Selected publications from the Food Prices for Nutrition project

Details and other project publications are at https://sites.tufts.edu/foodpricesfornutrition

1. **Extract from SOFI 2020** on the number of people who cannot afford a healthy diet, used to inform agricultural and food policy

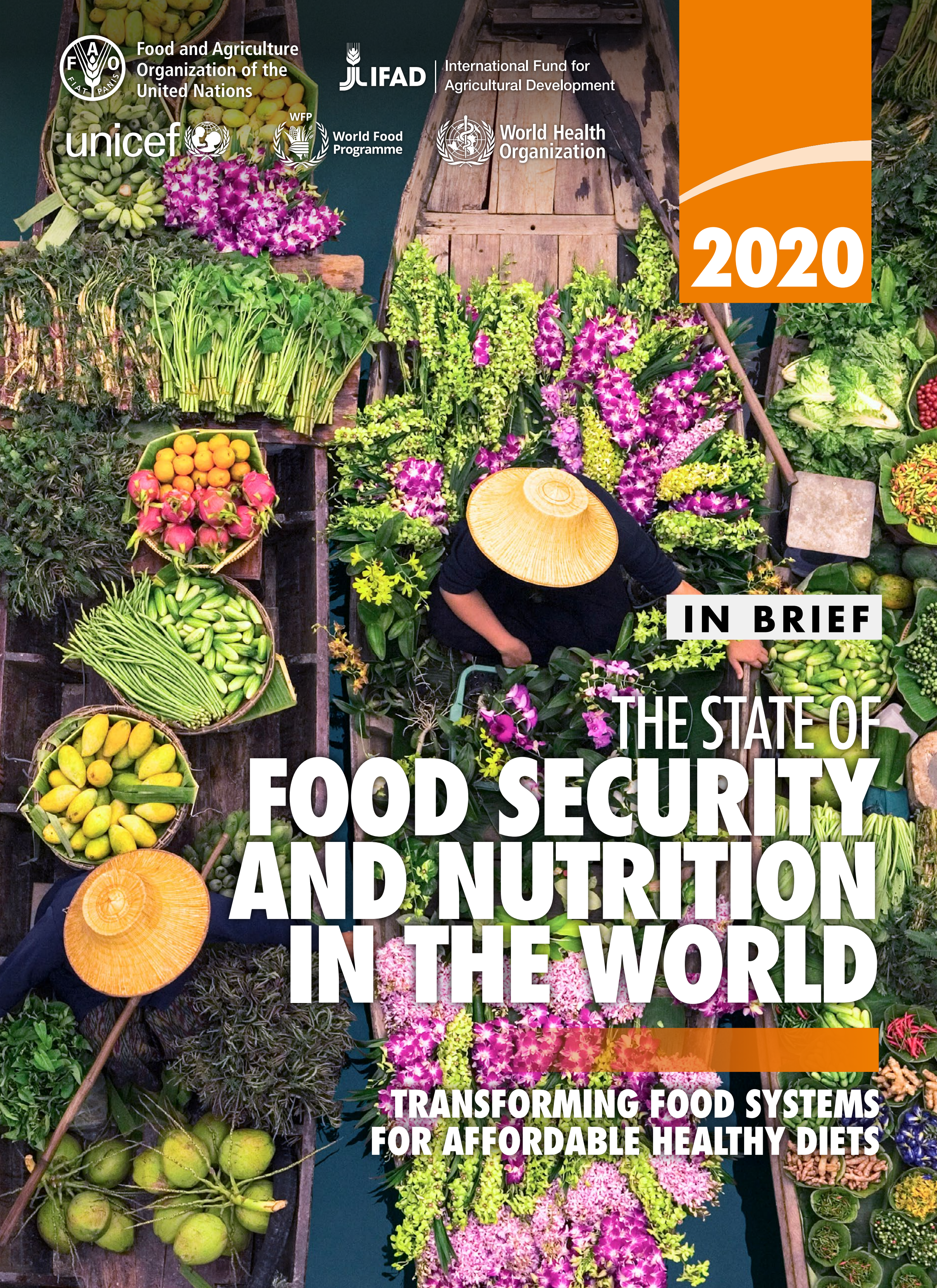
   FAO, IFAD, UNICEF, WFP and WHO (2020), The State of Food Security and Nutrition in the World 2020. Rome, FAO.

2. **Extract from SOFI background paper** on use of healthy diet costs for poverty lines in Myanmar

   Herforth A, Bai Y, Venkat A, Mahrt K, Ebel A & Masters WA (2020). Cost and affordability of healthy diets across and within countries. Background paper for The State of Food Security and Nutrition in the World 2020. Agricultural Development Economics Technical Study No. 9. Rome, FAO.

3. **Paper on national food markets**, using diet costs to study seasonality in Ethiopia, Malawi and Tanzania

   Bai Y, Naumova EN and Masters WA (2020). Seasonality of diet costs reveals food system performance in East Africa. *Science Advances*, 6(49): eabc2162.



Food and Agriculture Organization of the United Nations

IFAD | International Fund for Agricultural Development

unicef

WFP World Food Programme

World Health Organization

2020

IN BRIEF

THE STATE OF FOOD SECURITY AND NUTRITION IN THE WORLD

TRANSFORMING FOOD SYSTEMS FOR AFFORDABLE HEALTHY DIETS

Extract from SOFI 2020 with Food Prices for Nutrition analysis of data from ICP 2017 to guide UN agencies and member states' agricultural and nutrition policy

Required citation:
FAO, IFAD, UNICEF, WFP and WHO. 2020. *In Brief to The State of Food Security and Nutrition in the World 2020. Transforming food systems for affordable healthy diets*. Rome, FAO.
https://doi.org/10.4060/ca9699en

This booklet contains the key messages and content from the publication *The State of Food Security and Nutrition in the World 2020*. The numbering of the table and figures corresponds to that publication.

COVER PHOTOGRAPH ©Mint Images
THAILAND. Floating market on a canal in Bangkok, where local boats are laden with fresh food.

Each year's SOFI has a standardized Part 1, followed by new work

CONTENTS

Extract: Part 2 only

PART 2
TRANSFORMING FOOD SYSTEMS TO DELIVER AFFORDABLE HEALTHY DIETS FOR ALL

Part 2 of this year's report looks closely at the cost and affordability of healthy diets. As noted in Part 1, diet quality is a critical link between food security and nutrition outcomes that needs to be present as part of all efforts to achieve the hunger, food security and nutrition targets of SDG 2. Meeting these targets will only be possible if we ensure that people have enough food to eat, and that *what they are eating is nutritious.*

One of the biggest challenges to achieving this is the current cost and affordability of healthy diets. New evidence presented in this part of the report shows that healthy diets are unaffordable for many people in every region of the world, especially for the poor and those facing economic challenges. However, the story does not end here, because there are also hidden costs and externalities associated with current food consumption patterns, notably those related to the health and environmental consequences of our dietary choices.

Further, this part of the report also identifies the main drivers behind the high cost of nutritious foods and provides guidance on policy and investments for countries to transform their food systems to provide access to affordable healthy diets for everyone, while tackling trade-offs and making the most of synergies for environmental sustainability.

