Household consumption, individual requirements, and the affordability of nutrient-adequate diets – Application to Malawian households

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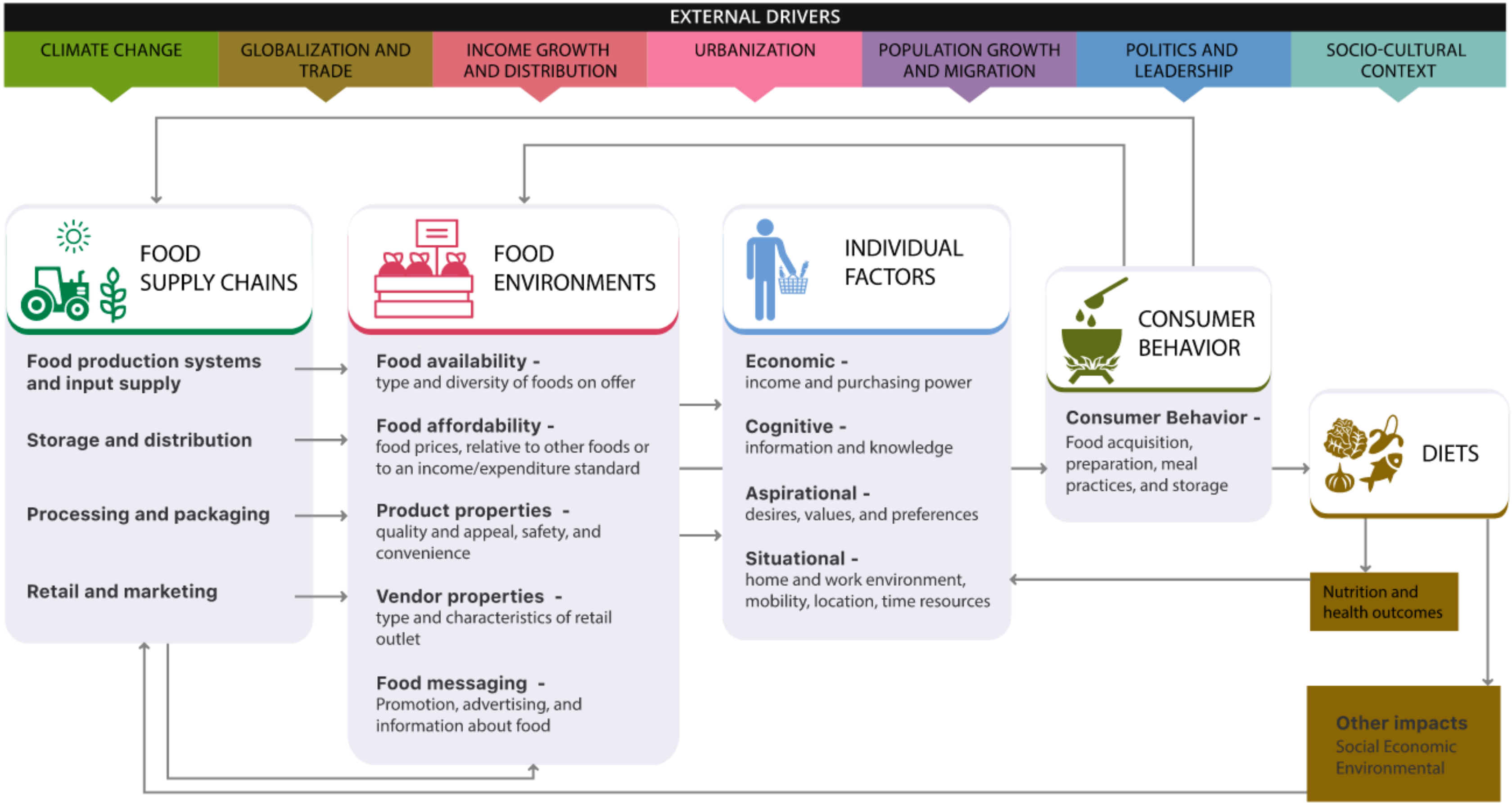
Presentation to IFPRI-Malawi team
December 8, 2021

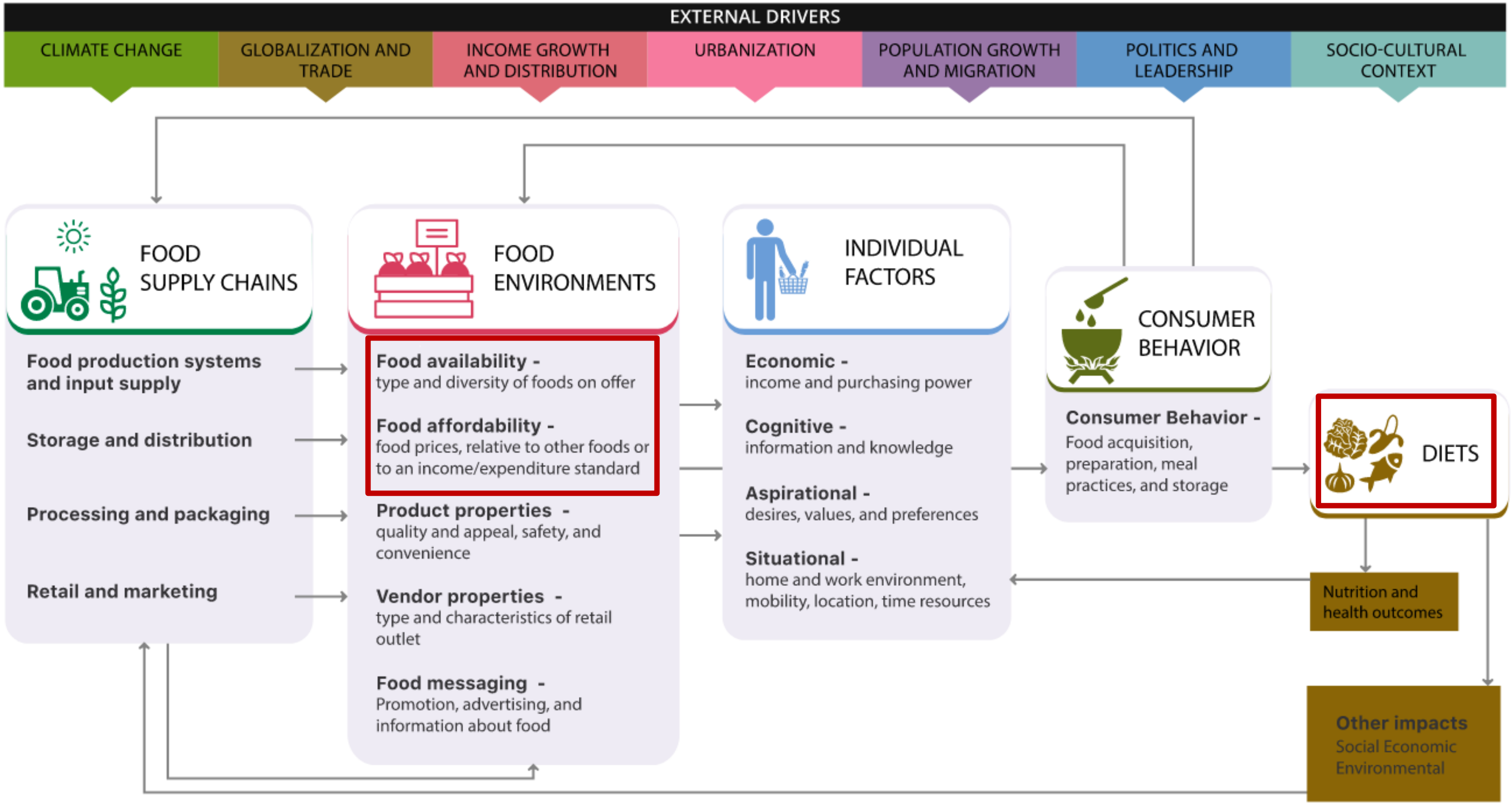
A food system



ADAPTED FROM: HLPE (2017). NUTRITION AND FOOD SYSTEMS. A REPORT BY THE HIGH LEVEL PANEL OF EXPERTS ON FOOD SECURITY AND NUTRITION OF THE COMMITTEE ON WORLD FOOD SECURITY, ROME, ITALY.

Source: Fanzo et al., 2020 & the Food Systems Dashboard

The food system



ADAPTED FROM: HLPE (2017). NUTRITION AND FOOD SYSTEMS. A REPORT BY THE HIGH LEVEL PANEL OF EXPERTS ON FOOD SECURITY AND NUTRITION OF THE COMMITTEE ON WORLD FOOD SECURITY, ROME, ITALY.

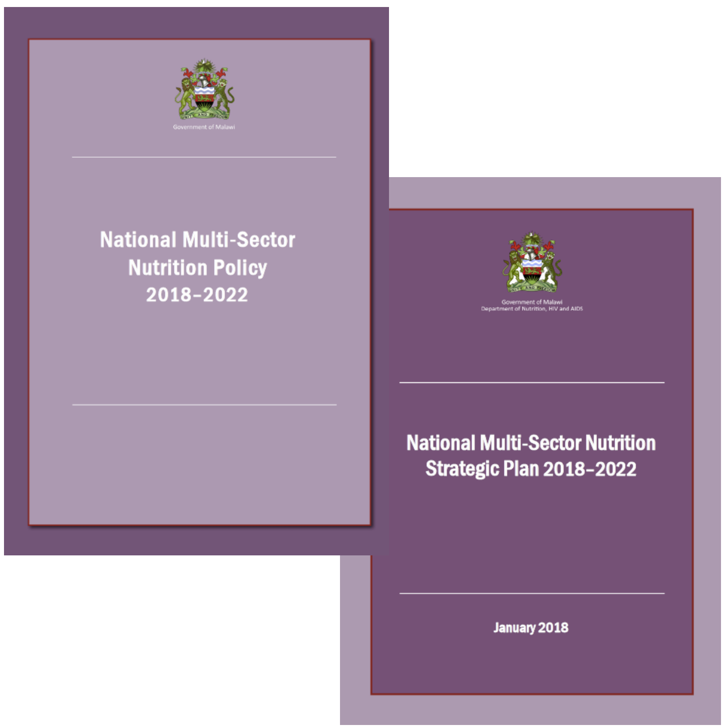
Key terms:

- **Nutrient adequacy:** meeting minimum scientific nutrient requirements without exceeding upper bounds.
  Institute of Medicine, 2006

- **High quality diet:** those that are adequate in nutrients – including energy – without exceeding limits, balanced in macronutrients, and have variety.
  Trijsburg et al., 2019

- **Nutrient density:** quantity of essential nutrients per unit of energy.
  Trijsburg et al., 2019

Political will exists to make changes.



Information and research needs:

- Data for nutrition and diet quality surveillance;
- Data availability and quality assessment;
- Evidence to guide nutrition education and behavior change messaging;
- Evidence to identify crops and agricultural practices to increase nutrient-dense food production;
- Metrics for a national multi-sectoral nutrition monitoring and evaluation system.

Motivation: Household surveys and least-cost diets can be used to evaluate how well the food system delivers diets that meet the needs of the population.

