Nutrition Demand, Subsistence Farming, and Agricultural Productivity

Stepan Gordeev
University of Connecticut

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agricultural productivity $\downarrow$

Contributions

- explore farm-level subsistence, document scale-dependent product choice

▶ *literature*

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- build model with nutrition demand driven by caloric needs as explanation
- show importance of farm-level subsistence for aggr. agricultural productivity

▶ *literature*

Data

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  ▶ *food* ▶ *output*

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

  → "per capita" measures, weighted by energy needs

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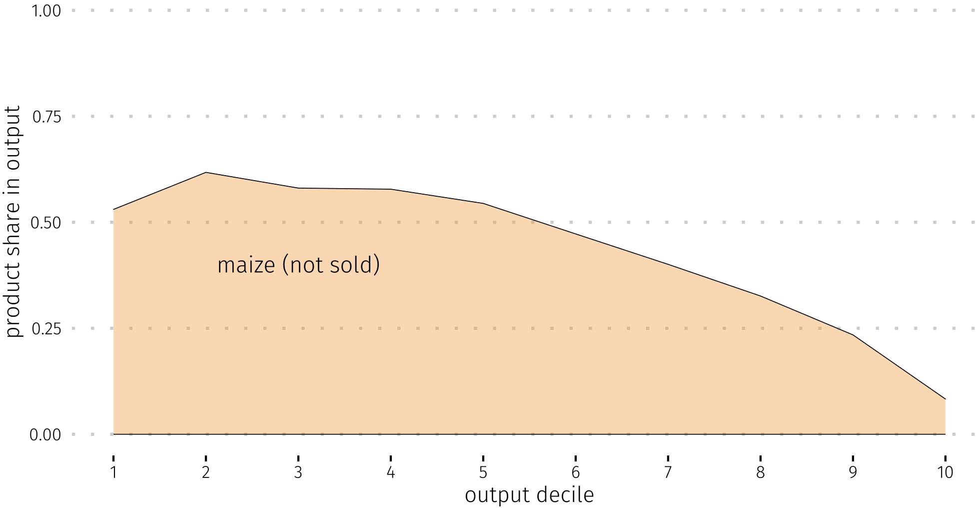
  - avg share of output sold: 16%

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



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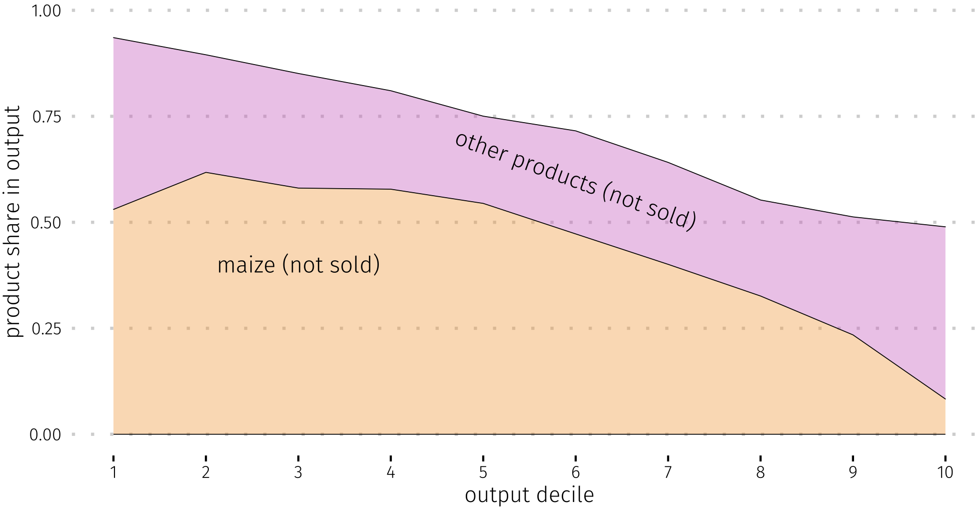

