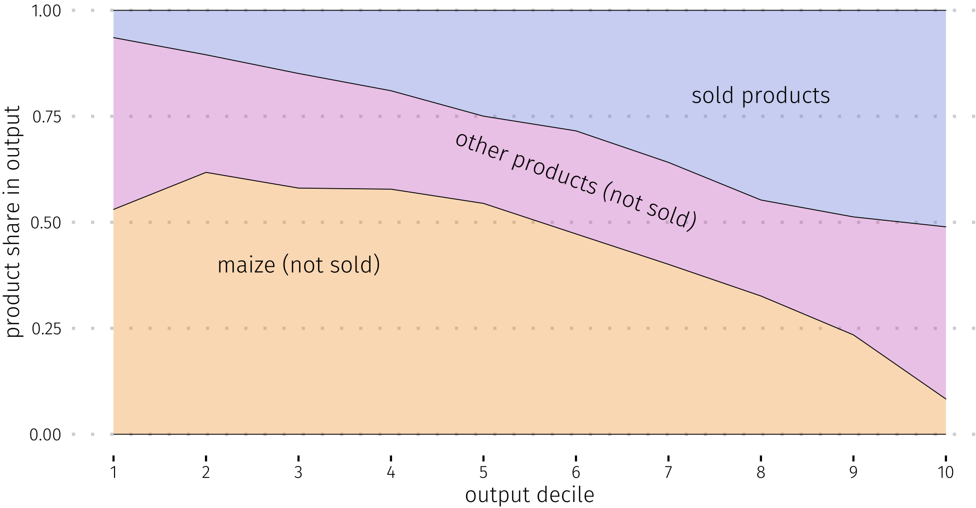

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Aggregate Productivity

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  - ▶ *plot*
  - $\rightarrow$ subsistence matters more for macro, nutrition matters for micro

Conclusion

Conclusion

Subsistence farmer nutrition demand

$\downarrow$

Farm production decisions

$\downarrow$

Aggregate agricultural productivity $\downarrow$

- smallest farms specialize in calories
- medium farms diversify diet & production
- largest farms become market-oriented

- if partially leave subsistence $\rightarrow$ agric. productivity $\uparrow$
- half because improved product choice
- calories matter less than subsistence itself

Next Steps

- Analyze government programs targeting smallholder farmers

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  - smallholder farmer support is central to public policy in poor countries
  - existing & proposed policies: encourage staples, biodiversity, or cash crops?
  - framework well suited for predicting nutritional, economic outcomes

Literature

economics literature:

Subsistence Farming &

Agricultural Productivity

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Subsistence Farming & Agricultural Productivity

- *Gollin and Rogerson (2014), Rivera-Padilla (2020), Sotelo (2020), Kebede (2020)*
  - region/village-level subsistence
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nutrition literature:

Subsistence Farming & Nutrition

- *Jones (2017), Sibhatu et al. (2015)*
  - smallholder farm biodiversity related to dietary diversity
  - especially with poor market access
  - → farm characteristics matter for nutritional outcomes

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- Non-farm income
  - income from employment and non-farm enterprises

back

Model: HH Problem

$$\max \left((1-\varphi_m) \left(\sum_{i=1}^{n} \varphi_i c_{h,i}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1} \frac{\gamma-1}{\gamma}} + \varphi_m c_{h,m}^{\frac{\gamma-1}{\gamma}} \right)^{\frac{\gamma}{\gamma-1}}$$

- HH h consumes n foods $\{c_{h,i}\}_{i=1}^{n}$ and a manufactured good $c_{h,m}$

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$$\sum_{i=1}^{n} x_{h,i}^{p} p_i d_h + p_m c_{h,m} \leq \sum_{i=1}^{n} x_{h,i}^{s} \frac{p_i}{d_h} + wN_h$$

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back

$f\left(\sum_i c_i k_i, K_{req}\right)$ PROPERTIES

Properties:

1. $f(bK_{in}, bK_{req}) = f(K_{in}, K_{req})$ (homogeneity of deg. 0)
2. $f(bK_{req}, K_{req}) = f\left(\frac{K_{req}}{b}, K_{req}\right)$ (symmetry around K_{req} in ratios)
3. $\min_{K_{in}>0} f(K_{in}, K_{req}) = f(K_{req}, K_{req}) = 0$ (minimum and zero if eat K_{req})
4. $f_{11}(K_{in}, K_{req}) = \frac{2\psi K_{req}}{K_{in}^3} > 0$ (convex in intake)

back

Calories Skew Consumption: Model

- Consider the problem of a household
- Suppose $\psi = 0$ (CES-only)

$$MU_i^{CES}(c_i) = MC_i \qquad (c_i \text{ FOC})$$

back

Calories Skew Consumption: Model

- Consider the problem of a household
- Suppose $\psi > 0$ (benchmark)

$$MU_i^{CES}(c_i) - k_i f_1\left(\sum_i c_i k_i,\ K_{req}\right) = MC_i \qquad (c_i \text{ FOC})$$

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- $k_i > 0$

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  $\rightarrow$ predictions on kcal-diversity tradeoff in consumption and on farm product choice

back

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Agricultural Goods

- 6 agricultural goods commonly produced and consumed
  - *list*

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▶ *Calibration: parameters & moments*

Agricultural Goods Used in Calibration

- Selected goods:
  1. maize
  2. pigeonpea
  3. groundnut
  4. tomato
  5. soybean
  6. tobacco
- These goods account for, on average,
  - 70% of HH output market value
  - 43% of HH food consumption market value

back

General Equilibrium: Agricultural Goods

- Solve for agricultural prices $\{p_i\}_i$ s.t. edible good markets clear:

$$\sum_h \frac{1}{d_h} x^s_{h,i} = \sum_h d_h x^p_{h,i} \quad \forall i$$

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  - tobacco traded internationally at exogenous $\bar{p}_t$

$$\underbrace{\bar{p}_{\text{tobacco}} \left(\sum_h \frac{1}{d_h} x^s_{h,\text{tobacco}} - \sum_h d_h x^p_{h,\text{tobacco}} \right)}_{\text{tobacco exports}}$$

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  - tobacco traded internationally at exogenous $\bar{p}_t$
  - some manufactured good is imported to balance the trade:

$$\underbrace{\bar{p}_{\text{tobacco}} \left(\sum_h \frac{1}{d_h} x^s_{h,\text{tobacco}} - \sum_h d_h x^p_{h,\text{tobacco}} \right)}_{\text{tobacco exports}} = \underbrace{p_m \left(\sum_h c_{h,m} - Y_m \right)}_{\text{manuf. good imports}}$$

back

Farm Sales are Specialized: Model & Data

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  - **69%** sell just 1 good, only **9%** produce just 1 good
  - on avg, top good accounts for **91%** in sales but **67%** in output

back

Lower Trade Costs $\longrightarrow$ All Specialize: Model & Data

- Model: $d_h \downarrow \rightarrow$ specialize production
  - below some cutoff $\tilde{d}_h$, HH h only produces the revenue-maximizing good

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  - below some cutoff $\tilde{d}_h$, HH h only produces the revenue-maximizing good
- Data:
  - HHs with better market access specialize production
    ▶ *table*

back

Large Farms Sell More: Model & Data

- Larger farms are more active sellers:

output quartile	sold output share
1	
4	

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size $\uparrow$ $\longrightarrow$ energy intake $\uparrow$ $\nearrow$ food diversity $\uparrow$ $\searrow$ need revenue

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$$
\begin{tikzcd}
 & & \text{food diversity} \uparrow \arrow[dr] & \\
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\end{tikzcd}$$

back

Cutoff Trade Cost $\bar{d}$

$$\bar{d}_h = \sqrt{\frac{\max_i p_i z_{h,i}}{\min_i p_i / k_i \cdot \max_i k_i z_{h,i}}}$$

back

Food Diversity

- Food Diversity = Inverse Simpson Index

$$\text{Food Diversity}_h = \left(\sum_{i=1}^{n} \left(\frac{\text{food quantity}_{h,i} \times \text{median purchase price}_i}{\sum_{j=1}^{n} \text{food quantity}_{h,j} \times \text{median purchase price}_j} \right)^2 \right)^{-1}$$

  where h is the HH index, n is the total number of distinct foods in the dataset.