- **Household consumption and expenditure surveys (HCES) offer a useful but imperfect substitute for individual dietary data.**
  Coates et al., 2017; Fiedler & Lividini, 2017; Zezza et al., 2017

- **Least-cost diets are particularly amenable as a food system metric since they are flexible to changes in the availability and price of foods.**
  Allen, 2017; Masters et al, 2018; FAO, 2020; Herforth et al., 2020; Stigler, 1945

1. What level of diet quality would meet all members needs? How nutrient-dense are current diets?

2. Are nutrient adequate diets affordable year-round?

3. What are the drivers of diet infeasibility and high cost? What policy solutions are available?

https://farm1.staticflickr.com/4/9022793_d09fe087f7_z.jpg

Data & Methods

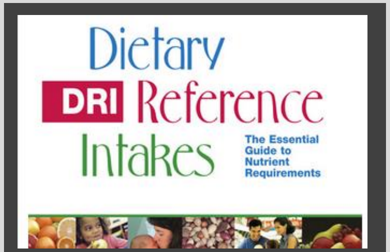

https://livestocksystems.files.wordpress.com/2019/02/img-20170623-wa0005.jpg?w=1200


http://houseofbots.com/images/news/3539/cover.png

Integrated Household Panel Survey
Malawi NSO & World Bank (2010, 2013, 2016/17)

CPI Market Price Data
Malawi NSO (Jan 2013 – July 2017)

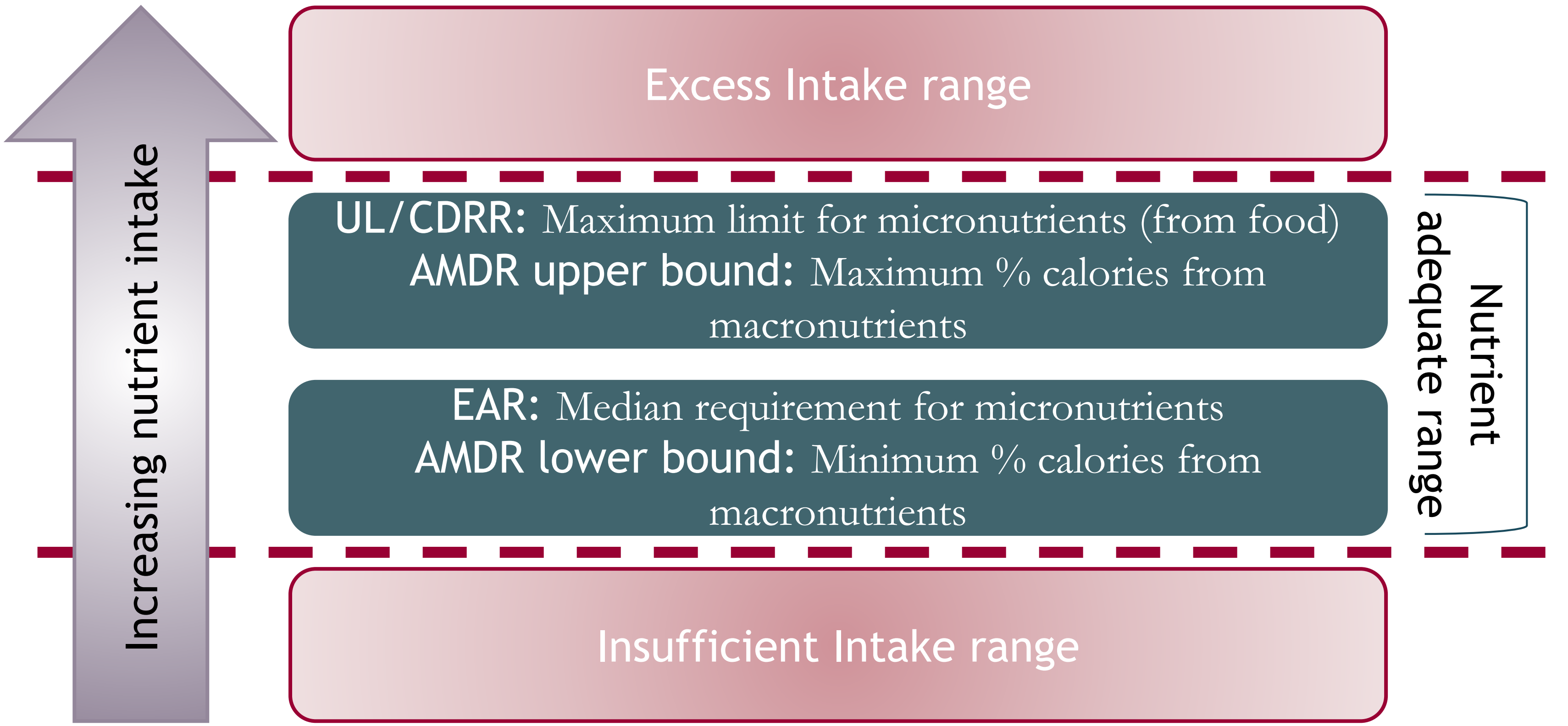
Malawi FCT
SAMRC, LUANAR, Nutrition Innovation Lab



Dietary Reference Intakes
Institute of Medicine, US & Canada

Individual Nutrient Requirements

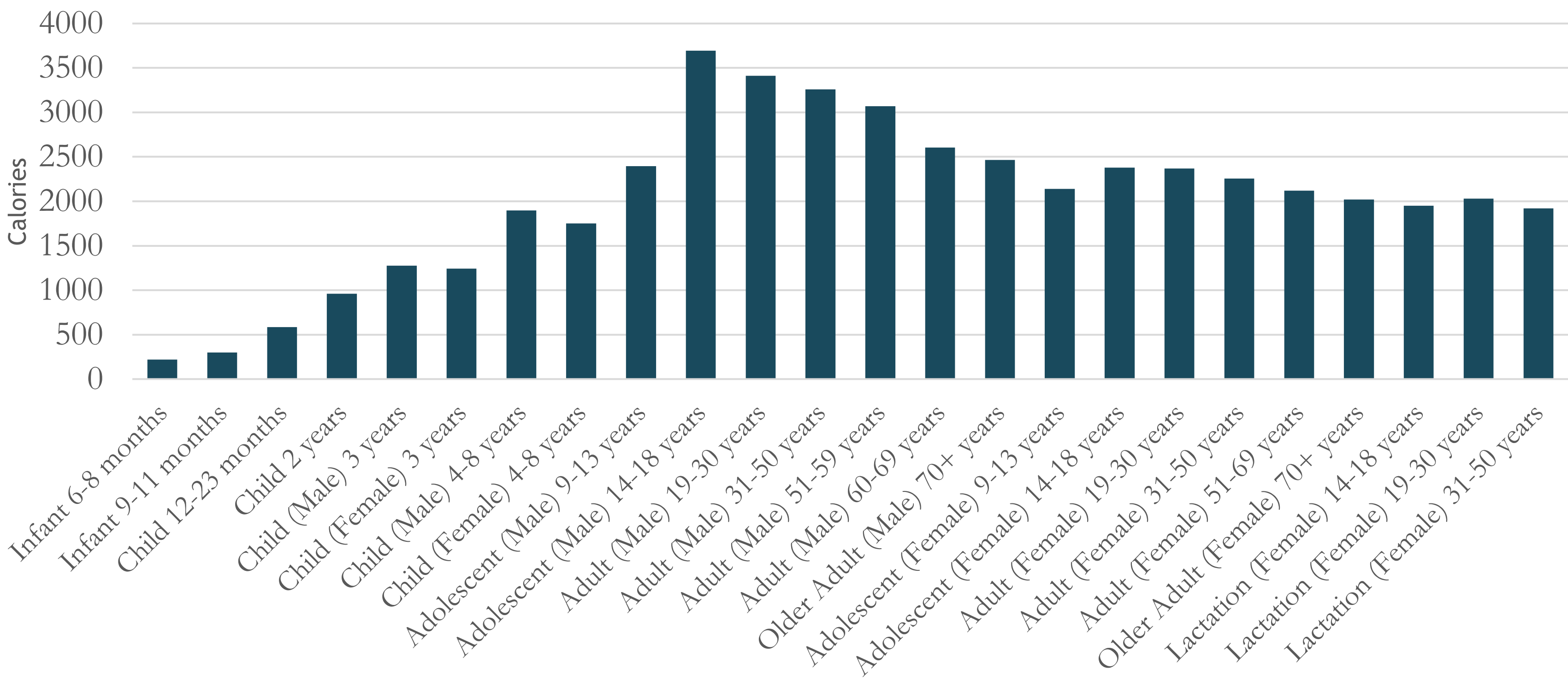
DRIs define a nutrient adequate diet.



Nutrients included: Energy, Carbohydrates, Protein, Lipids, Vit A (Retinol UL), Vit C, Vit E, Thiamin, Riboflavin, Niacin, B6, Folate, B12, Calcium, Copper, Iron, Magnesium, Phosphorus, Selenium, Zinc

Individual Energy Requirements

Daily energy needs calculated by EER using WHO reference anthropometrics, by age, sex, maternity, and physical activity.



Individual Nutrient Requirements

Key assumptions

- Reference heights and weights from WHO growth charts
- Physical activity assumed to be active for most people
- Physical activity assumed to be very active for men 14-59 whose occupation is likely to be physically demanding (e.g. unmechanized agriculture)
- Pregnancy unobserved, all women assume to be non-pregnant
- Breastfeeding unobserved, all mothers of children under 2 assumed to be breastfeeding

Household Nutrient Requirements

Nutrient density satisfies neediest member.

$$HHLower_{hj} = \sum_m E_m * max_m\{MinimumNeed_{j,m}/E_m\}, j = 1, \ldots, 19$$

$$HHUpper_{hj} = \sum_m E_m * min_m\{MaximumTolerance_{j,m}/E_m\}, j = 1, \ldots, 13$$

$$HHE_h = \sum_m E_m$$

h = household
m = household member
j = density of each nutrient
e/E = energy

Least-cost diets

Food items and quantities that meet nutrient requirements at lowest total cost.

$$CoNA: minimize\ C = \sum_i p_i * q_i$$

Subject to:

$$\sum_i a_{ij} * q_i \geq Lower_j\ ,\quad j = 1, \dots, 19$$

$$\sum_i a_{ij} * q_i \leq Upper_j,\ j = 1, \dots, 13$$

$$\sum_i a_{ie} * q_i = E$$

$$q_1 \geq 0, q_2 \geq 0, \dots\ q_i \geq 0, \text{for all foods } i = 1, \dots 51$$

e/E = energy
p_i = food price for item i
q_i = food quantity for item i
a_{ij} = nutrient contents

By the numbers

	2010*	2013	2016/17
Observations			
Households	1,615*	1,982	2,505
Rural	1,142*	1,428	1,839
Rural matched to food prices‡	1,142	1,424	1,693
Urban*	473*	554*	666*
Individuals (rural)	7,375	7,153	8,221
Markets		25	25
Food items	129*	51	51
Nutrients†	22	22	22

	2013 – 15	2016 – 17
Months	24	19
Linear models estimated		
Lower bound cost	171,672	156,199
Upper bound cost	34,176	32,167
Nutrient shadow prices	34,176	32,167
Policy Scenarios (8)	546,816	514,672
Total		**1,522,045**

* Used for Aim 1 only

‡ Households unmatched to markets are coded as rural but reside in districts where the central market is one of Malawi's 4 main cities and we do not have access to the price data

† Energy, Carbohydrates, Protein, Lipids, Vit A (Retinol UL), Vit C, Vit E, Thiamin, Riboflavin, Niacin, B6, Folate, B12, Calcium, Copper, Iron, Magnesium, Phosphorus, Selenium, Zinc, Sodium (CDRR)

1

Assessing diet quality when families share their meals

Schneider, K., Webb, P., Christiaensen, L., & Masters, W. (2021) Assessing diet quality when families share their meals: Evidence from Malawi. *Journal of Nutrition nxab287*. doi:10.1093/jn/nxab287

What level of diet quality would meet all members needs?