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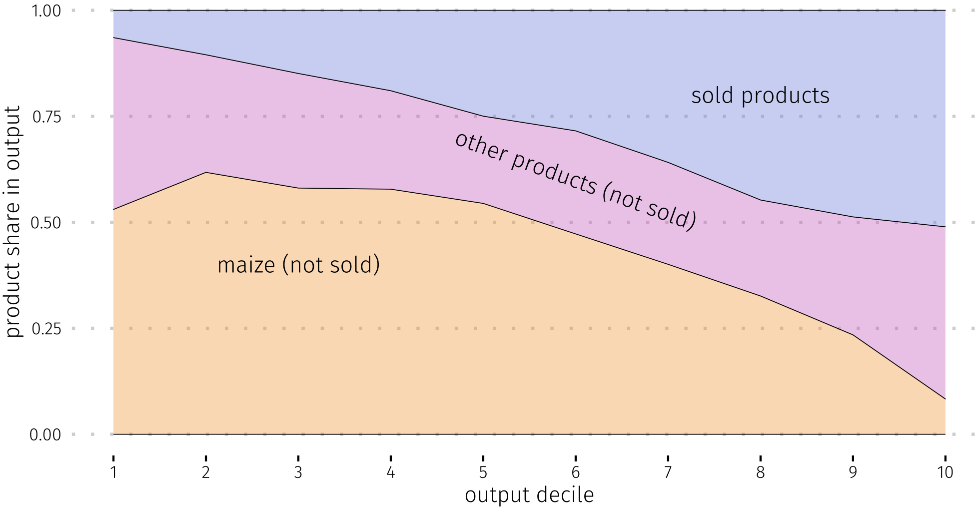

Model

Model: HH Problem

- heterogeneous households and agricultural products, solve GE ▶ *details*
- HH h consumes n foods $\{c_{h,i}\}_{i=1}^{n}$ and a manufactured good $c_{h,m}$

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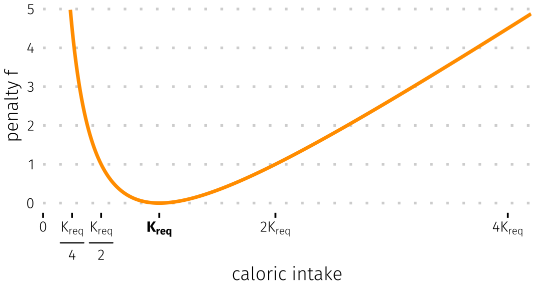
▶ *details*

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	0.732 (0.001)	
log non-farm income	0.289 (0.001)	
N	35,520	
Adj. R^2	0.937	

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

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

Farm Size $\uparrow$ $\longrightarrow$ Shift From Dietary Energy to Diversity: Model & Data

	log kcal intake	food diversity ▶ *def* ▶ *nutrients*
	model: CES-only	model: CES-only
log output	0.732	−0.061
	(0.001)	(0.001)
log non-farm income	0.289	0.031
	(0.001)	(0.002)
N	35,520	35,520
Adj. R^2	0.937	0.054

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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	0.732	0.124	-0.061
	(0.001)	(0.001)	(0.001)
log non-farm income	0.289	0.084	0.031
	(0.001)	(0.001)	(0.002)
N	35,520	33,613	35,520
Adj. R^2	0.937	0.393	0.054

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- CES-only ($\psi = 0$): relative consumptions invariant to size/income
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- $\psi > 0$ (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	0.732	0.124	-0.061	0.428
	(0.001)	(0.001)	(0.001)	(0.002)
log non-farm income	0.289	0.084	0.031	0.396
	(0.001)	(0.001)	(0.002)	(0.002)
N	35,520	33,613	35,520	33,613
Adj. R^2	0.937	0.393	0.054	0.762

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

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

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log output	0.732	0.124	0.091***	-0.061	0.428
	(0.001)	(0.001)	(0.005)	(0.001)	(0.002)
log non-farm income	0.289	0.084	0.063***	0.031	0.396
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log non-farm income	0.289 (0.001)	0.084 (0.001)	0.063*** (0.004)	0.031 (0.002)	0.396 (0.002)	0.857*** (0.033)
N	35,520	33,613	8,674	35,520	33,613	8,675
Adj. R^2	0.937	0.393	0.063	0.054	0.762	0.131

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Selling Behavior: Model & Data

Large Farms Are More Active Sellers ▶ *details*

- Model & Data: farm size $\uparrow$ $\rightarrow$ sell bigger fraction of output
- **model mechanism**: size $\uparrow$ $\rightarrow$ reallocate cons. to diversity, manuf. $\rightarrow$ need revenue