2.1 THE COST AND AFFORDABILITY OF HEALTHY DIETS AROUND THE WORLD

KEY MESSAGES

➔ Analyses conducted for this report show that healthy diets cost 60 percent more than diets that only meet the requirements for essential nutrients and almost 5 times as much as diets that meet only the dietary energy needs through a starchy staple.

➔ The cost of a diet increases incrementally as the diet quality increases – from a basic energy sufficient diet to a nutrient adequate diet and then a healthy diet including more diversified and desirable food groups – across all regions and country income groups globally.

➔ The high cost and unaffordability of healthy diets is associated with increasing food insecurity and different forms of malnutrition, including child stunting and adult obesity.

➔ Healthy diets – that reflect global guidelines and include foods from several groups and have greater diversity within food groups – are unaffordable for more than 3 billion people, and more than 1.5 billion people cannot even afford a diet that only meets required levels of essential nutrients.

➔ The cost of a healthy diet is much higher than the international poverty line, established at USD 1.90 purchasing power parity (PPP) per day. This puts healthy diets beyond the reach of those living in poverty or just above the poverty line.

➔ Food systems transformation is required to address the problem of millions of people not being able to afford healthy diets because of high food price and income constraints. At the same time, this transformation should create supportive food environments, encourage people to learn about nutrition and spur behaviour change that can lead to healthy food choices.

Cost and affordability of healthy diets are critical for food security and nutrition

The world faces immediate challenges of making healthy diets accessible for everyone, an essential requirement in meeting the hunger and nutrition targets of SDG 2. The COVID-19 pandemic has made the situation even more difficult. One of the biggest challenges is the current cost and unaffordability of healthy diets.

What does the evidence tell us?

The cost and affordability of the foods that form a healthy diet are important determinants of food choices. As such, they can affect food security, nutrition and health. The cost refers to what people have to pay to secure a specific diet. Affordability, on the other hand, is the cost of the diet relative to income.

New analysis in this report shows that, across regions and country income groups, the more unaffordable a healthy diet is, the greater the prevalence of undernourishment (PoU) and child stunting becomes. The association between adult obesity and affordability of a healthy diet is the inverse of the other associations. High-income countries have the highest affordability figures for the healthy diet and, at the same time, the highest rates of adult obesity.

Healthy diets are unaffordable for many people in all regions of the world, especially the poor

New evidence presented below shows that healthy diets are unaffordable to many people, especially for the poor, in every region of the world. This evidence emanates from analysing the estimated cost of three reference diets denoting increasing levels of diet quality, starting from a basic energy sufficient diet meeting calorie needs, to a nutrient adequate diet and then a healthy diet, the latter including an estimation of recommended intake of more diversified and desirable food groups. Subsequently, the affordability – or cost relative to people's income – of the three diets was estimated and compared across regions and country income groups.

The ultimate aim of the analysis presented is to measure whether the food system brings the three levels of diet quality within reach of the poorest, using those foods that meet each standard at the lowest possible cost.

Analysis of cost and affordability of three diets

Lowest cost of the three diets around the world

As expected, the cost of a diet increases incrementally as the diet quality increases. This pattern holds across all regions and country income groups (Table 7). The cost of a healthy diet is 60 percent higher than the cost of the nutrient adequate diet, and almost 5 times the cost of the energy sufficient diet.

To understand what is driving the high cost of healthy diets, we need to look at cost contribution of each food group in a healthy diet to identify the most costly food groups. An analysis of the percentage share of the total cost of each food in a healthy diet shows that the highest-cost food groups are those that are more nutritious: dairy, fruits, vegetables and protein-rich foods (plant-based and animal source), with some variations by region.

Affordability of the three diets around the world

The affordability analysis shows that while most of the poor around the world can afford an energy sufficient diet, as defined here, they cannot afford either a nutrient adequate or a healthy diet (Figure 28). A healthy diet is far more expensive than the full value of the international poverty line of USD 1.90 PPP per day, let alone the upper bound portion of the poverty line that can credibly be reserved for food of USD 1.20 PPP per day.

It is estimated that more than 3 billion people in the world could not afford a healthy diet in 2017.[1] Most of these people live in Asia (1.9 billion) and Africa (965 million), although there are millions that live in Latin America and the Caribbean (104.2 million), and in Northern America and Europe (18 million).

Countries in food crisis face even greater challenges in accessing a healthy diet, especially countries with a protracted crisis situation which are characterized by complex, multidimensional conflicts and extreme fragility. In these contexts, most or 86 percent of the population cannot afford a healthy diet. This is more than double the world average figure (38 percent) and is 57 percent higher than what is estimated for the Global South.

These findings imply that: i) the cost of nutritious foods that constitute healthy diets need to decrease, particularly nutritious foods that contribute to a healthy diet including dairy, fruits, vegetables and protein-rich foods; and ii) poverty lines may need to rise, as they are the basis for programme targets and social safety net programmes, and currently do not provide a good gauge of people's ability to access even the least-cost versions of a healthy diet.

[1] To estimate the cost of the aforementioned three diets, this report uses retail prices from the World Bank's International Comparison Program (ICP) for internationally standardized items for 2017, which was the most updated available at the time of writing.

KENYA
Women harvesting French beans at one of Kenya's Njukini Corporative farms.
©FAO/Fredrik Lerneryd

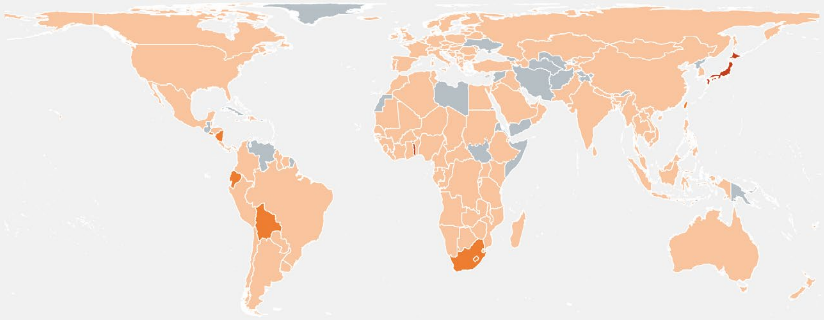
TABLE 7 THE COST OF A HEALTHY DIET IS 60 PERCENT HIGHER THAN THE COST OF THE NUTRIENT ADEQUATE DIET, AND ALMOST 5 TIMES THE COST OF THE ENERGY SUFFICIENT DIET IN 2017