- **Shared diets must be of higher diet quality than any one member needs alone.**
  Beaton, 1995; Beaton, 1999; Institute of Medicine, 2000

Why use a shared nutrient requirement?

- **Practicality.**
  Where only household data are observed, household consumption can be compared to household needs.
- **Normative welfare principle.**
  Evaluate the welfare of the household by the welfare of the neediest member.
- **Gender equity.**
  Setting household diet quality at the level needed by the neediest member often requires the whole family to consume a diet that meets *her* minimum needs.

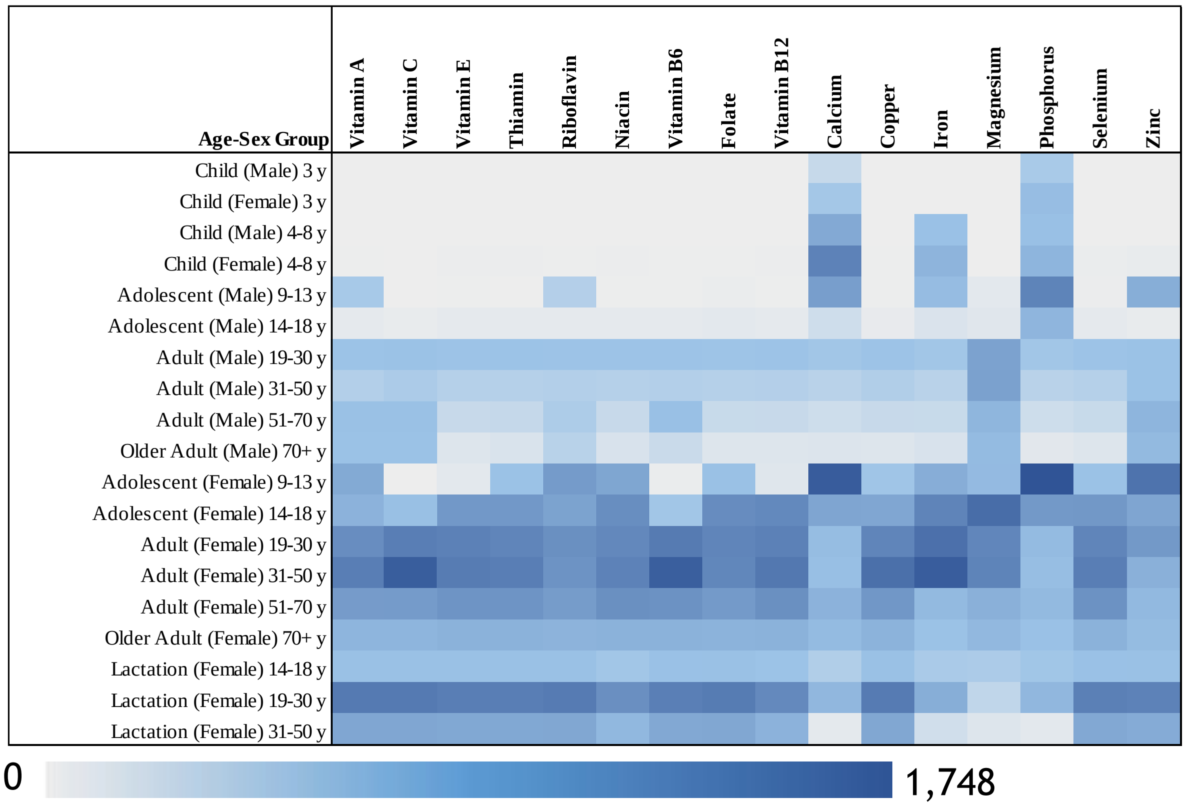
Methods

- **Aggregate household nutrient requirements.**
  Defines the total quantity and nutrient density of the diet that is adequate in all nutrients for all members when shared.
  Beaton 1995, Beaton 1999, IOM 2000
- **Total nutrient intakes calculated from reported food consumption.**
  All foods converted to kilograms using reference weights, matched to nutrient composition. Iron and zinc intakes adjusted for low bioavailablity.
- **Energy-adjusted nutrient adequacy ratios.**
  Comparing energy-adjusted observed household food consumption to the aggregate household nutrient requirements.
  Willett & Stampfer, 2013

Household characteristics

	2010		2013		2016/17		Overall	
	Mean	(SE)	Mean	(SE)	Mean	(SE)	Mean	(SE)
Household size	4.63	(0.14)	4.88	(0.12)	4.93	(0.12)	4.81	(0.10)
Number of adult (>18) members	2.15	(0.04)	2.15	(0.04)	2.27	(0.04)	2.19	(0.03)
Number of child (≤18) members	3.57	(0.08)	3.59	(0.08)	3.64	(0.08)	3.60	(0.06)
Dependency Ratio (<15 or >64 defined as dependent)	0.78	(0.03)	0.83	(0.05)	0.73	(0.03)	0.77	(0.03)
Under 5 stunting (%)[2]	0.33	(0.03)	0.27	(0.02)	0.27	(0.02)	0.30	(0.02)
Rural (%)	0.81	(0.04)	0.79	(0.04)	0.79	(0.03)	0.80	(0.03)
Head Education (Years)	6.11	(0.28)	6.29	(0.30)	6.42	(0.24)	6.27	(0.23)
Spouse Education (Years)	3.70	(0.22)	4.06	(0.24)	4.13	(0.20)	3.95	(0.18)
Food Spending Share of Total Expenditures	0.65	(0.01)	0.66	(0.01)	0.60	(0.01)	0.63	(0.01)
Observations								
Households[3]		1,615		1,982		2,505		6,102
Individuals		7,375		9,534		11,540		28,449
Excluded[4]								
Individuals, no meals		141		294		503		938
Infants		147		172		215		534

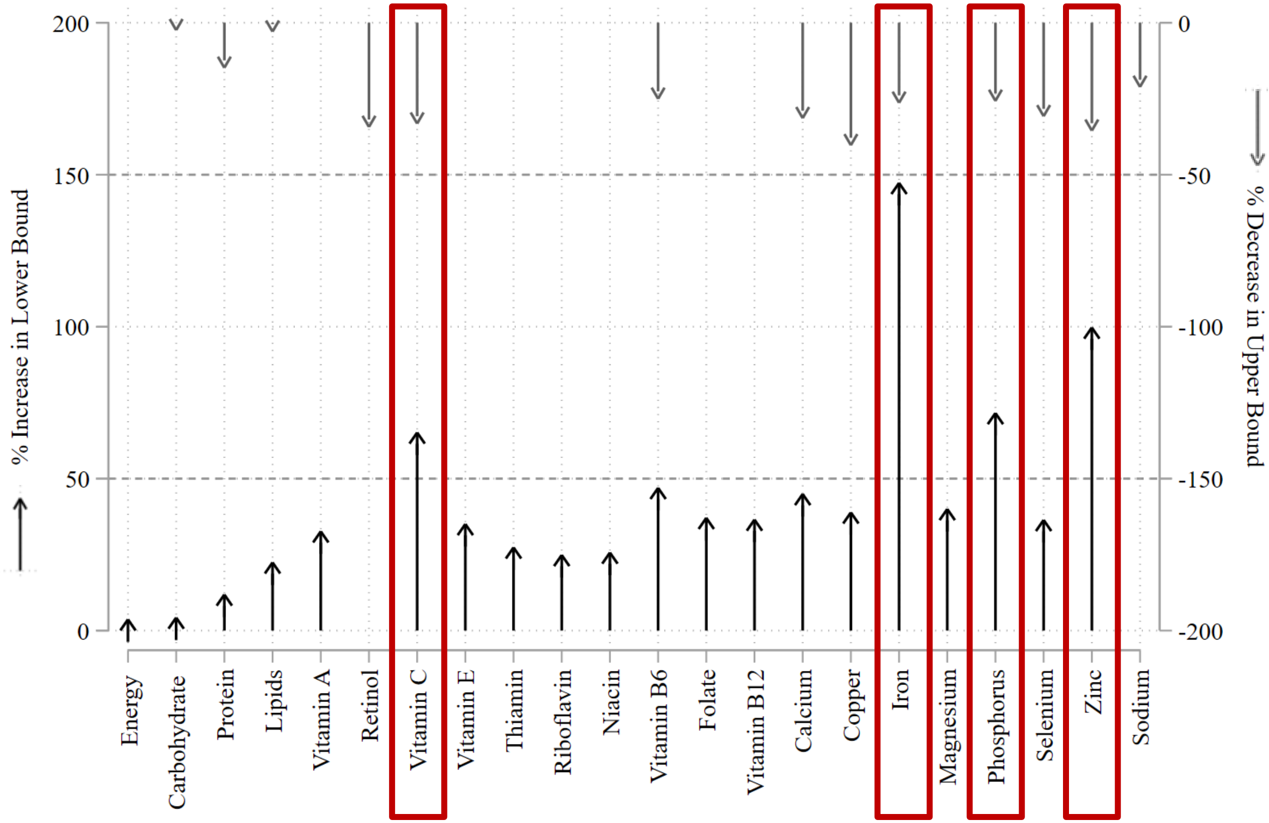
Women and girls have the highest need for nutrient density in their diets.

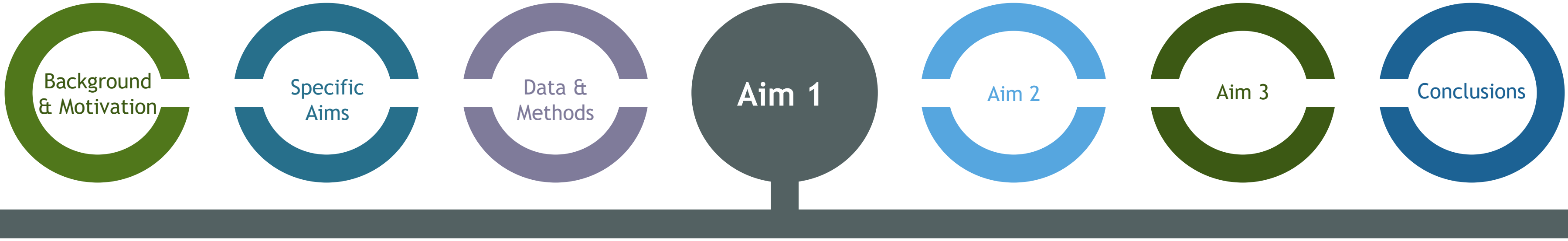


*Total households are 6,102. Variation in household composition explains why at most a single age-sex group defines the household need for a nutrient for one third of all households.

Range tightens most for vitamin C, iron, phosphorus, and zinc.