- Simpson Index: sum of squared food shares within HH's consumption
  - same as HHI
  - interpretation: probability that two random dollars of (shadow) food expenditure come from the same product
- Inverse Simpson Index $= \frac{1}{SI}$, commonly used in measuring species diversity

back

Nutrient Richness

	NRF9		NRF9.3	
	(1)	(2)	(3)	(4)
log output	17.046***	5.695***	-13.296***	-13.400***
	(0.964)	(0.724)	(3.326)	(3.358)
log non-farm income	10.285***	2.441***	-7.257**	-7.305**
	(0.792)	(0.603)	(3.898)	(3.548)
log kcal intake		124.025***		0.550
		(2.282)		(26.234)
N	8,675	8,674	8,675	8,674
Adj. R^2	0.054	0.451	0.002	0.002

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

- NRF9: sum of daily intakes (relative to recommended level) of 9 nutrients
- NRF9.3: subtracts the relative excessive consumption of 3 disqualifying nutrients

back

Lower Trade Costs → All Specialize: Data

	production diversity
N	
Adj. R^2	

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Note. Controls: log output, log non-farm income.

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	production diversity
sold output share	−0.044***
	(0.016)
N	4,042
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Lower Trade Costs → All Specialize: Data

	production diversity	
sold output share	−0.044***	
	(0.016)	
$\mathbb{1}$[good mkt access]		−0.164***
		(0.018)
N	4,042	8,675
Adj. R^2	0.025	0.099

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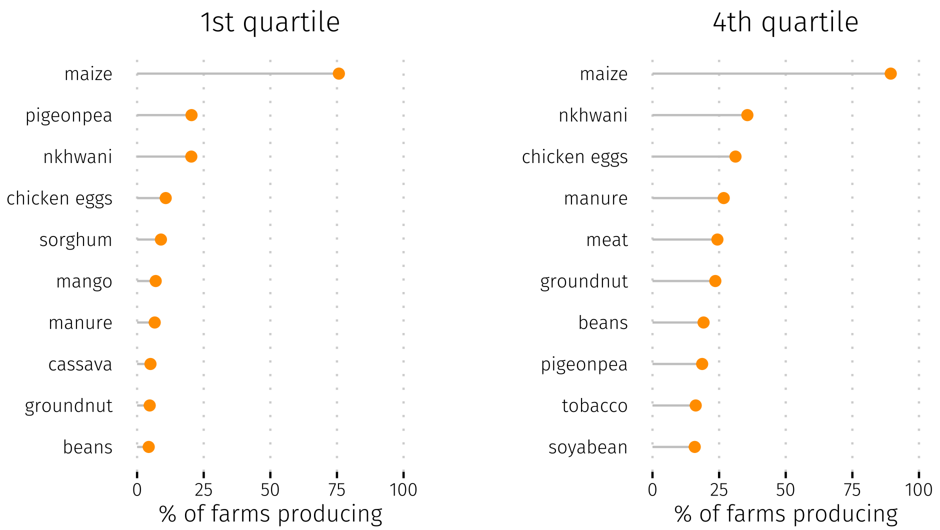
back

Product Frequency by Size: Data



back

Calibration

parameter	value	moment/source	**data** moment	**model** moment
Distributions				

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$\mathbb{E}(\log L_h)$	-14.9	avg $K_{in,h}/K_{req,h}$	1.036	0.904