Regions	Energy sufficient diet	Nutrient adequate diet	Healthy diet
WORLD	**0.79**	**2.33**	**3.75**
AFRICA	**0.73**	**2.15**	**3.87**
Northern Africa	0.75	2.90	4.12
Sub-Saharan Africa	0.73	2.06	3.84
Eastern Africa	0.61	1.98	3.67
Middle Africa	0.73	2.09	3.73
Southern Africa	0.86	2.29	3.99
Western Africa	0.80	2.05	4.03
ASIA	**0.88**	**2.18**	**3.97**
Central Asia	0.84	2.04	3.39
Eastern Asia	1.27	2.63	4.69
South-eastern Asia	0.92	2.42	4.20
Southern Asia	0.80	2.12	4.07
Western Asia	0.74	1.87	3.58
LATIN AMERICA AND THE CARIBBEAN	**1.06**	**2.83**	**3.98**
Caribbean	1.12	2.89	4.21
Latin America	1.00	2.78	3.75
Central America	1.13	3.04	3.81
South America	0.91	2.61	3.71
OCEANIA	**0.55**	**2.07**	**3.06**
NORTHERN AMERICA AND EUROPE	**0.54**	**2.29**	**3.21**
COUNTRY INCOME GROUPS			
LOW-INCOME COUNTRIES	**0.70**	**1.98**	**3.82**
LOWER-MIDDLE-INCOME COUNTRIES	**0.88**	**2.40**	**3.98**
UPPER-MIDDLE-INCOME COUNTRIES	**0.87**	**2.52**	**3.95**
HIGH-INCOME COUNTRIES	**0.71**	**2.31**	**3.43**

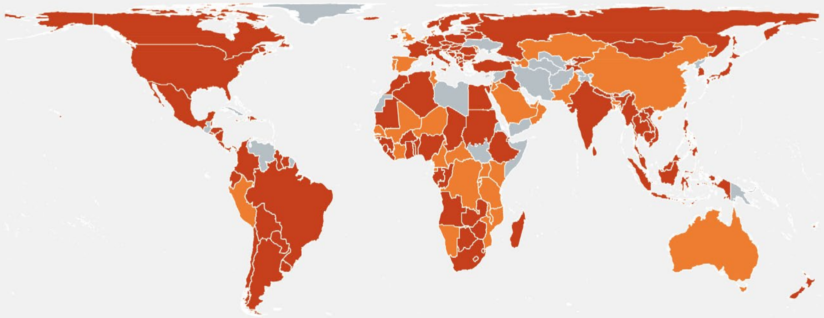
NOTES: The table shows the USD cost per person per day of the three reference diets (energy sufficient, nutrient adequate and healthy diet) by region and country income group in 2017. The analysis is based on a sample of 170 countries for which retail food price data are available in year 2017. Prices are obtained from the World Bank's International Comparison Program (ICP) for internationally standardized items, converted to international dollars using purchasing power parity (PPP). The cost of each diet represents a simple average of the cost incurred by countries belonging to a specific region or country income group. In the report, see Box 10 for the definition of the three diets and Box 11 for a brief description of the cost methodology. For the full methodological notes and data sources, see Annex 3 in the report.
SOURCE: Herforth, A., Bai, Y., Venkat, A., Mahrt, K., Ebel, A. & Masters, W.A. 2020. *Cost and affordability of healthy diets across and within countries*. Background paper for *The State of Food Security and Nutrition in the World 2020*. Rome, FAO.

FIGURE 28 A HEALTHY DIET IS UNAFFORDABLE FOR THE POOR IN EVERY REGION OF THE WORLD IN 2017

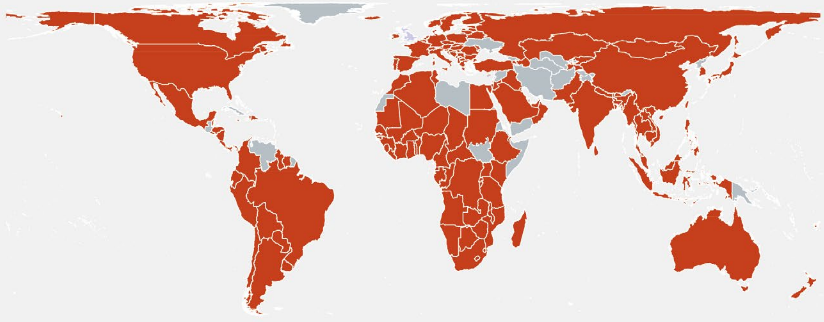
A) COST OF AN ENERGY SUFFICIENT DIET COMPARED WITH THE INTERNATIONAL POVERTY LINE



B) COST OF A NUTRIENT ADEQUATE DIET COMPARED WITH THE INTERNATIONAL POVERTY LINE



C) COST OF A HEALTHY DIET COMPARED WITH THE INTERNATIONAL POVERTY LINE



NOTES: The maps show the cost of the three reference diets (energy sufficient, nutrient adequate and healthy diet) compared with the international poverty line (USD 1.90 purchasing power parity (PPP) per day) for 170 countries in year 2017. A diet is considered unaffordable when its cost exceeds USD 1.20, i.e. 63 percent of USD 1.90 PPP per day. The 63 percent accounts for a portion of the poverty line that can be credibly reserved for food. In the report, see Box 10 for the definition of the three diets and Boxes 11 and 12 for a brief description of the cost and affordability methodology. For the full methodological notes and data sources, see Annex 3 in the report. For disclaimers on map boundary lines, see Annex 5 in the report.

SOURCE: Herforth, A., Bai, Y., Venkat, A., Mahrt, K., Ebel, A. & Masters, W.A. 2020. *Cost and affordability of healthy diets across and within countries*. Background paper for *The State of Food Security and Nutrition in the World 2020*. Rome, FAO.

Costs and affordability within countries

The cost and affordability of diets varies around the world, across regions and in different development contexts. They may also vary within countries due to temporal and geographical factors, as well as variations in the nutritional needs of individuals across the life cycle. These within-country variations in cost are not captured in the above global and regional analysis – but evidence from case studies makes it clear such variations can be substantial. ■

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9

Cost and affordability of healthy diets across and within countries

Background paper for *The State of Food Security and Nutrition in the World 2020*

FAO AGRICULTURAL DEVELOPMENT ECONOMICS TECHNICAL STUDY

9

Cost and affordability of healthy diets across and within countries

Background paper for *The State of Food Security and Nutrition in the World 2020*

By

Anna Herforth
Independent consultant and researcher

Yan Bai and Aishwarya Venkat
Doctoral students, Friedman School of Nutrition Science and Policy, Tufts University

Kristi Mahrt
Senior Research Analyst, International Food Policy Research Institute (IFPRI)

Alissa Ebel
Master's student, Friedman School of Nutrition Science and Policy, Tufts University

William A. Masters
Professor, Friedman School of Nutrition Science and Policy, Tufts University

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Extract with Myanmar study using poverty lines based on cost of healthy diet in terms of food groups

Contents

4 Results: Country case studies

KEY MESSAGES

- National price datasets allow subnational analysis of the cost of diets. These food price datasets are collected by national statistical organizations or agriculture market information systems.
- The cost of healthy diets varies by region, as seen in the United Republic of Tanzania, and is driven by different high-cost food groups in different regions. The cost of healthy diets and nutrient adequate diets varies by season, as seen in Malawi. Food price data can also be used to examine low availability of specific food groups in specific times and places, as seen in Ghana. The Ethiopia case study shows that the cost of the most nutrient-rich non-staple food groups has gone up more rapidly than starchy staples.
- Poverty lines are typically insufficient to support the purchase of least-cost healthy diets. The standard cost of basic needs (CBN) approach to determining food poverty lines selects a food basket that meets neither nutrient needs nor dietary recommendations for healthy diets, as demonstrated in Myanmar. Instead, we demonstrate a feasible method for generating food poverty lines that would satisfy dietary guidelines, as well as taking into account typical consumption patterns of the poor.