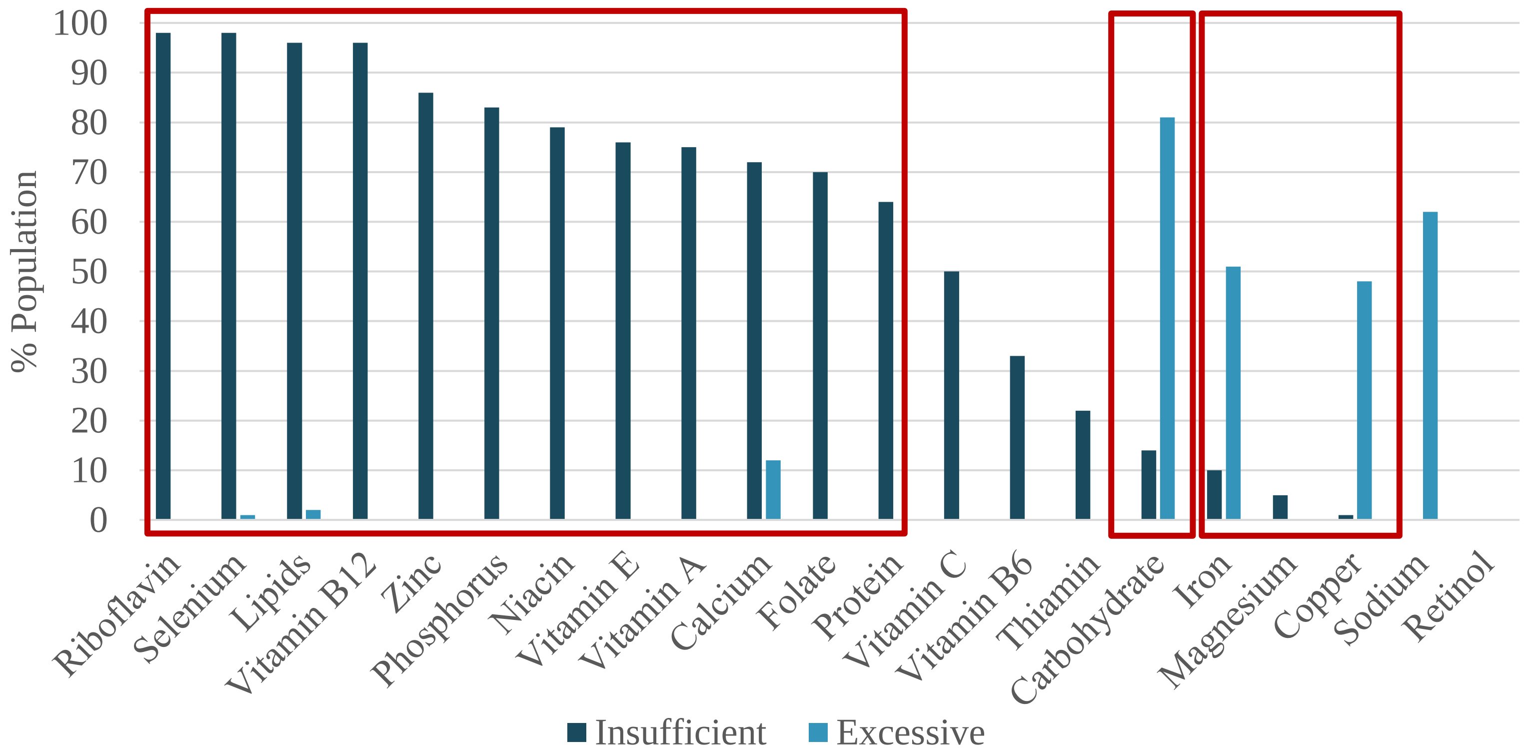
Percent Difference in Nutrient Bounds from Individual Diets to Household Sharing





Diets are not dense enough in riboflavin, selenium, lipids, B12. Too many calories from carbs. Too much copper.

% Population with suboptimal nutrient density in the diet



Background & Motivation | Specific Aims | Data & Methods | Aim 1 | **Aim 2** | Aim 3 | Conclusions

2

Affordability of nutritious diets year-round

Schneider, K., Webb, P., Christiaensen, L., & Masters, W. "Assessing the affordability of nutrient-adequate diets." (under final review of resubmission)

https://www.theguardian.com/science/2015/apr/28/bowel-cancer-risk-may-be-reduced-by-rural-african-diet-study-finds#img-1

http://www.andiamotrust.org/wp-content/uploads/2012/05/kwacha.jpg

Are nutrient adequate diets affordable year-round?

- **The sum of the cost of meeting individual nutrient requirements is a lower bound on household diet cost.** ("Individualized diets")
- **The cost of meeting shared nutrient requirements is an upper bound on household diet cost.** ("Household sharing")

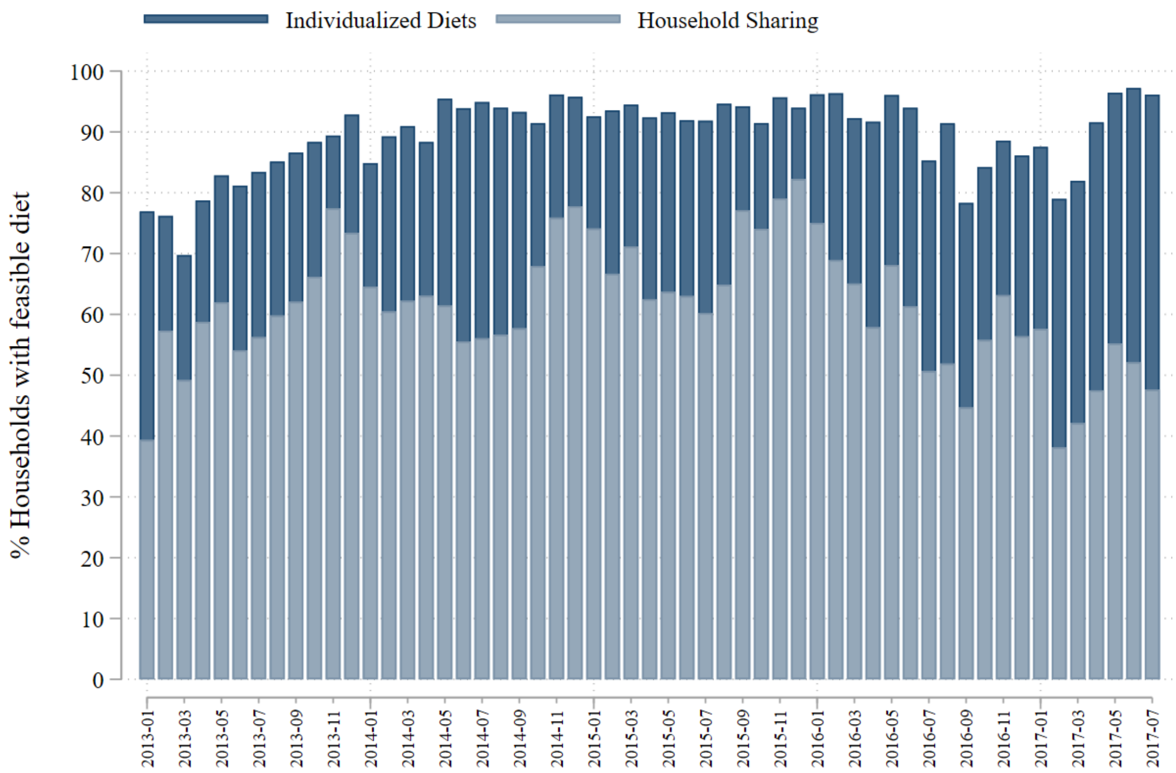
- Range estimate is more realistic than either bound alone.
- Monthly price data allow to assess seasonal fluctuation in diet cost.

Methods

- **Lower bound diet cost:**
  Sum of individual diet costs meeting minimum individual needs.
- **Upper bound diet cost:**
  Cost of the diet meeting aggregate household nutrient requirements.
- **Affordability:**
  Diet cost compared to monthly food and total spending for households where a diet solution is identified in the same month the household was surveyed.

Shared diets are feasible in the market 60% of the time.

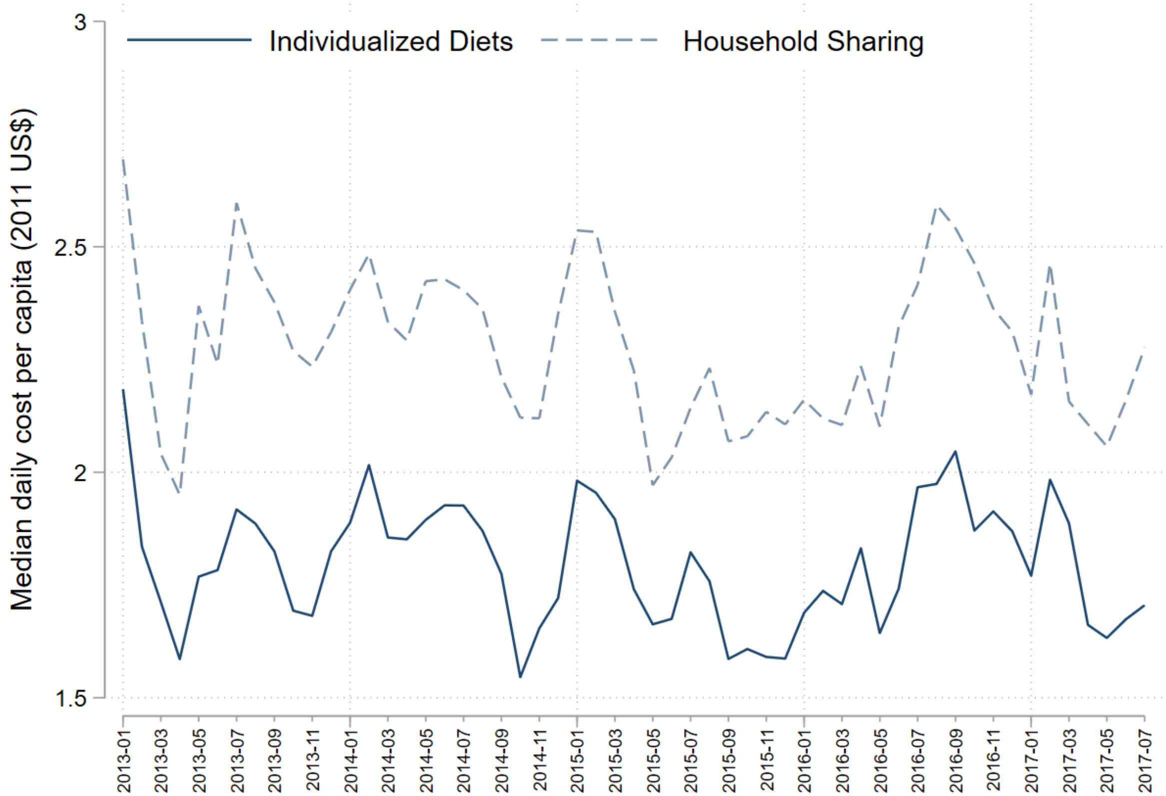
Monthly variation in feasibility of nutrient adequate diet, 2013–2017



Population statistics corrected using sampling weights. Percent of households with a feasible diet under the individualized diets scenario is defined as households with a solution for all members.

Cost is $1.75 (2011 US$ PPP) per person per day for the median household at the lower bound, $2.26 at the upper.