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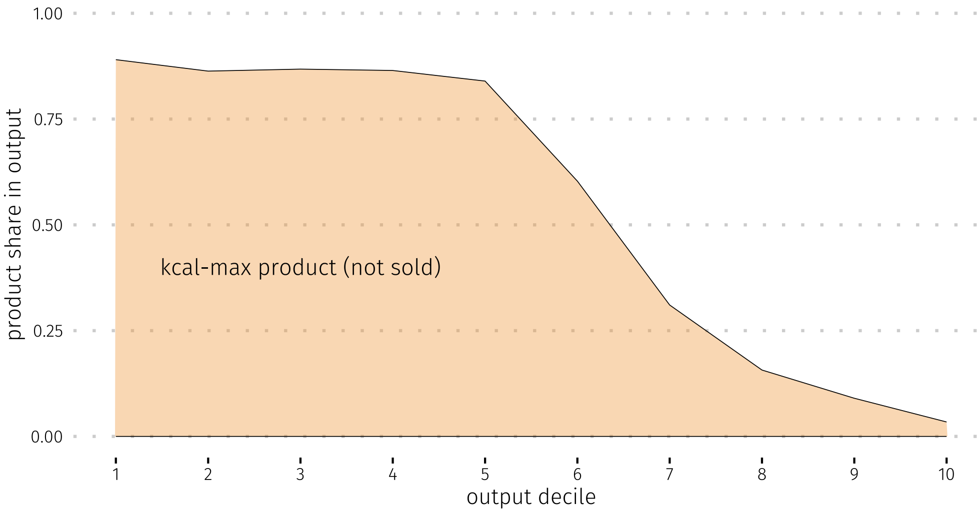
Sales Are Specialized ▶ *details*

- 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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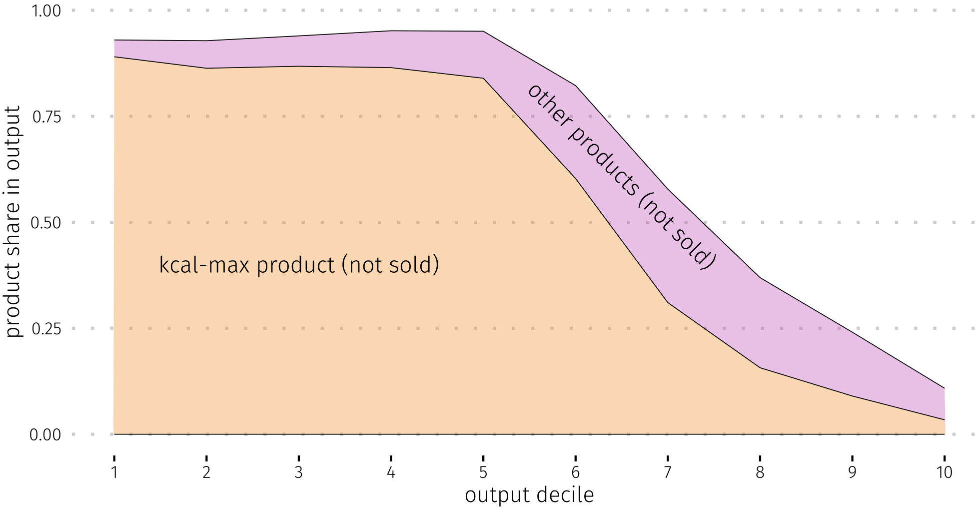

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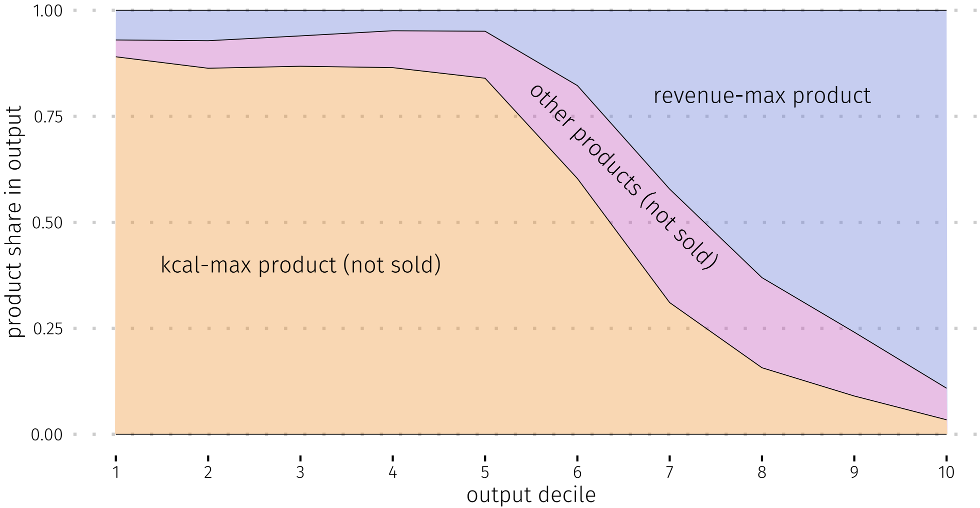