Each country case study is intended to showcase a different aspect of how national and subnational food price data shed light on the cost of the nutrient adequate diet and the healthy diet. Each country's unique circumstances reveal important aspects of how food prices relate to nutrition, showing how the cost of these diets can vary by region, by season, by life stage, and when accounting for food preferences.

4.5 Myanmar

The Myanmar country study drew upon the 2015 MPLCS household survey to gain insight into the cost of diets in Myanmar. In particular, this study expanded upon the cost of healthy diet metric's estimation of the bare minimum cost of achieving dietary recommendations with a variant that takes food preferences into account.

This case study also compared both cost of healthy diet metrics to Myanmar's official food poverty line (MoPF and World Bank, 2017a, 2107b). The country's food poverty line is derived from a basket of foods determined by food consumption quantities of poor households in the 2015 MPLCS. Unlike the nutritious foods outlined in recommended diets that form the basis of the costs of a healthy diet and of a healthy diet with food preferences, the Myanmar food poverty line basket includes all foods and non-alcoholic beverages in the 2015 MPLCS household food survey. In order to satisfy the most basic nutrition requirement, the basket is scaled to meet energy sufficiency based on the caloric needs of the Myanmar population (2 238 per capita). The food poverty line is simply the cost of acquiring the energy sufficient food basket at median household prices. To achieve consistency between the two, both healthy diet food baskets are also scaled to meet the 2 238 calorie target.[12] (For a more detailed methodology, see Annex 6.)

The healthy diet with food preferences method is analogous to the determination of food poverty lines in that within-food group costs are based on consumption quantity shares observed in the poorest households (within 10 percentage points of the poverty line) in the household survey. We take advantage of this similarity to show how nutritional needs can be taken into account in determining poverty lines and poverty estimation. Unlike current food poverty line estimation methods, the healthy diet with food preferences method additionally requires that minimum food group-level proportional criteria are met so that diets used in the estimation align with FBDG.

Myanmar does not have quantitated FBDG, and therefore guidelines from neighbouring Bangladesh provide the recommended diet used in this analysis. The Bangladesh FBDG is generally consistent with the food groupings and messages presented in a preliminary FBDG developed by the Myanmar Government (Shaheen *et al.*, 2013; MoHS, no date).

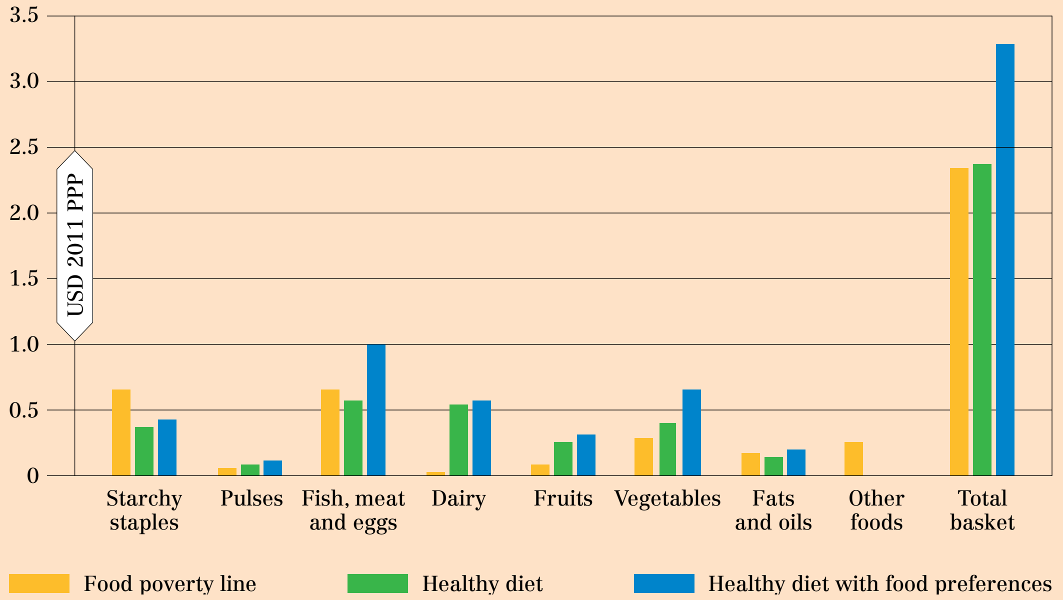
Figure 20 presents total and food group costs of the three food baskets: food poverty line, healthy diet, and healthy diet with food preferences. Differences in costs between the three are driven by two factors: basket composition and the costs of items within each food group. Basket composition is the primary factor driving differences in food group costs between the food poverty line and healthy diet with food preferences baskets, as food group costs in both baskets are based on the same actual consumption patterns. Differences between the costs of the cheapest foods and the preferred foods in each food group drive the differences in costs between the healthy diet and healthy diet with food preferences baskets. For the latter, a preference for higher-priced animal source foods is the main driver of its higher cost.

Figure 21 highlights the considerable difference in the caloric content between the food poverty line and healthy diet with food preferences baskets. Not surprisingly, nearly three-quarters (72 percent) of calories in the former are derived from starchy staples compared to just over half (53 percent) in the latter, which allocates a greater share of the diet to more nutrient-dense foods. Figure 22 illustrates cost shares of the two baskets. The cost share of starchy staples in the food poverty line basket is more than double that of the healthy diet with food preferences basket (30 percent versus 13 percent). Notable in both Figures 21 and 22 is the absence of dairy from actual consumption which stands in sharp contrast

12 This calorie target is 91 kcal lower than the calorie target for an active 30-year-old woman used in the global analyses of this report.

to its 17 percent cost share in the healthy diet with food preferences basket. These large differences in the composition of both baskets are evident in the total costs of nearly every food group (Figure 20).

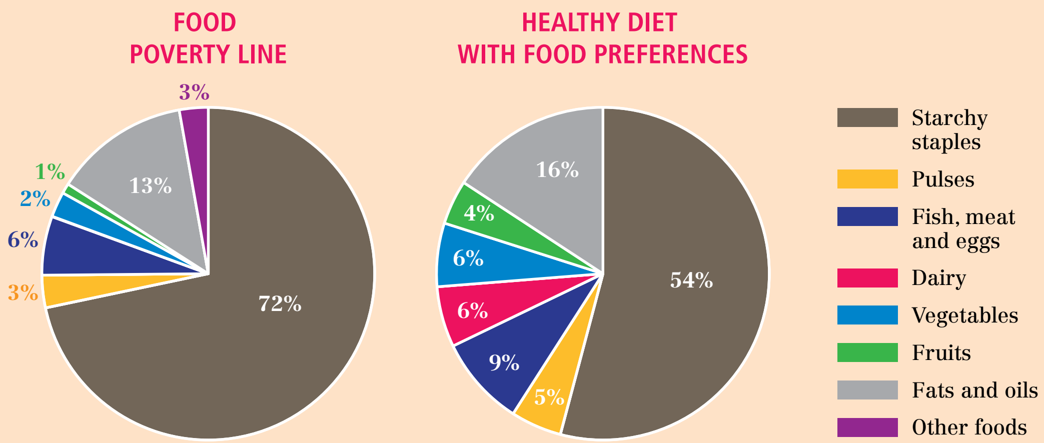
FIGURE 20 Cost of each food group for three food baskets in Myanmar



Notes: Data shown are 2011 USD purchasing power parity (PPP) per day and refer to the items in the food baskets used to compute the country's food poverty line, healthy diet and healthy diet with food preferences baskets. All diet costs exclude food away from home, and are scaled to 2 238 kcal/day.