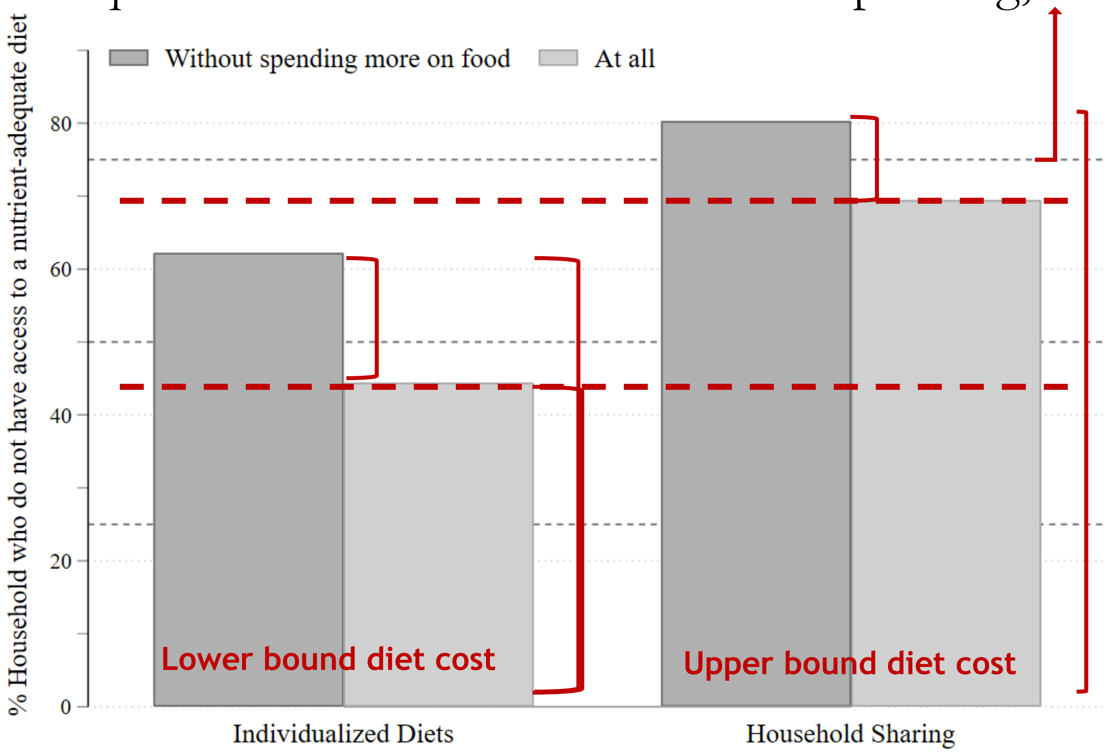
Monthly variation in cost of nutrient adequate diet, 2013–2017



All prices expressed in 2011 US Purchasing Power Parity (PPP) dolla

Fraction of households who cannot purchase the adequate diet in the market the month of survey.

Cost of nutrient adequate diet relative to food and total spending, 2013 & 2016/17



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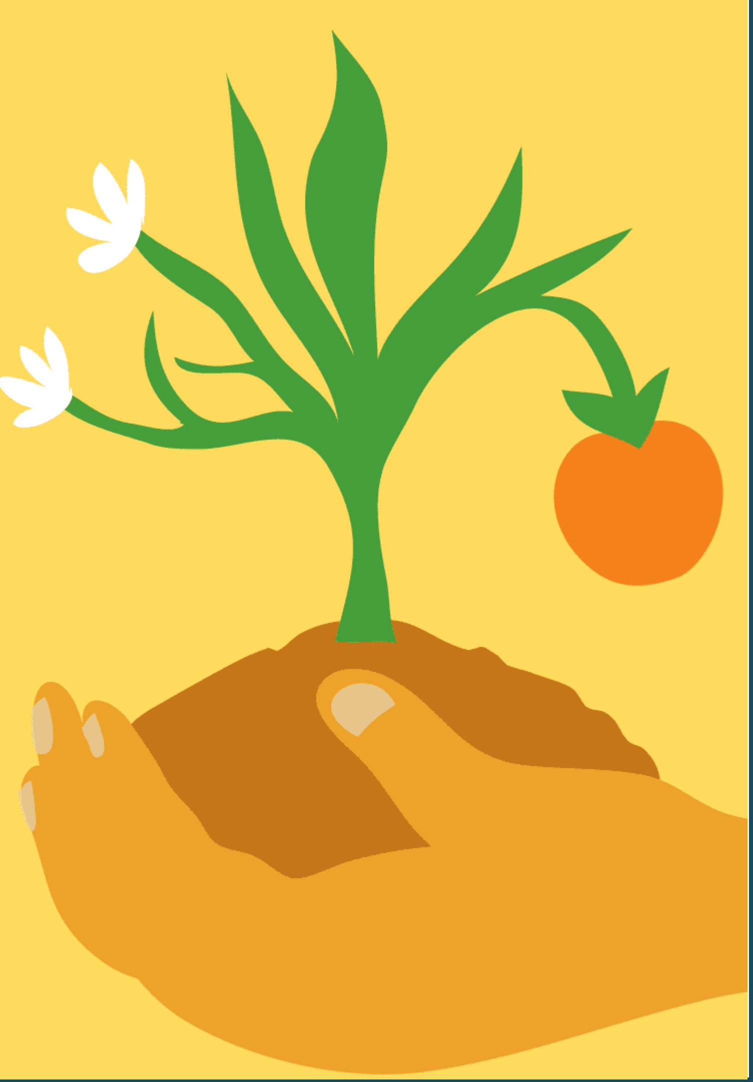
Nutrient drivers and policy options

Schneider, K. 2020. "Nationally Representative estimates of the cost of adequate diets, nutrient level drivers, and policy options for households in Malawi." (in revisions, *Food Policy*)



What are the drivers of diet infeasibility and high cost and what policy solutions are available?

- **Analysis of feasibility by household size, composition, and policy scenarios.**
- **Nutrient shadow prices; arguably *an underutilized tool* in human nutrition and food systems analysis.**
  Håkansson, 2015
- **Policy scenarios can identify which actions throughout the food system would be most effective to increase access to nutrient adequate diets.**
  Global Panel, 2020

Methods

- **Least-cost diets meeting shared household nutrient needs**
- **Nutrient shadow prices**
- **Policy scenario simulations:**
  1. Lower price of eggs (10, 15, and 20%).
  2. Increased availability of dried fish.
  3. Increased availability and lower price of groundnuts (10%).
  4. Lower price of fresh milk (10%).
  5. Increased availability of powdered milk.
  6. Soil biofortification (for maize).

Foods	Nutrients provided:
Eggs	Riboflavin, B12, Lipids
Fish	B12, Niacin
Groundnuts	Vitamin E, Lipids, Niacin
Milk	Riboflavin, Lipids

Riboflavin and B12 largely drive the cost.

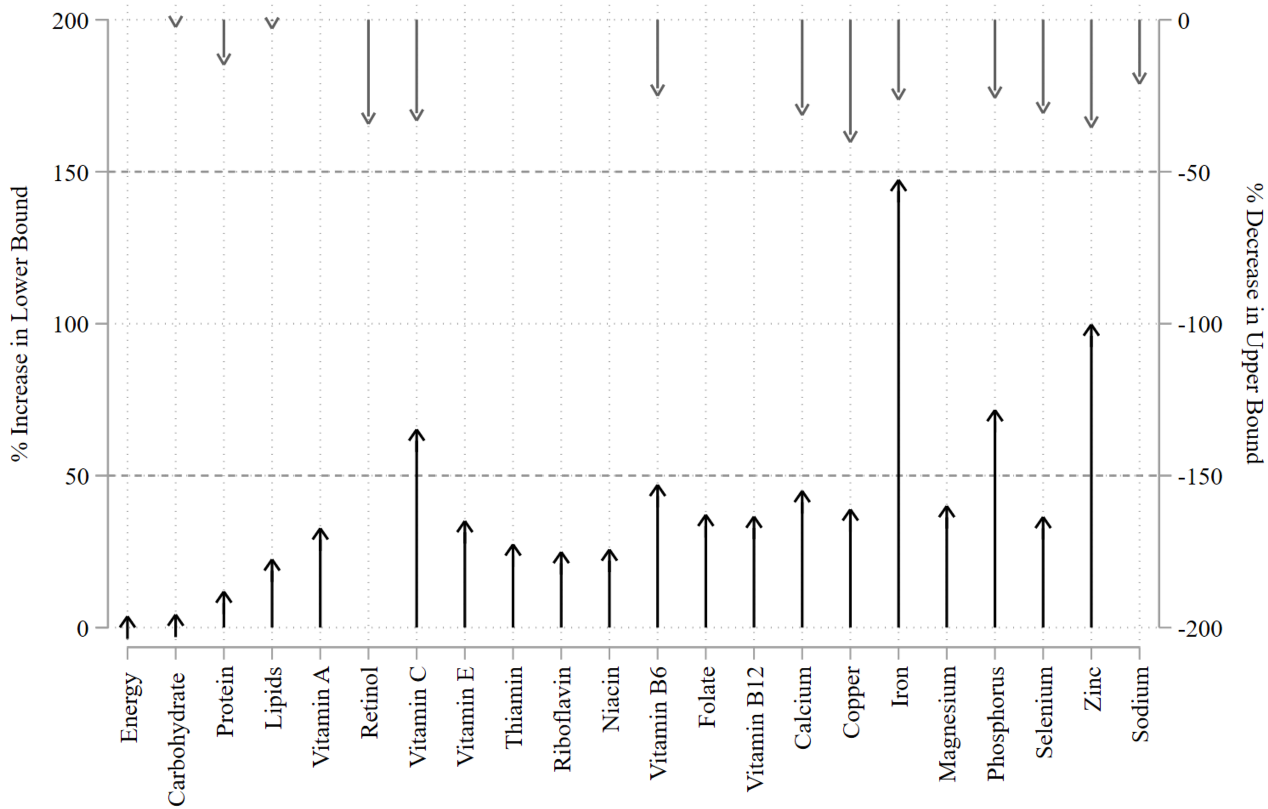
Cost rises $2.57 per household per day for a 1% increase in riboflavin need.

Diet cost, feasibility, and nutrient semi-elasticities

	Mean	**(SE)**
Household cost per day (2011 US$)	10.06	(0.28)
Per 1,000 kcal	1.21	(0.01)
Per person	2.32	(0.03)
Diet Feasible (% HH-Months)	59.37	(1.58)
Semi-elasticities – Lower Bound*		
Riboflavin	2.57	(0.19)
Niacin	0.01	(0.00)
Vitamin B12	0.14	(0.01)
Selenium	0.01	(0.00)
Semi-Elasticities – Upper Bound*		
Copper	-0.24	(0.01)
Iron	-0.01	(0.00)
Zinc	-0.01	(0.00)

Notes: Heteroskedasticity robust standard errors clustered at the enumeration area level. Outliers, defined as households with a HHCoNA more extreme than 1.5 times the IQR, excluded. *Only non-zero shadow prices are shown. All prices expressed in 2011 US Purchasing Power Parity (PPP) dollars.

Percent Difference in Nutrient Bounds from Individual Diets to Household Sharing



How does household composition drive feasibility or cost?