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$\bar{d}$ *(median trade cost)*	1.75	avg share sold	0.159	0.199
σ_d^2 *(s.d. of log trade cost)*	0.01	variance of share sold	0.061	0.091
Parameters				
σ *(EoS across foods)*	0.75	estimated	—	—

back

Calibration

parameter	value	moment/source	**data** moment	**model** moment
Distributions				
$\mathbb{E}\,(\log L_h)$	-14.9	avg $K_{in,h}/K_{req,h}$	1.036	0.904
$V\,(\log L_h)$	1.68	$V\,(\log \text{output}_h)$	1.528	1.546
$P\,(N_h = 0)$	0.112	$P\,(\text{non-farm income}_h = 0)$	0.112	0.113
$V\,(\log N_h \mid N_h > 0)$	2.103	$V\,(\log \text{non-farm income}_h)$	2.103	1.940
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σ_d^2 *(s.d. of log trade cost)*	0.01	variance of share sold	0.061	0.091
Parameters				
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γ *(EoS between food & manuf.)*	1	—	—	—

back

Calibration

parameter	value	moment/source	**data** moment	**model** moment
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$\mathbb{E}\left(\log L_h\right)$	-14.9	avg $K_{in,h}/K_{req,h}$	1.036	0.904
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Parameters				
σ *(EoS across foods)*	0.75	estimated	—	—
γ *(EoS between food & manuf.)*	1	—	—	—
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back

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Good characteristics				

back

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parameter	value	moment/source	**data** moment	**model** moment
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Parameters				
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ψ *(kcal deviation penalty)*	0.5	output elasticity of K_{in}	0.091	0.109
Good characteristics				
φ_m *(manuf. taste weight)*	0.36	$\frac{\text{aggr. non-farm income}}{\text{aggr. farm output}}$	1.539	1.554

back

Calibration

parameter	value	moment/source	**data** moment	**model** moment
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$\mathbb{E}(\log L_h)$	-14.9	avg $K_{in,h}/K_{req,h}$	1.036	0.904
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Parameters				
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Good characteristics				
φ_m *(manuf. taste weight)*	0.36	$\frac{\text{aggr. non-farm income}}{\text{aggr. farm output}}$	1.539	1.554
$\bar{p}_{\text{tobacco}}/p_{\text{maize}}$	5.25	aggr. tobacco output share	0.091	0.092

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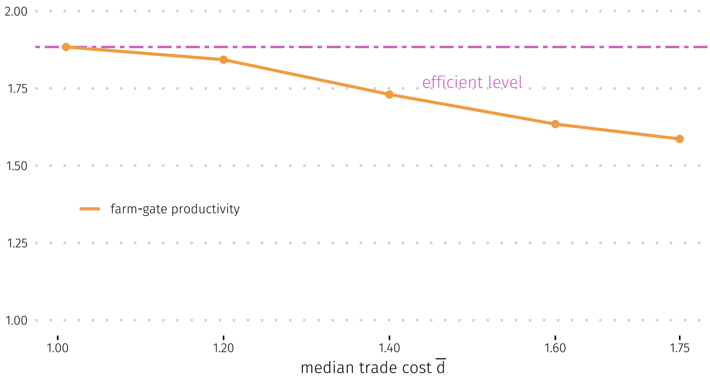
Trade Costs ↓ → Aggregate Productivity ↑

- Compare “farm-gate” production to final consumption (“aggregate productivity”)
  - farm production only accounts for product choice changes



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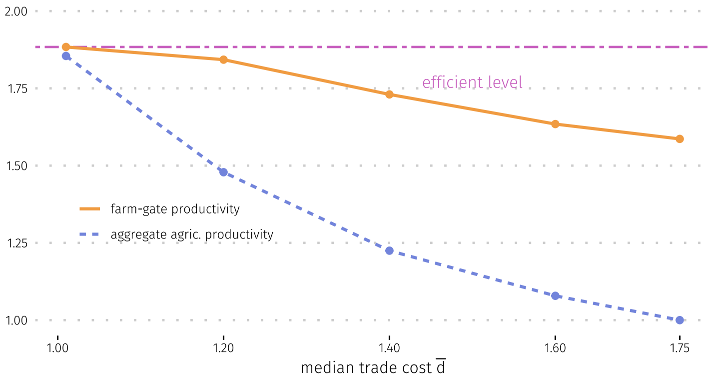
Trade Costs ↓ → Aggregate Productivity ↑

- Compare "farm-gate" production to final consumption ("aggregate productivity")
  - farm production only accounts for product choice changes
  - final consumption also accounts for mechanical losses from d