Source: Authors' elaboration; Ministry of Planning and Finance (Myanmar) and World Bank, 2017a.

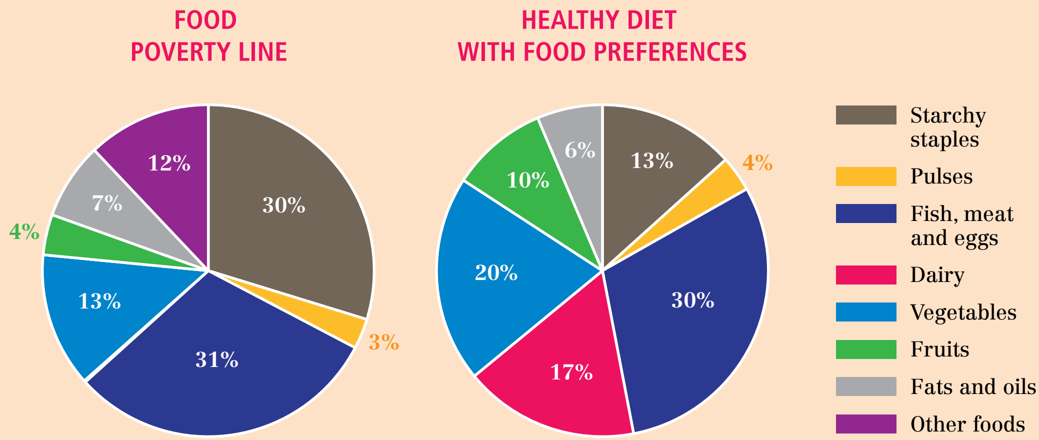
FIGURE 21 Calorie shares by food group in two Myanmar food baskets: food poverty line and healthy diet with food preferences



Note: The food poverty line basket excludes food away from home and is scaled to meet the 2 238 calorie target.

Source: Authors' elaboration; Ministry of Planning and Finance (Myanmar) and World Bank, 2017a.

FIGURE 22 Cost shares by food group in two Myanmar food baskets: food poverty line and healthy diet with food preferences

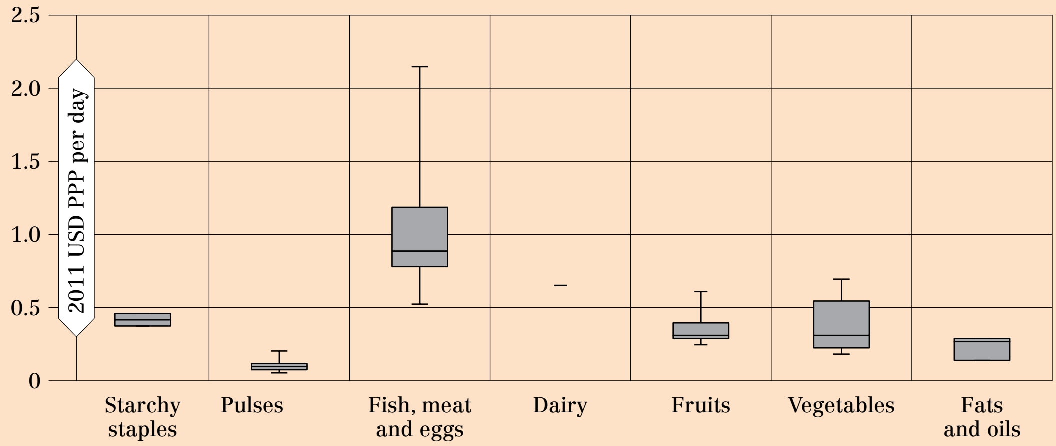


Note: The food poverty line basket excludes food away from home and is scaled to meet the 2 238 calorie target.

Source: Authors' elaboration; Ministry of Planning and Finance (Myanmar) and World Bank, 2017a.

Figure 23 highlights the other important factor driving differences in the cost of diets – the price premium of current consumption patterns compared to least-cost food selection. The cost of starchy staples, pulses, and oils varies little among the most commonly consumed food items. In contrast, the costs of animal source, protein-rich foods, and to a lesser extent vegetables, have a much wider distribution. This variation in costs is reflected in the large differences in the cost of fish/meat/eggs and vegetables between the healthy diet and healthy diet with food preferences baskets.

FIGURE 23 Costs of items in each food group in Myanmar



Note: Data shown are 2011 USD purchasing power parity (PPP) per day, as box plots for the cost of each food group in Myanmar. Box plots show the median, 25th and 75 percentile and 1.5 times that interquartile range for acquiring the recommended diet quantity in each food group. Food items are limited to those in the healthy diet with food preferences basket, using the median price of each food item observed in local markets. 2015 kyat converted to 2011 USD PPP using the World Bank's PPP conversion factor for private consumption (local currency units per international USD).

Source: Authors' own elaboration.

Table 7 provides greater detail on the costs of protein-rich foods in the healthy diet and healthy diet with food preferences baskets. The least-cost, animal source protein-rich foods are fish and eggs. Though the cost share of fish, legumes, and meat/eggs is quite similar between the two baskets, the addition of meat, particularly chicken, results in a diet cost that is nearly double that of a healthy diet (USD 1.38 PPP versus USD 0.78 PPP).

TABLE 7 Cost of protein-rich foods in two Myanmar food baskets: healthy diet and healthy diet with food preferences

Protein group food item or subgroup	Healthy diet basket		Healthy diet with food preferences basket	
	Cost per day (2011 USD PPP)	Protein group cost share (%)	Cost per day (2011 USD PPP)	Protein group cost share (%)
Fish/seafood	0.20	37	0.28	35
Legumes	0.06	13	0.08	10
Eggs	0.27	50	0.29	12
Chicken			0.80	22
Pork			0.55	14
Beef			0.77	7

Notes: Data shown are cost levels in 2015 kyat converted to 2011 USD purchasing power parity (PPP) using the World Bank's PPP conversion factor for private consumption (local currency units per international USD).