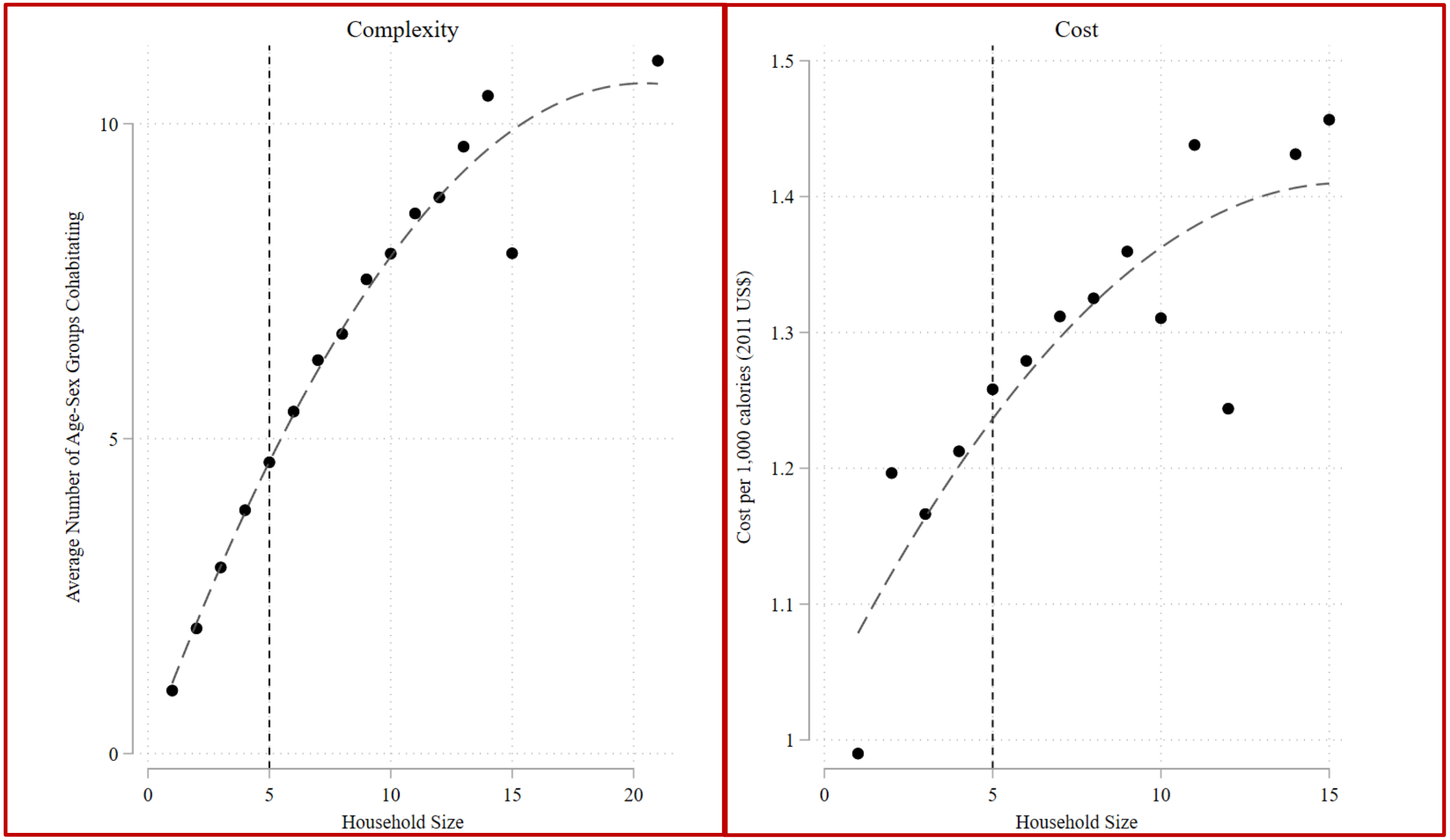
Household composition, diet feasibility, and diet cost

	Households (%)	Feasibility (%)		Cost per 1,000 kcal (2011 US$)	
		Mean	(SE)	Mean	(SE)
Most common compositions					
Older child(ren), adolescent(s), male and female adults	15.6	38.67	(2.78)	1.32	(0.02)
Older child(ren), male and female adults	12.0	69.93	(2.61)	1.28	(0.02)
Young child(ren), older kid(s), male and female adults	8.7	82.02	(2.36)	1.19	(0.02)
Young child(ren), older child(ren), male and breastfeeding female adults	7.0	55.04	(2.65)	1.31	(0.02)
Young child(ren), older child(ren), adolescent(s), male and female adults	5.8	61.58	(2.10)	1.28	(0.02)
Total	49.4	58.99	(1.85)	1.27	(0.01)

Notes: Population statistics corrected using sampling weights. Composition types sorted by frequency observed. Definition of age groups aggregates the age groups in the DRIs as follows: Young children = 3 and below, Older children = 4-13, Adolescent = 14-18, Adult = 19-69, Older adult = 70 and above. All prices expressed in 2011 US Purchasing Power Parity (PPP) dollars.

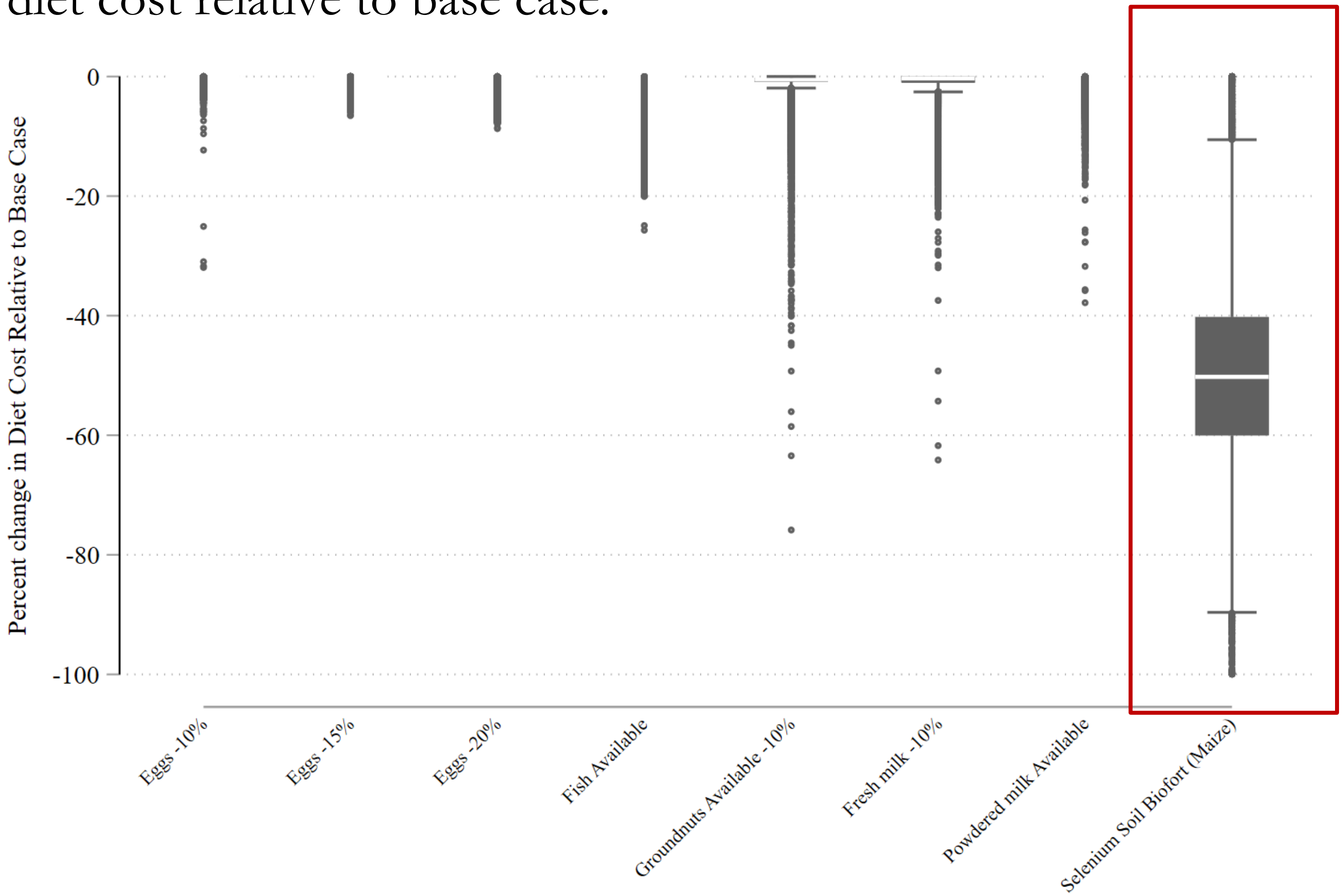
Does household composition drive feasibility or cost?

Household size, composition, and cost per 1,000 calories



Selenium biofortification is a promising option.

Change in diet cost relative to base case.



Selenium biofortification is a promising option.

Impact on cost, feasibility, and nutrient shadow prices.

	Base case		Soil fortification	
	Mean	SE	Mean	SE
Household cost/day (2011 US$)	10.06	(0.28)	5.91	(0.18)
Per person	2.32	(0.03)	1.22	(0.02)
Diet Feasible (% HH-Months)	59.37	(1.58)	94.94	(0.52)
Semi-Elasticities – Lower Bound*				
Riboflavin	2.57	(0.19)	2.62	(0.17)
Niacin	0.01	(0.00)	0.00	(0.00)
Vitamin B12	0.14	(0.01)	0.10	(0.01)
Selenium	0.01	(0.00)	0.00	(0.00)
Semi-Elasticities – Upper Bound*				
Copper	-0.24	(0.01)	-0.01	(0.00)
Iron	-0.01	(0.00)	-0.00	(0.00)
Zinc	-0.01	(0.00)	-0.01	(0.00)

All prices expressed in 2011 US Purchasing Power Parity (PPP) dollars.

Summary & Conclusions

https://professorowl.files.wordpress.com/2013/06/fotolia_35265232_xl5.png

Conclusions

- Aggregate nutrient density requirements relative to that observed in household diets provides a useful food system metric in contexts where families eat shared meals.
- Nutrients of concern in terms of inadequate nutrient density in household diets: selenium, vitamin B12, lipids, riboflavin, phosphorus, and zinc.
- Differences by wealth and location are small, for most nutrients.
- Minerals of concern reflect Malawi's soil composition and few animal source foods in the diet.

Conclusions

- A combination of foods that can meet the higher diet quality demanded when families share meals is less often feasible in the market and costs more than if families were to pursue individualized diet strategies.
- The seasonal gap in the lower bound diet cost is comparable with that of food groups, and lower than that of individual food prices -- substituting items within food groups can meet nutrition needs and stabilize diet cost throughout the year.
- Adequate diets are unaffordable to a minimum 44% of the rural Malawian population. Shared diets are unaffordable to 80%, within current food budgets.

Conclusions

- Riboflavin is by far the costliest nutrient to obtain in rural Malawi's food system, followed by B12.
- The feasibility of an adequate diet varies more by household composition than the cost of the diet if it is available.
- As household size increases, the cost per 1,000 of an adequate shared diet also rises, largely irrespective of composition.
- Selenium is the nutrient hindering the feasibility of adequate diets.
- Selenium biofortification of maize would reduce the diet cost by half and result in near universal feasibility of an adequate diet.