- $d \to 1$: aggr. productivity ↑ **85%**

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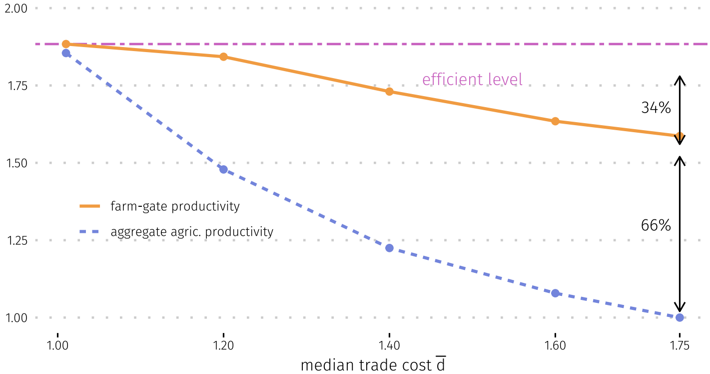
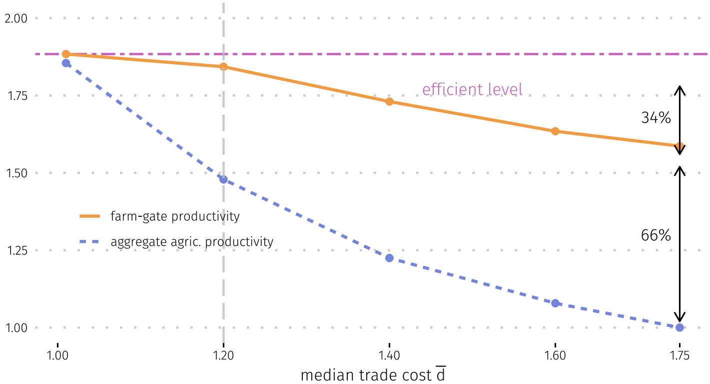


- $d \to 1$: aggr. productivity ↑ **85%** ($\frac{1}{3}$ due to product choice)

back

Trade Costs ↓ → Aggregate Productivity ↑

- Compare "farm-gate" production to final consumption ("aggregate productivity")
  - farm production only accounts for product choice changes
  - final consumption also accounts for mechanical losses from d



- $d \to 1$: aggr. productivity ↑ **85%** ($\frac{1}{3}$ due to product choice)
- $d \downarrow$ s.t. avg share sold 16% → 50%: aggr. productivity ↑ **47%** ($\frac{1}{2}$ due to product choice)

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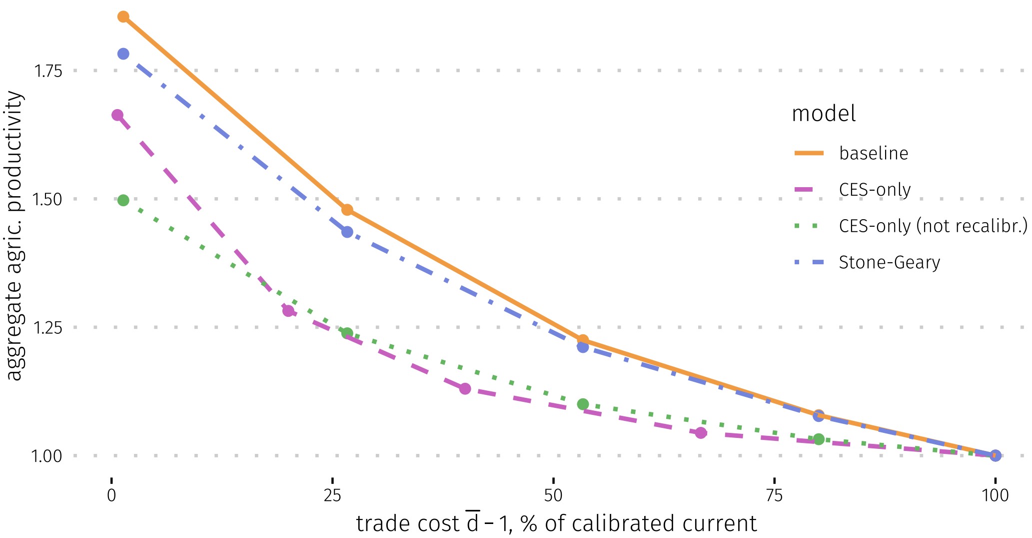
Aggregate Agricultural Productivity Across Models