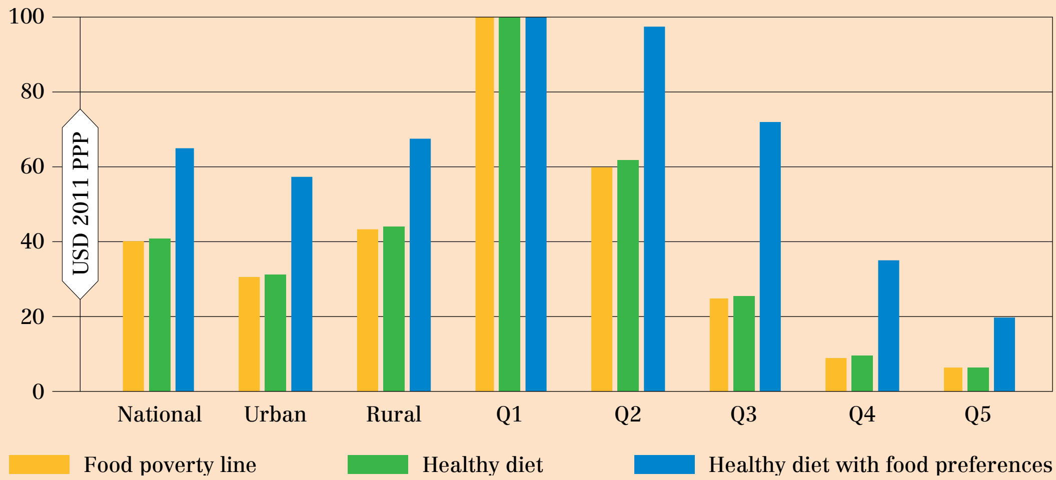
Source: Authors' own elaboration.

The three food baskets exceed reported household food expenditure for a large share of the population (Figure 24). Nationally, 40 percent and 41 percent of the population live in households that cannot afford the food poverty line or healthy diet basket without shifting non-food expenditure to food expenditure. Sixty-five percent cannot afford a healthy diet that aligns with food preferences. Furthermore, the majority of the population in the three lowest wealth quintiles cannot easily afford the healthy diet with food preferences basket.

In order to explore the impact of a more nutritionally complete diet that is also consistent with food group consumption patterns of poor households, we use the healthy diet with food preferences basket in place of the food poverty line basket to estimate a nutrition-sensitive poverty line. To facilitate comparison with Myanmar's official poverty rates, we calculate this poverty line as the sum of the healthy diet with food preferences poverty line and the official non-food poverty allowance. The non-food poverty allowance is an estimate of non-food expenditures by households with total consumption expenditures near the poverty line. Table 8 shows the composition of the official and healthy diet with food preferences poverty lines. Figure 25 shows the percentage of the population living in households with total expenditure below each poverty line. The healthy diet with food preferences poverty line indicates the share of the population that faces insecurity in attaining a healthy diet, and suggests that the share of the population facing such nutrition insecurity is 17 percentage points higher than the poverty rate, nationally, and 46 points higher (compared to zero) for the third wealth quintile.

Finally, we compare the nutrient composition of the baskets to the estimated average requirement (EAR) (IOM, 2006) of a 19–30 year old woman (Table 9). The costs of the healthy diet and healthy diet with food preferences baskets meet or exceed the EAR of most key nutrients, with the exception of vitamin E. In contrast, the food poverty line basket meets approximately half of the EAR for calcium (53 percent), vitamin A (55 percent) and vitamin E (56 percent), and less than 80 percent of the EAR for vitamin C (74 percent), folate (78 percent) and vitamin B12 (71 percent). These serious micronutrient shortfalls call into question whether a calorie standard provides a sufficient nutrient standard for poverty line calculations.

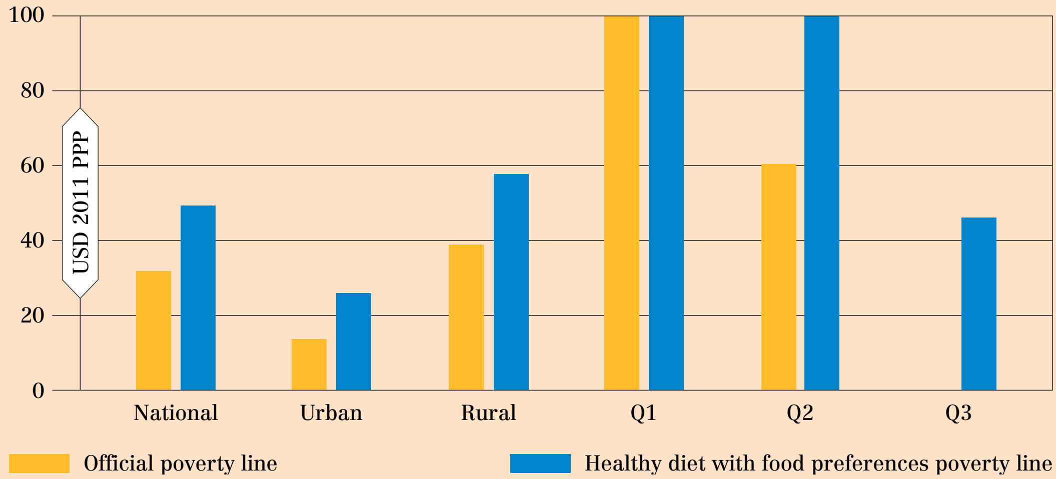
FIGURE 24 Affordability of food poverty line, healthy diet and healthy diet with food preferences baskets: % of the population living in households with food expenditure below the cost of each basket in Myanmar



Note: 2015 kyat converted to 2011 USD purchasing power parity (PPP) using the World Bank's PPP conversion factor for private consumption (local currency units per international USD). Q1 to Q5 denote wealth quintiles.

Source: Authors' elaboration; Ministry of Planning and Finance (Myanmar) and World Bank, 2017a.

FIGURE 25 Official poverty line headcounts compared to healthy diet with food preferences poverty line headcounts (%), by national, urban/rural and expenditure quintile in Myanmar



Note: Q1 to Q3 denote wealth quintiles.

Source: Authors' elaboration; Ministry of Planning and Finance (Myanmar) and World Bank, 2017a.

TABLE 8 Official and healthy diet with food preferences poverty lines in Myanmar

	Official poverty lines	Healthy diet with food preferences poverty lines
Food poverty line	2.34	3.27
Non-food poverty line	1.26	1.26
Total poverty line	3.60	4.53

Notes: For comparability, the official non-food poverty line is combined with the healthy diet with food preferences poverty line to estimate the total healthy diet with food preferences poverty line. 2015 kyat converted to 2011 USD purchasing power parity (PPP) using the World Bank's PPP conversion factor for private consumption (local currency units per international USD).

Source: Authors' elaboration; Ministry of Planning and Finance (Myanmar) and World Bank, 2017a.

TABLE 9 Nutrient adequacy of least-cost food baskets in Myanmar

		Percentage of EAR		
Nutrient	EAR	Food poverty line	Healthy diet	Healthy diet with food preferences
Protein (g)	38	144	163	177
Carbohydrates (g)				
Calcium (mg)	750	53	112	119
Iron (mg)	11	105	123	137
Magnesium (mg)	265	91	126	129
Phosphorus (mg)	580	139	176	185
Zinc (mg)	9	89	99	105
Copper (mg)	1	280	209	384
Selenium (mcg)	45	137	171	153
Vitamin C (mg)	80	74	153	190
Thiamin (mg)	1	87	103	122
Riboflavin (mg)	1	51	122	100
Niacin (mg)	11	112	97	128
Vitamin B6 (mg)	1	106	135	135
Folate (mcg)	250	78	169	149
Vitamin B12 (mcg)	2	71	118	154
Vitamin A (mcg)	490	55	107	116
Vitamin E (mg)	12	56	89	84

Notes: Data shown are adequacy levels by nutrient of the food baskets shown for a representative woman aged 19–30, with a 2 238 calorie diet. Light shading indicates above 90 percent, medium 80–89 percent, and dark below 80 percent.