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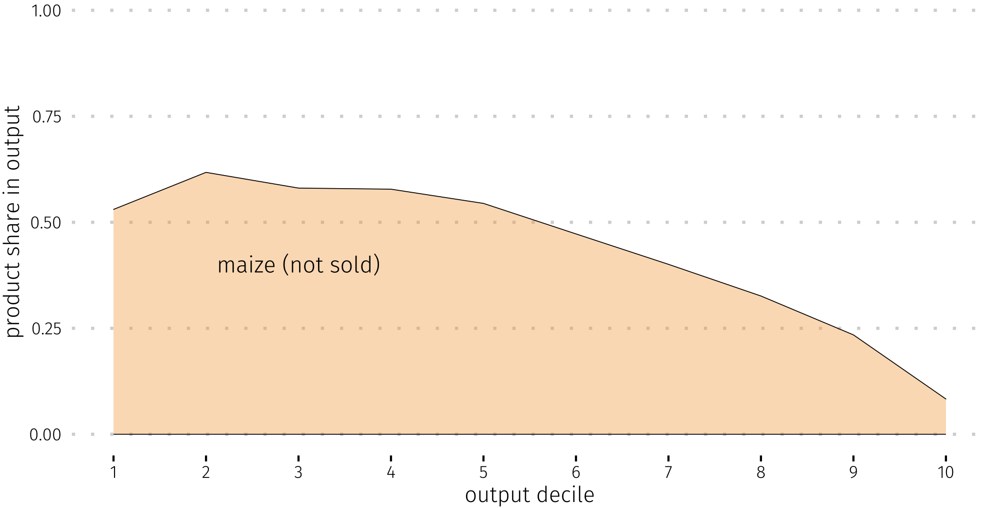

▶ *diversity* ▶ *product frequency*

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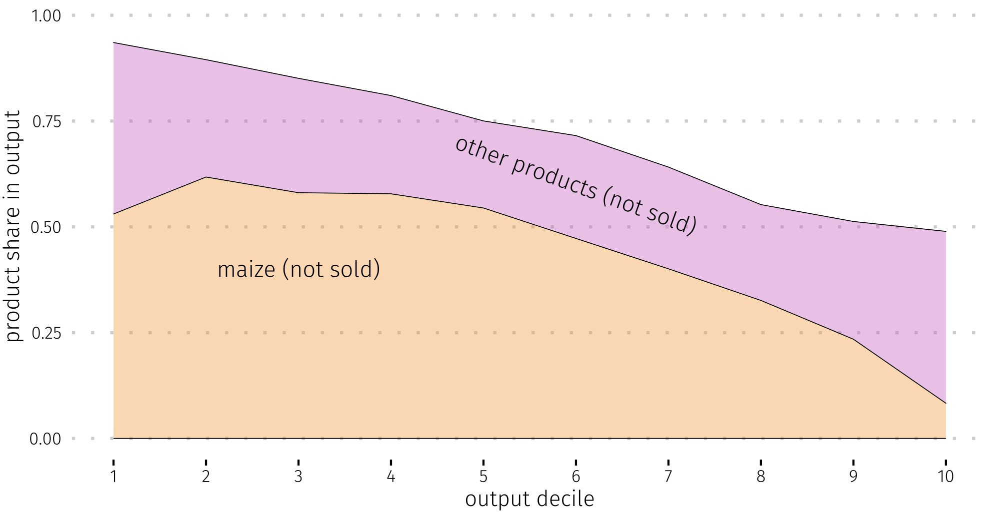

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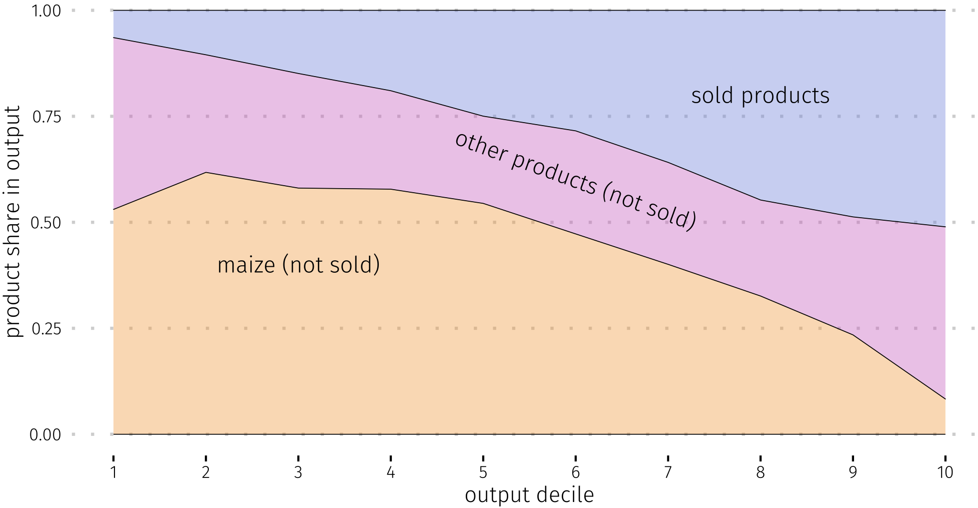