Sensitivity to analytical choices: Diet quality

Key assumption	Support for choice (triangulation)	Difference if included/ addressed	Indicator affected: Direction of bias
Duration of breastfeeding	DHS 2015/16 reported median duration of breastfeeding=23 months	Increased household energy need, defines nutrient density for multiple nutrients	Diet nutrient density relative to shared benchmark: downward (insufficient)
No pregnancy status	Nutrient requirements	Increased energy for short period	Diet nutrient density: likely unaffected
Omitted foods	NSO documentation Few restaurant meals reported (but unobserved food away from home is likely)	Greater nutrient intakes	Diet nutrient density relative to shared benchmark: downward May be differential by household size and wealth (Beegle et al., 2012; de Weerdt et al., 2016).
Bioavailability	Current diets adjusted for low bioavailablity.	Analysis of iron and zinc by source.	Nutrient density for iron and zinc: upward
Missing nutrients in food composition (e.g. selenium)	Selenium: studies show deficiency in soil and human status	More food items that could meet selenium requirements	Nutrient density relative to shared benchmark: downward

Sensitivity to analytical choices: Diet feasibility & cost

Key assumption	Support for choice	Difference if included	Indicator affected: Direction of bias
"Missing" prices	NSO documentation	If price missing but item was available AND item *would have been selected* into the least cost diet	*If item would have been selected* into the least cost diet, CoNA cost: upward (too high); CoNA availability: downward (less feasible)
Duration of breastfeeding	DHS 2015/16 reported median duration of breastfeeding=23 mo	Increased household energy need, defines density for some nutrients with non-zero shadow price	Diet cost: upward
No pregnancy status	Nutrient requirements	Increased energy for short period	Diet cost: slightly downward
Omitted foods	List is all foods >0.02% total expenditure in 2010	Additional food items available to supply nutrients	*If item would have been selected* into the least cost diet, CoNA cost: upward; CoNA availability: downward
Bioavailability	Adequate diets must contain some ASFs by definition (for B12)	Increased iron and zinc requirements or required from ASFs	CoNA cost: downward
Missing nutrients in food composition (e.g. selenium)	Selenium: studies show deficiency in soil and human status	More food items that could meet selenium requirements	*If item would have been selected* into the least cost diet, CoNA cost: upward; CoNA availability: downward

Conclusions

- Household consumption and expenditure surveys together with least-cost diets bring additional data and metrics that can be useful to guide policy.
- Household diets are suboptimal in terms of nutrient density, insufficient for most nutrients to meet needs if eaten in energy balance.
- Nutrient adequate diets are currently out of reach for most households, explained in part by household composition and size.
- Riboflavin and B12 are the costliest nutrients, but selenium shortage makes nutrient adequate diets infeasible.
- Soil biofortification of maize with selenium offers a promising policy option.

THANKS!

I express my gratitude to so many people, first and foremost the families of Malawi.

- My committee: Will Masters, Patrick Webb, & Luc Christiaensen
- CANDASA team (especially Stevier, Yan, and Anna)
- Family, friends & neighbors
- Friedman PhDs
- Colleagues current and past
- Friedman faculty
- Teachers and mentors
- My book clubs!

This thesis is dedicated to all the families of Malawi who selflessly shared their information with interviewers and without whom this work would not be possible. I hope I have done justice to the responsibility and trust they have placed in my hands.

Most of the work was completed in eastern Massachusetts on the ancestral homeland of the Massachusett tribal nations including the Mashpee and Aquinnah, Wampanoag, Nipmuc, and Massachusett tribes. I honor and express gratitude to the people who have stewarded this land for hundreds of generations.

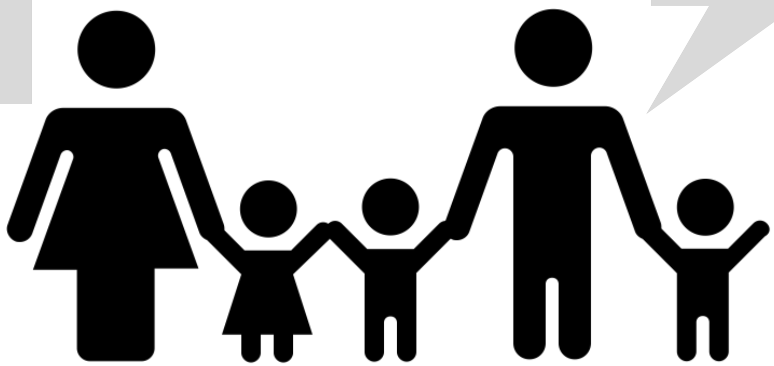
Extra slides

Household Nutrient Requirements

Nutrient density satisfies neediest member.

Iron density required :
1.2 mg/1,000 kcal

Iron density required:
4mg /1,000 kcal



Under household sharing:
Household nutrient density for iron = 4mg/kcal
Mother eats: 2,043 kcal containing 8.1 mg iron per day
Father eats: 2,825 kcal containing 11.2 mg iron per day

Credit: created by kiddo from Noun Project

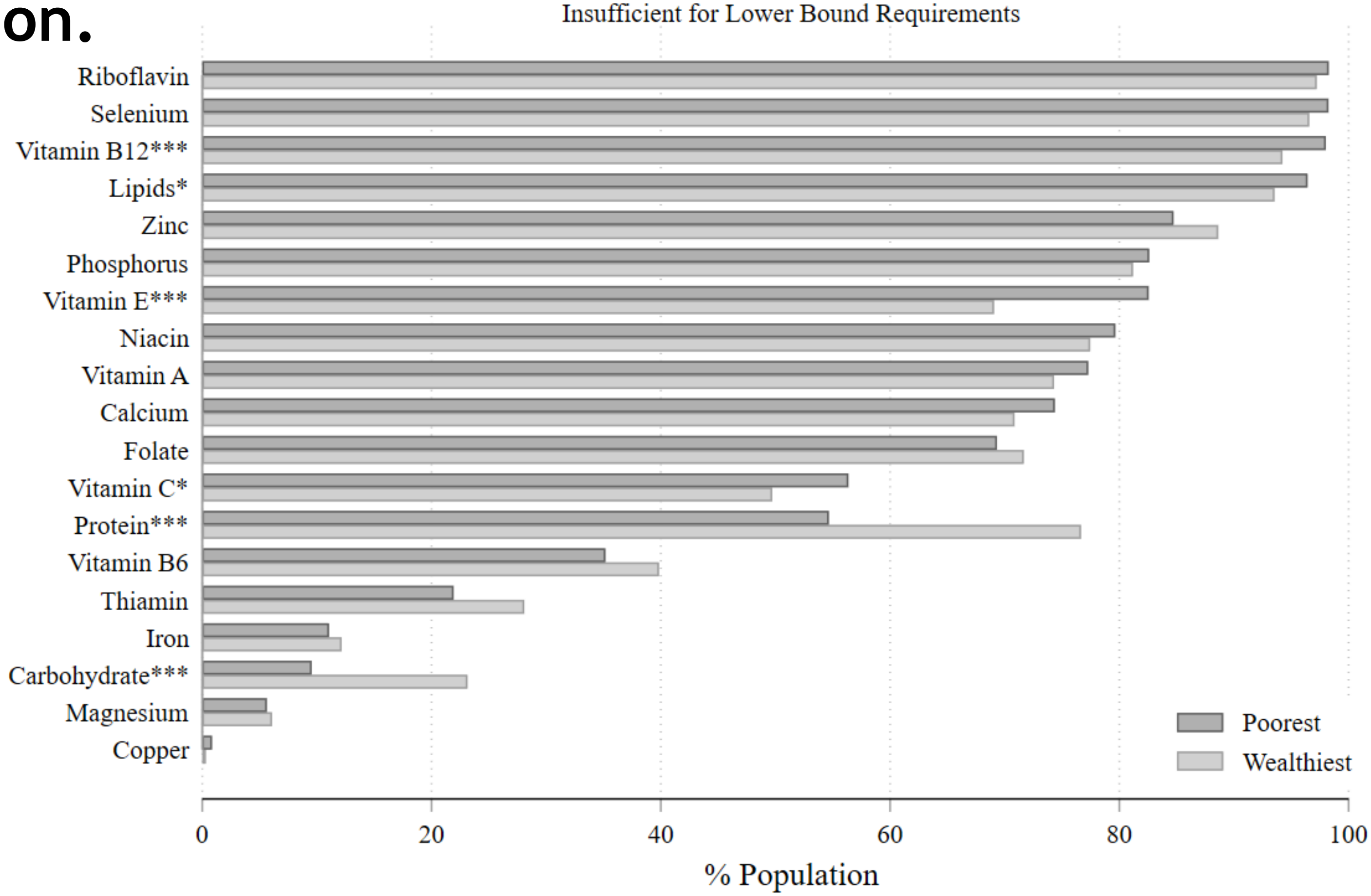
Household sharing increases requirements for iron, zinc, vitamin C, and phosphorus more than any other nutrient.

Minimum Requirements per 1,000 calories

	Household Sharing		Individual		% Difference	
	Mean	SE	Mean	SE	Mean	SE
Nutrient Needs						
Iron	7.02	(0.02)	3.38	(0.03)	141.27	(0.65)
Zinc	6.46	(0.01)	3.44	(0.01)	96.25	(0.48)
Vitamin C	33.91	(0.11)	23.87	(0.09)	67.04	(1.24)
Phosphorus	519.76	(2.80)	348.25	(1.07)	67.03	(0.91)
Vitamin B6	0.63	(0.00)	0.47	(0.00)	43.57	(0.57)
Calcium	600.44	(1.82)	460.47	(1.51)	40.86	(0.49)
Magnesium	140.03	(0.39)	110.47	(0.43)	35.99	(0.50)
Copper	0.38	(0.00)	0.29	(0.00)	35.89	(0.37)
Folate	173.85	(0.32)	135.53	(0.27)	33.66	(0.32)
Selenium	23.76	(0.04)	18.62	(0.04)	33.21	(0.30)
Vitamin B12	1.04	(0.00)	0.81	(0.00)	32.71	(0.26)
Vitamin A	292.59	(1.07)	231.24	(0.39)	31.85	(0.61)
Vitamin E	6.41	(0.01)	5.14	(0.01)	31.04	(0.27)
Thiamin	0.48	(0.00)	0.40	(0.00)	23.35	(0.23)
Riboflavin	0.50	(0.00)	0.42	(0.00)	21.49	(0.27)
Niacin	5.75	(0.01)	4.90	(0.01)	21.15	(0.19)
Lipids[2]	29.28	(0.09)	25.00	(0.05)	18.91	(0.25)
Protein[2]	25.10	(0.00)	23.85	(0.03)	9.70	(0.28)
Carbohydrate[2]	113.39	(0.04)	112.50	(0.00)	0.80	(0.04)