Source: Authors' elaboration; Ministry of Planning and Finance (Myanmar) and World Bank, 2017a.

5 Global simulation of policy impacts on the cost of a nutrient adequate diet

KEY MESSAGES

- Public investment and government services can lower food prices and diet costs through innovation and market infrastructure, but governments also often cause prices to rise when they impose trade restrictions. Restricting imports protects a country's producers of a particular item, at the expense of others in that society. Trade restrictions arise most often where the burden of higher prices is spread among many dispersed consumers, while the protected group is well-organized and influential.
- Analysing price data by food group reveals that protectionism raises price the most for poultry and eggs, and vegetables. These items have economies of scale and are grown on larger farms, near cities, whose owners have more influence than other farmers, while consumers of these items are dispersed and may not know that prices are raised by trade restrictions. Protection of influential groups also raises prices for other foods, especially in middle- and high-income countries.
- The overall rise in cost of the most affordable diets was in the range of USD 35–USD 70 per year (10–20 cents/day) in middle- and high-income countries in 2011, with the same level in high-income countries in 2017, and wide variation elsewhere. This increase in diet costs could be a significant factor in diet quality, especially for low-income people in middle-income countries.
- Easier access to some imported commodities could lower consumer prices, as could reducing transport costs within countries. Using Monitoring and Analysing Food and Agricultural Policies (MAFAP) data we find impacts on total diet cost in Africa of possible domestic transport cost reductions in the range of USD 2–USD 11 per year. Greater price reductions might be possible through a combination of interventions that raise farm productivity and lower marketing costs in various ways, tailored to local needs for each type of food.

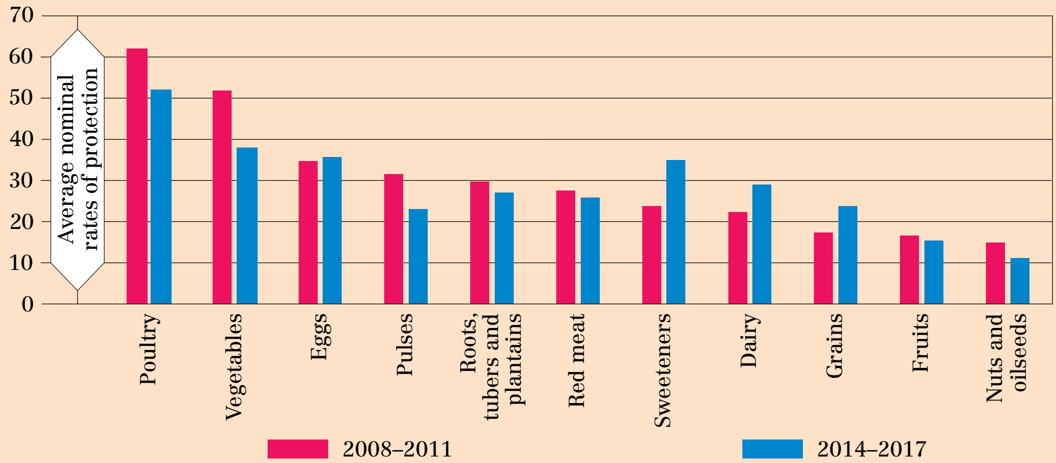
5.1 Impacts of trade policy and farm-to-market transport costs on the cost of nutrient adequate diets

A wide range of policies can lower the cost and improve affordability of nutritious foods, including government support for research and development of new technology, public irrigation infrastructure, land development, rural transport, electrification and markets, as well as the institutions and regulations needed to maintain product standards and quality assurance. These policies offer highly cost-effective ways to help both farmers and food consumers by raising productivity, typically lowering diet cost and improving access to nutrient adequate and healthy diets through delivery of public services tailored to each place and time (Norton, Alwang and Masters, 2014).

In this section, we focus on trade restrictions at each country's borders, as a type of agricultural policy that allows governments to help specific groups without need for public expenditure or service delivery. We describe the available data on how these restrictions change prices in low- and middle-income countries, and the effect of those price changes on diet costs. For comparison, we also show how food prices and diet costs would change if governments aimed to reduce the cost of transporting foods by investing in improved infrastructure and institutional reforms. Governments impose trade restrictions, and invest less in transport-cost reductions than consumers might want, so as to protect the influential local producers who benefit from higher prices without having to incur any fiscal cost. Some trade barriers actually raise government revenue through tariffs and the sale of quotas or licenses. The price changes that result from trade restrictions typically deliver gains that are concentrated among few members of well-organized groups that advocate for restriction, while their costs are spread among all consumers in the country so that each consumer bears a small share of the burden and is unlikely to be aware of that cost. Which sectors receive this protection depends on their relative influence in government, as detailed in Anderson (2016).

Our data on trade policies consist of percentage nominal rates of protection (NRPs), obtained by comparing a country's observed farm-gate commodity prices with the best available estimate of what that price would be if government policies did not restrict international trade. These estimates are available for 58 food commodities in 62 countries, based on prices observed in farm surveys and rural wholesale markets, as well as commodity prices observed for international trade adjusted for estimates of inland transport and handling costs, reported as farm-gate equivalent NRPs. To smooth fluctuations and match with our retail prices, we use all values observed in the four years leading up to and including each round of ICP price collection, then aggregate them into food groups and national income levels as shown in Figure 26 and Figure 27.

FIGURE 26 Worldwide average nominal rates of protection, 2008–2011 and 2014–2017



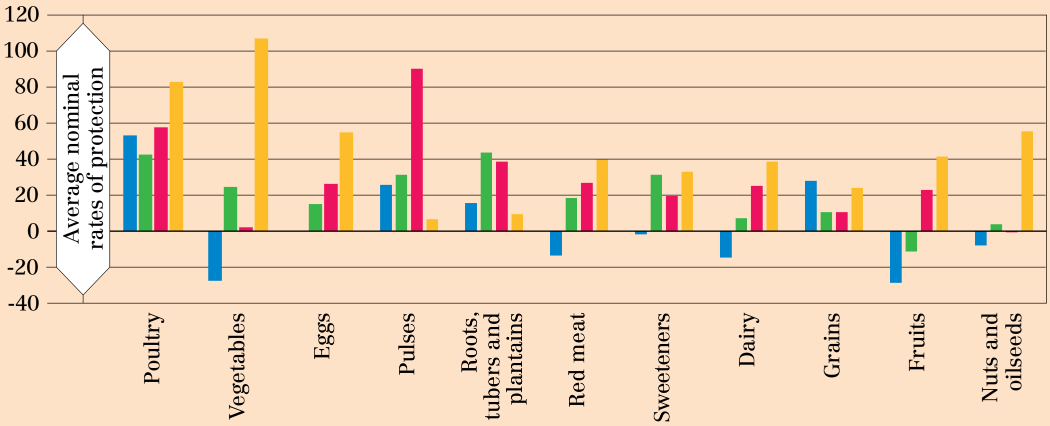
Notes: Data shown are worldwide average percentage effects of trade policy on the wholesale price of commodities from each food group computed from a total of 3 581 observations over 58 food products in 62 countries. Sources are detailed in the methodological Annex 7.