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Aggregate Productivity

Trade Costs $\downarrow$ $\rightarrow$ Aggregate Productivity $\uparrow$

- Model: nutrition demand + trade costs $\rightarrow$ explain behavior of subsistence farmers
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$d\downarrow$ s.t. avg share sold **16%** $\rightarrow$ **50%**:

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- aggr. productivity $\uparrow$ **42%** ▶ *details*

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

- aggr. productivity $\uparrow$ **42%** ▶ *details*
  - $\frac{1}{2}$ due to smaller mechanical losses from d

Trade Costs $\downarrow \rightarrow$ Aggregate Productivity $\uparrow$

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  - scale-dependence of consumption, production, selling
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$d \downarrow$ s.t. avg share sold **16%** $\rightarrow$ **50%**:

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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

Future Research

- Analyze government programs targeting smallholder farmers

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  - 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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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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back

Food

- Food consumption

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

back

Model: HH Problem

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

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$$\sum_{i=1}^{n} \frac{x_{h,i}}{z_{h,i}} \leq L_h$$

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

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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. $\mathbf{min}_{K_{in}>0} f(K_{in}, K_{req}) = f(K_{req}, K_{req}) = 0$ (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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  - endogenous predictions on allocation across agricultural goods

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

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Calibration

Agricultural Goods

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

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Households

Calibration

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  1. taste weight φ_i
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  3. distribution of productivity across households $z_{h,i}$
- Solve for market-clearing prices ▶ *GE details*

Households

- Heterogeneous in

Calibration

Agricultural Goods

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

- Heterogeneous in
  1. Non-farm income wN_h
  2. Land L_h
  3. Good productivity $z_{h,i}$

▶ *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:

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

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back

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  - data: tobacco accounts for 60% of Malawi's exports
  - tobacco traded internationally at exogenous $\bar{p}_t$

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

back

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- Tobacco market doesn't need to clear
  - data: tobacco accounts for 60% of Malawi's exports
  - tobacco traded internationally at exogenous $\bar{p}_t$
  - some manufactured good is imported to balance the trade:

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

back

Farm Sales are Specialized: Model & Data

- Model: each farm sells at most one good

back

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back

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  - **69%** sell just 1 good, only **9%** produce just 1 good

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  - can produce more goods for own consumption
- Data: sales are specialized compared to overall production
  - **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: $d \downarrow \rightarrow$ specialize production
  - below some cutoff $\tilde{d}_h$, HH h only produces the revenue-maximizing good

back

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

- Model: $d\downarrow \rightarrow$ specialize production
  - 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	

back

Large Farms Sell More: Model & Data

- Larger farms are more active sellers:

output quartile	sold output share
	model
1	<1%
4	67%

back

Large Farms Sell More: Model & Data

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output quartile	sold output share	
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size ↑

back

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$$\text{size} \uparrow \longrightarrow \text{energy intake} \uparrow$$

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- Model mechanism:

$$\text{size}\uparrow \longrightarrow \text{energy intake}\uparrow \nearrow \text{food diversity}\uparrow$$

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- Model mechanism:

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

back

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$$
\begin{tikzcd}
 & & \text{food diversity} \uparrow \arrow[dr] & \\
\text{size} \uparrow \arrow[r] & \text{energy intake} \uparrow \arrow[ur] \arrow[dr] & & \text{need revenue} \\
 & & \text{manuf. cons} \uparrow \arrow[ur] &
\end{tikzcd}
$$

back

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output quartile	sold output share	
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- Model mechanism:

$$\begin{array}{ccccccc} & & & \text{food diversity} \uparrow & & & \\ & & \nearrow & & \searrow & & \\ \text{size} \uparrow & \longrightarrow & \text{energy intake} \uparrow & & & \text{need revenue} & \longrightarrow \text{sell} \\ & & \searrow & & \nearrow & & \\ & & & \text{manuf. cons} \uparrow & & & \end{array}$$