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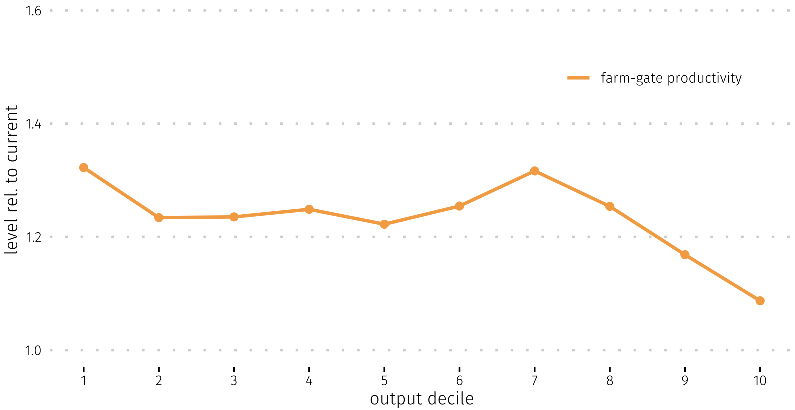
Trade Costs $\downarrow$ $\rightarrow$ Heterogeneous Effects in Farm Size

- $d \downarrow$ s.t. avg share sold 16% $\rightarrow$ 50%:

back

Trade Costs $\downarrow$ $\rightarrow$ Heterogeneous Effects in Farm Size

- $d \downarrow$ s.t. avg share sold 16% $\rightarrow$ 50%:
  - farm productivity: small $\uparrow$ the most, large $\uparrow$ the least



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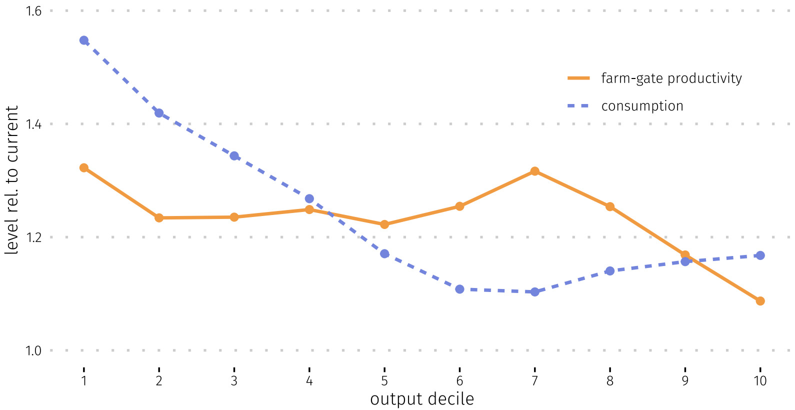
Trade Costs ↓ → Heterogeneous Effects in Farm Size

- $d \downarrow$ s.t. avg share sold 16% → 50%:
  - farm productivity: small ↑ the most, large ↑ the least
  - consumption: small ↑ the most, medium ↑ the least



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Farm Size and Food Consumption: Stone-Geary

Household food consumption vs farm size: Stone-Geary vs baseline model and data

	log kcal intake			food diversity		
	(1)	(2)	(3)	(4)	(5)	(6)
	model: Stone-Geary	**model**: baseline	**data**	**model**: Stone-Geary	**model**: baseline	**data**
log output	0.233	0.109	0.091***	−0.100	0.445	0.395***
	(0.001)	(0.001)	(0.005)	(0.001)	(0.001)	(0.034)
log non-farm income	0.203	0.089	0.063***	0.012	0.425	0.857***
	(0.001)	(0.001)	(0.004)	(0.001)	(0.002)	(0.033)
N	70,793	70,750	8,674	70,793	70,750	8,675
Adj. R^2	0.762	0.395	0.063	0.134	0.758	0.131

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

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