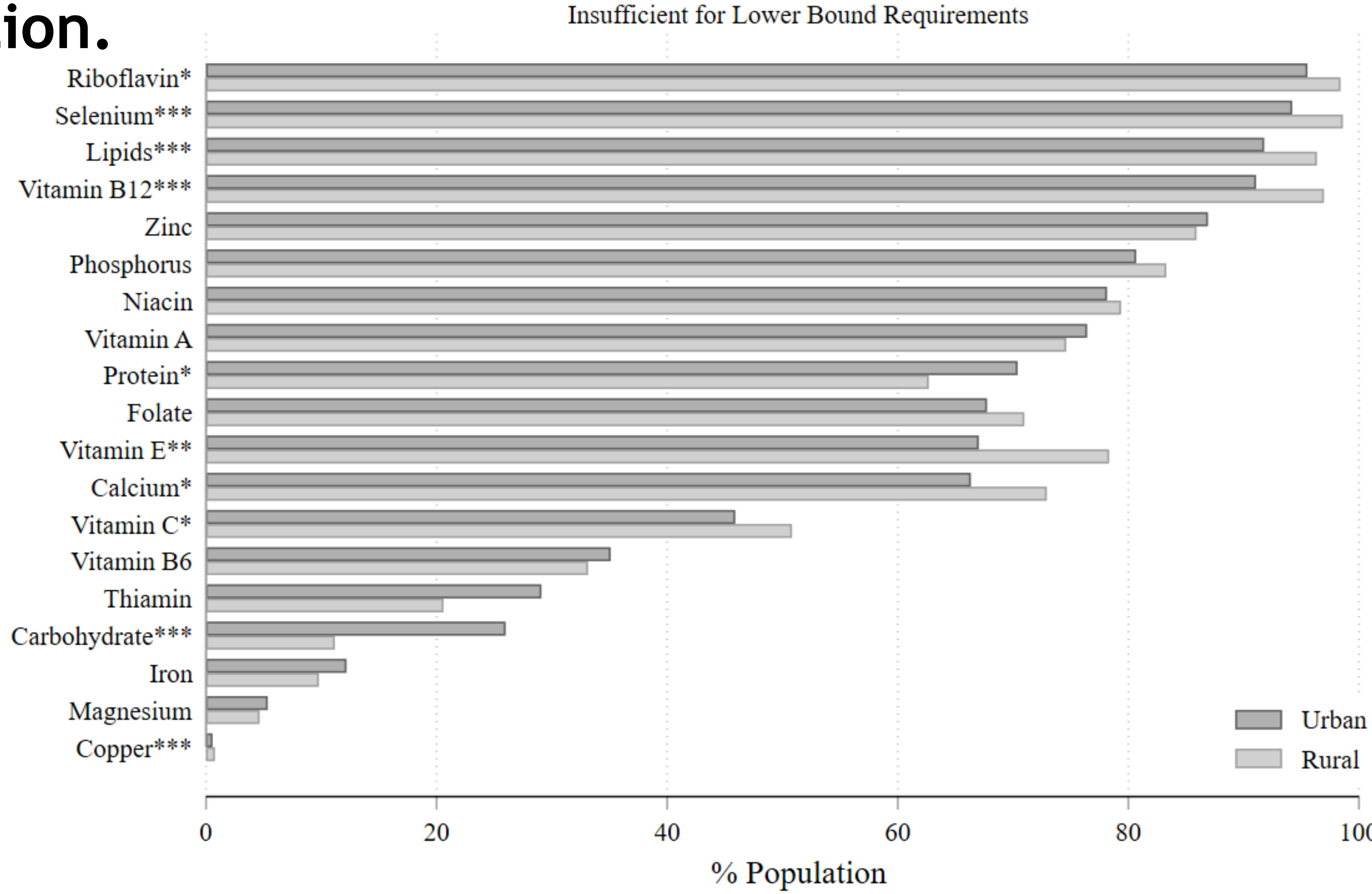
1 Population statistics corrected using sampling weights. 2 Macronutrient needs and limits defined by AMDR lower and upper bounds, respectively. Slight differences for carbohydrates due to rounding, the AMDR range does not change under household sharing since it is constant across all individual types. 3 Sodium upper bound defined by the CDDR.

Insufficient nutrient density varies little by wealth or location.



Population statistics corrected using survey weights. Top and bottom wealth quintiles shown. Stars represent statistically significant difference between the wealthiest and poorest as tested in bivariate regression
***p<0.001
**0<0.01
*p<0.05

Insufficient nutrient density varies little by wealth or location.



Population statistics corrected using survey weights.
Stars represent statistically significant difference between the rural and urban households as tested in bivariate regression
***p<0.001
**0<0.01
*p<0.05

Methods

- **Seasonality in diet cost.**

  Estimated by seasonal dummy regression allowing multiple fluctuations in the year, by scenario.

$$\Delta_k C_{hym} = C_{hym} - C_{hy,m-k-1} = k\gamma + \sum_{i=1}^{k-1} \delta_{m-i}(s_{m-i}) + w_{hym}$$

Seasonal differenced dummies:

$$s_{m-i} = \begin{cases} 1 & m = m \\ -1 & k = 0 \\ -1-k & k > 0 \\ 0 & otherwise \end{cases}$$

Seasonal factors:

$$s_m = \delta_m - \frac{1}{12}\sum_{i=1}^{12} \delta_i \quad m = 1 \ldots .12$$

C = log diet cost (nominal)
h = household
m = month
y = year
s = seasonal factor
k = gap months between observations with solution

Methods

- **Seasonality in food item prices.**
  Estimated by trigonometric regression by food item, estimated separately for each food group.

$$\Delta C_{hym} = \gamma + \alpha \Delta \cos\left(\frac{m\pi}{6}\right) + \beta \Delta \sin\left(\frac{m\pi}{6}\right) + \mu_{hym}$$

$$S_m = \lambda \cos\left(\frac{m\pi}{6} - \omega\right)$$

Where $\lambda = \sqrt{\alpha^2 + \beta^2}$ and $\omega = \tan^{-1}(\frac{\alpha}{\beta})$

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Background & Motivation

Specific Aims

Data & Methods

Aim 1

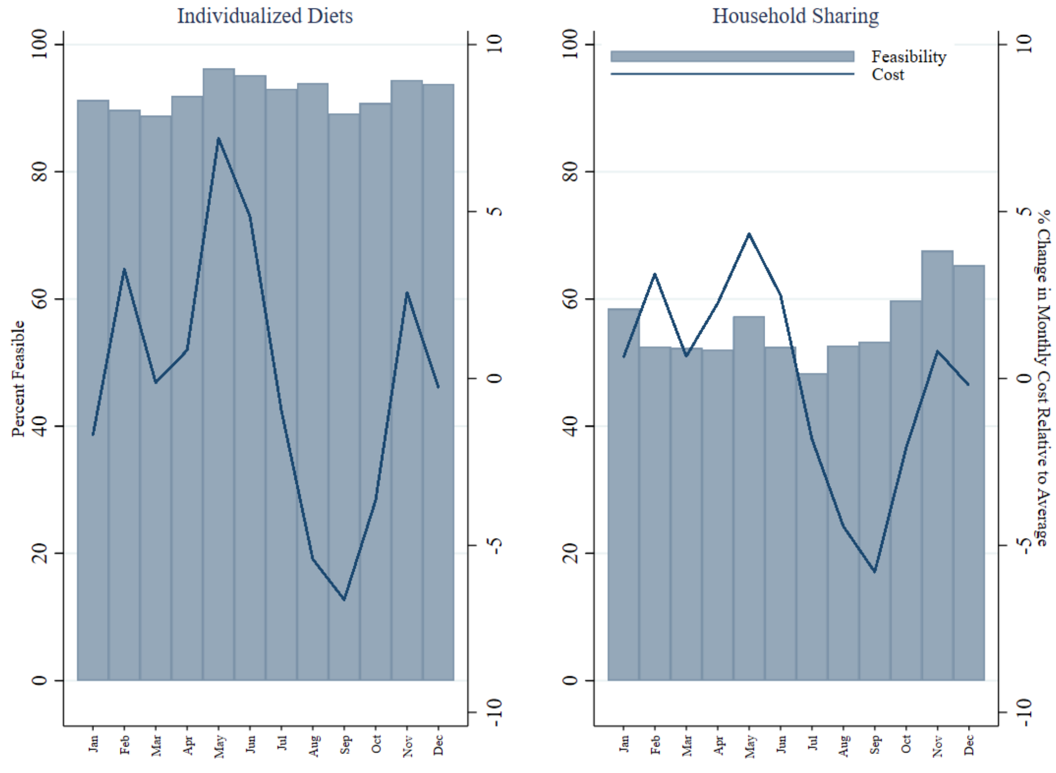
Aim 2

Aim 3

Conclusions

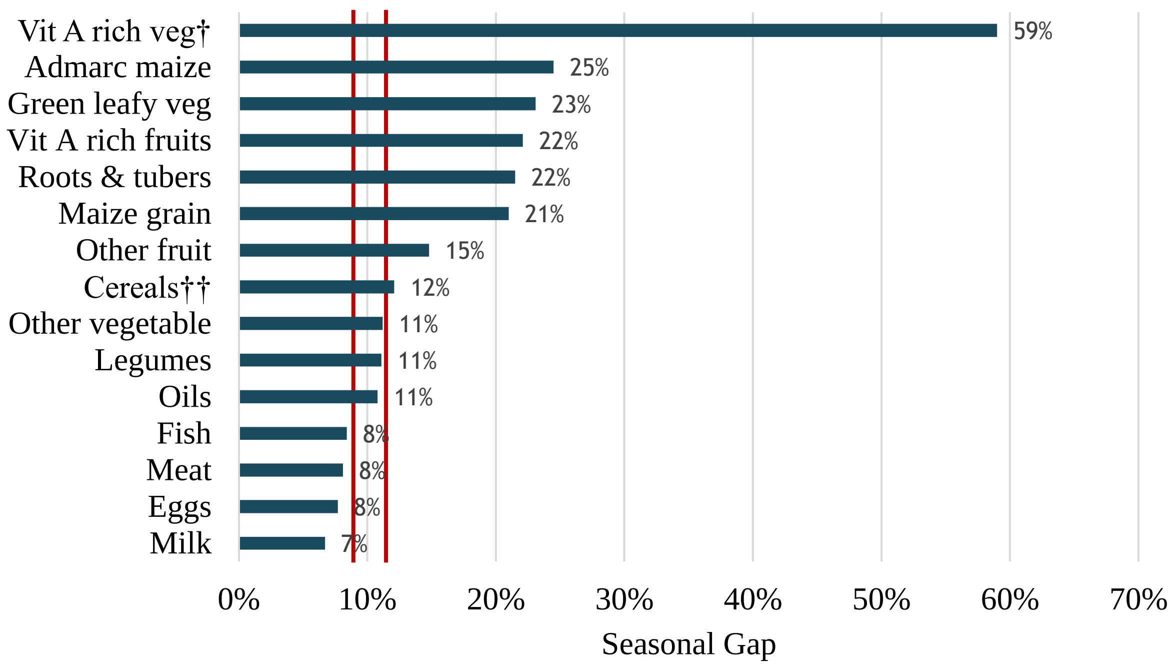
Seasonal variation in diet cost.

Seasonal gap is higher for individualized diets.



Seasonality varies by food group, larger for staples than whole diets.

Seasonal gap in food group median prices



Notes: Red line indicates the seasonal gap for whole diets under each sharing scenario.
Heteroskedasticity robust standard errors clustered at the market level. Fixed effects trigonometric regression estimated for all items in each food group.
†† Cereals includes maize grain, Admarc maize grain, maize flour dehulled, maize flour whole grain, rice, white bread.
† The single item in this food group is pumpkin.

Methods

- **Least-cost diets meeting shared household nutrient needs**
- **Nutrient shadow prices**

$$HHCoNA: minimize\ C = \sum_i p_i * q_i$$

Subject to:

$$-(\sum_i a_{ij} * q_i) + HHLower_j \leq 0, \quad j = 1, \ldots, 19$$

$$\sum_i a_{ij} * q_i - HHUpper_j \leq 0\ , \quad j = 1, \ldots, 13$$

$$\sum_i a_{ie} * q_i - HHE = 0$$

$$q_1 \geq 0, q_2 \geq 0, \ldots\ q_i \geq 0, \text{for all foods } i = 1, \ldots 51$$

C = cost
e/E=energy
p_i = food price for item i
q_i = food quantity for item i
a_{ij} = nutrient contents for item i, nutrient j

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$q_1 \geq 0, q_2 \geq 0, \ldots\ q_i \geq 0,$ for all foods $i = 1, \ldots 51$

$$\lambda_1(-\left(\sum_i a_{ij} * q_i) + HHLower_j\right)$$

$$\lambda_2(\sum_i a_{ik} * q_i - HHUpper_j)$$

$$\lambda_3(\sum_i a_{ie} * q_i - HHE)$$

C = cost

e/E=energy

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q_i = food quantity for item i

a_{ij} = nutrient contents for item i, nutrient j