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	

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

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

back

Lower Trade Costs → All Specialize: Data

	production diversity
sold output share	
N	
Adj. R^2	

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

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

back

Lower Trade Costs → All Specialize: Data

	production diversity
sold output share	−0.044***
	(0.016)
N	4,042
Adj. R^2	0.025

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

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

back

Lower Trade Costs → All Specialize: Data

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

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

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

back

Lower Trade Costs → All Specialize: Data

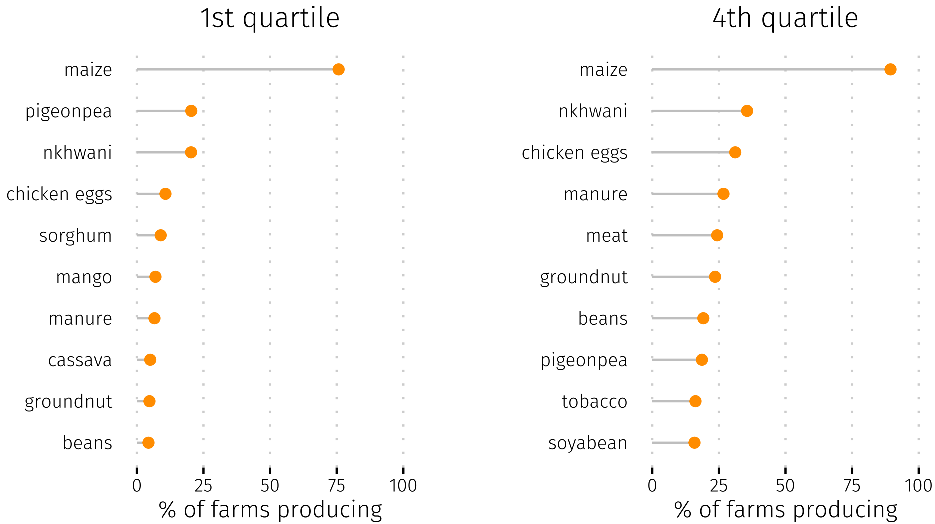
	production diversity	
sold output share	−0.044***	
	(0.016)	
𝟙[good mkt access]		−0.164***
		(0.018)
N	4,042	8,675
Adj. R^2	0.025	0.099

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

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

back

Product Frequency by Size: Data



back

Calibration

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

back

Calibration

parameter	value	moment/source	**data** moment	**model** moment
Distributions				
$\mathbb{E}\left(\log L_h\right)$	-15	avg $K_{in,h}/K_{req,h}$	1.036	0.902

back

Calibration

parameter	value	moment/source	**data** moment	**model** moment
Distributions				
$\mathbb{E}\left(\log L_h\right)$	-15	avg $K_{in,h}/K_{req,h}$	1.036	0.902
$V\left(\log L_h\right)$	1.5	$V\left(\log \text{output}_h\right)$	1.528	1.385

back

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$V\left(\log L_h\right)$	1.5	$V\left(\log \text{output}_h\right)$	1.528	1.385
$P\left(N_h = 0\right)$	0.112	$P\left(\text{non-farm income}_h = 0\right)$	0.112	0.117

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$V\left(\log N_h \mid N_h > 0\right)$	2.103	$V\left(\log \text{non-farm income}_h\right)$	2.103	1.924

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Parameters				

back

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Parameters				
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back

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Parameters				
σ *(EoS across foods)*	0.75	estimated	–	–
γ *(EoS between food & manuf.)*	1	–	–	–

back

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parameter		value	moment/source	**data** moment	**model** moment
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Parameters					
σ	*(EoS across foods)*	0.75	estimated	—	—
γ	*(EoS between food & manuf.)*	1	—	—	—
d	*(agricultural trade cost)*	1.75	avg share sold	0.159	0.203

back

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ψ *(kcal deviation penalty)*	0.5	output elasticity of K_{in}	0.091	0.124

back

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Parameters					
σ	*(EoS across foods)*	0.75	estimated	—	—
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Good characteristics					

back

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ψ *(kcal deviation penalty)*	0.5	output elasticity of K_{in}	0.091	0.124
Good characteristics				
φ_m *(manuf. taste weight)*	0.5	$\frac{\text{aggr. non-farm income}}{\text{aggr. farm output}}$	1.539	1.632

back

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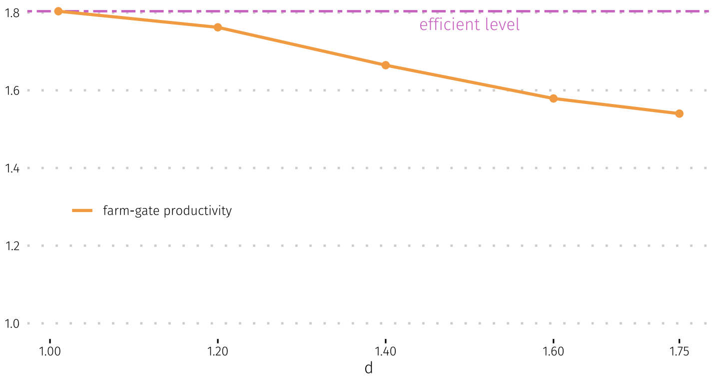
Good characteristics				
φ_m *(manuf. taste weight)*	0.5	$\frac{\text{aggr. non-farm income}}{\text{aggr. farm output}}$	1.539	1.632
$\bar{p}_{\text{tobacco}}/p_{\text{maize}}$	5.4	aggr. tobacco output share	0.091	0.094

back

Trade Costs ↓ → Aggregate Productivity ↑

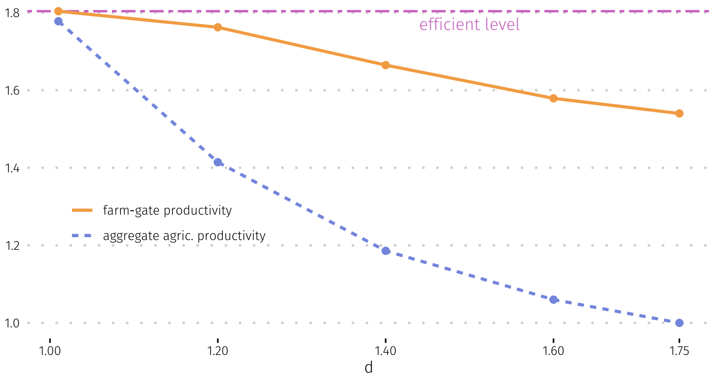
- Compare "farm-gate" production to final consumption ("aggregate productivity")
  - farm production only accounts for product choice changes



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 ↑ **78%**

back

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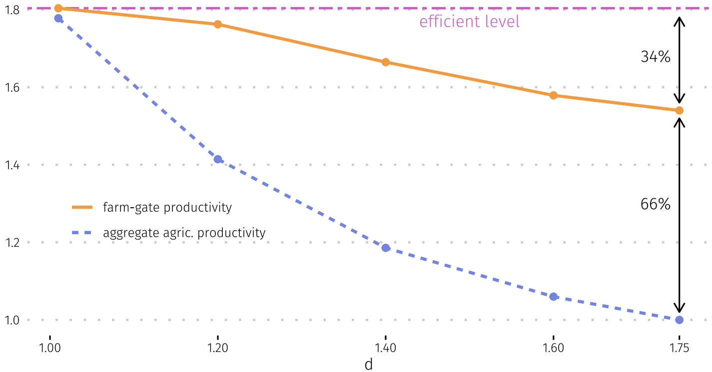

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back

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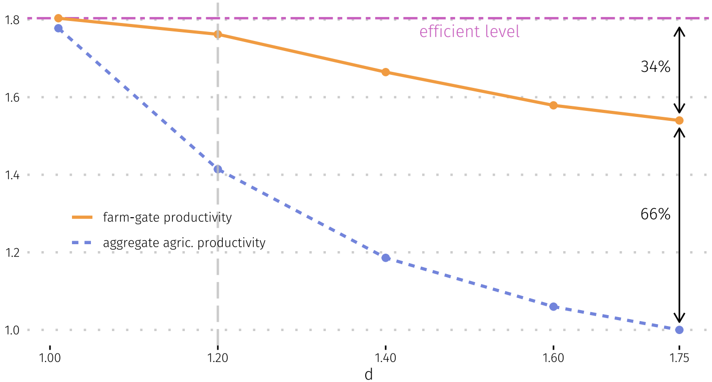
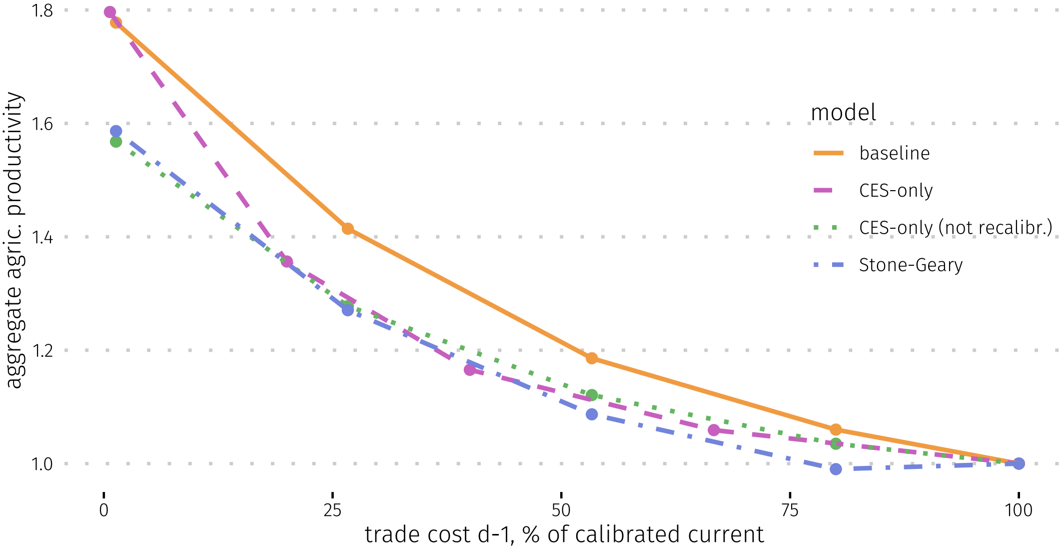


- $d \to 1$: aggr. productivity ↑ **78%** ($\frac{1}{3}$ due to product choice)
- $d \downarrow$ s.t. avg share sold 16% → 50%: aggr. productivity ↑ **42%** ($\frac{1}{2}$ due to product choice)

back

Aggregate Agricultural Productivity Across Models



back

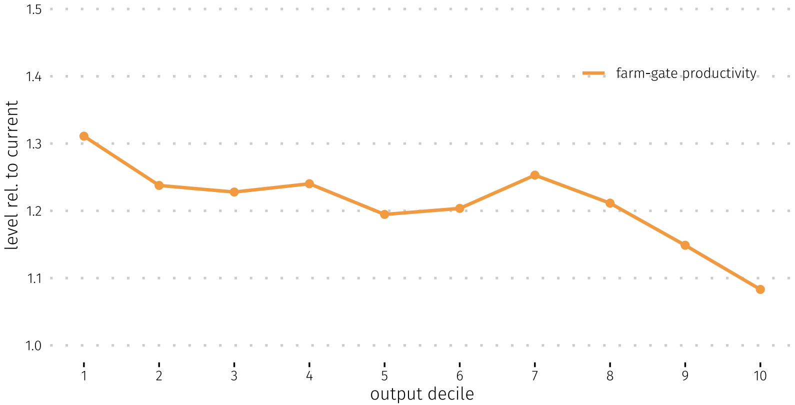
Trade Costs $\downarrow$ $\to$ Heterogeneous Effects in Farm Size

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

back

Trade Costs ↓ → Heterogeneous Effects in Farm Size

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



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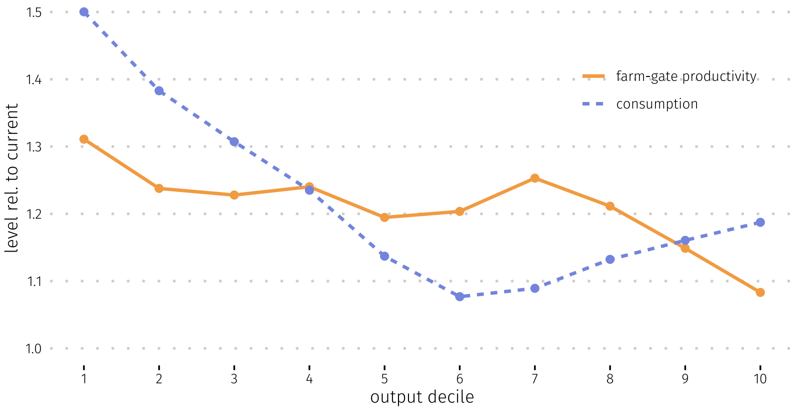
Trade Costs $\downarrow$ $\rightarrow$ Heterogeneous Effects in Farm Size

- $d\downarrow$ s.t. avg share sold 16% $\rightarrow$ 50%:
  - farm productivity: small $\uparrow$ the most, large $\uparrow$ the least
  - consumption: small $\uparrow$ the most, medium $\uparrow$ 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	0.260	0.124	0.091***	−0.118	0.428	0.395***
	(0.001)	(0.001)	(0.005)	(0.001)	(0.002)	(0.034)
log non-farm income	0.223	0.084	0.063***	0.029	0.396	0.857***
	(0.001)	(0.001)	(0.004)	(0.001)	(0.002)	(0.033)
N	35,483	33,613	8,674	35,483	33,613	8,675
Adj. R^2	0.819	0.393	0.063	0.196	0.762	0.131

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

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