Source: Authors' own elaboration.

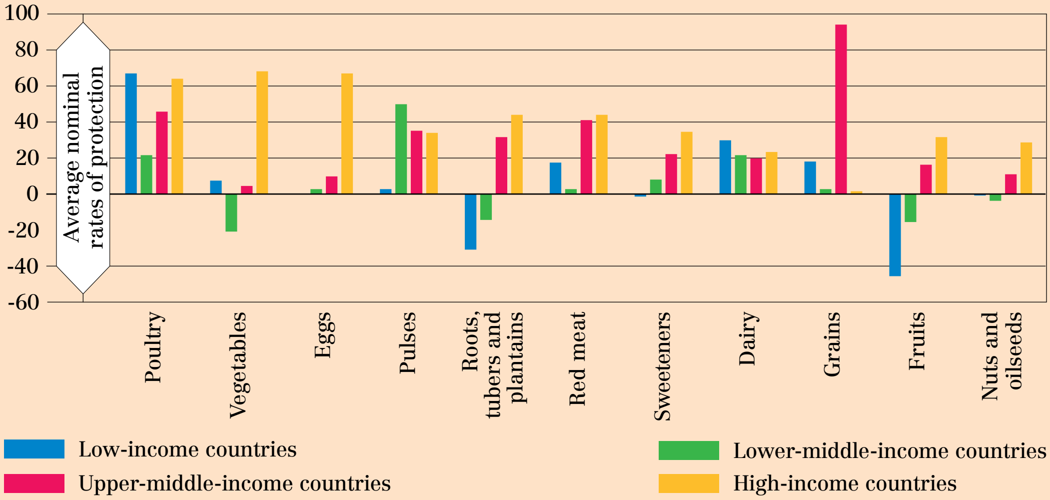
Figure 26 and Figure 27 are sorted by food group, in decreasing order of support for farmers producing the traded commodities in that food group. Poultry producers are the most highly protected worldwide in both time periods shown, and vegetable farmers are highly protected in high-income countries. Both groups, however, saw a decline in average protection from the 2008–2011 period to the 2014–2017 period. Most but not all categories are more protected in higher-income countries in both time periods. Pulses, often a significant contributor to least-cost diets, are less protected in the later period for all income groups except upper-middle-income countries. The average NRP is sometimes negative, which could be sustained over time only when the government restricts exports to help the country's buyers of that product. While countries in each income level observe some export restrictions on specific commodities, only for low- and lower-middle-income countries is this common enough to result in a negative average protection value at the food group level.

FIGURE 27 Average nominal rates of protection by food group and country income group

A. 2008–2011



B. 2014–2017



Notes: Data shown are average percentage effects of trade policy on the wholesale price of commodities from each food group in countries at each level of national income, computed from a total of 2 154 observations over 58 food products in 62 countries in 2008–2011 and from a total of 1 427 observations over 56 food products in 53 countries in 2014–2017. Sources are detailed in Annex 7.

Source: Authors' own elaboration.

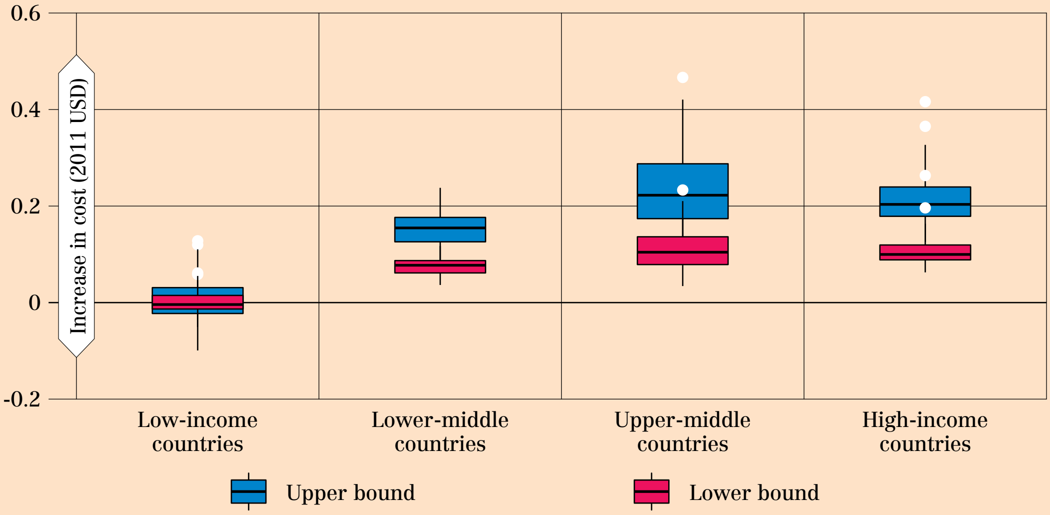
For all negative NRP observations, we check to ensure that the country is actively exporting that product or could do so competitively. When this is not the case, we classify these observations as measurement errors or temporary outliers and trim the value to zero. The criterion we apply is whether the country's FAO food balance sheet reports net exports of that product in any of the four years leading up to and including the year of observation. For these exportable foods, negative NRPs could be sustained by any policy that limits the quantity exported, whereas negative NRP observations in other settings could be sustained only through government subsidy payments for the entire quantity consumed in that country, which is implausible even in countries with large government outlays. We assume these values are caused by differences in quality, context and timing of comparisons between items whose prices are compared in the NRP.

To compute the consequences of agricultural protection for the cost and affordability of a nutrient adequate diet, first we estimate the impact of these commodity NRPs on the purchase price of retail items, taking account of variation in the wholesale product's share of each item's retail price. Our upper bound on price effects represents a scenario where farm-gate commodity prices account for one-half of retail prices paid, and our lower bound represents a scenario where that fraction is one-fourth. For each scenario we identify the quantities of items needed to meet nutrient requirements at the lowest total cost per day, and show the added expense imposed by the country's agricultural trade restrictions (see Annex 7 for detailed methodology).

Figure 28 and Figure 29 present the range of upper and lower bounds across countries in 2008–2011 and 2014–2017, showing that agricultural trade policies raise the cost of a nutrient adequate diet anywhere from 0 to 30 cents per day at the median, or roughly USD 0–USD 108 per year per person, globally. In both time periods, cost increases are highest in upper-middle-income and high-income countries. These groups see roughly the same median increase in 2008–2011. In 2014–2017, upper-middle-income countries see about 1.5 times the increase that high-income countries do, although with greater variation in effect. While lower-middle-income countries see a USD 28–USD 57 increase per annum due to trade policy in 2008–2011, this effect is much less in 2014–2017, at USD 7–USD 17. In low-income countries, the median change is approximately zero in 2008–2011, but in 2014–2017 this group sees potential cost savings of USD 15–USD 32 per person per annum, were trade restrictions to be lessened. For these countries, the food group for which agricultural protection most raises price is grains, followed by pulses, staple root vegetables, and other vegetables. In all of these categories, trade restrictions to protect farm producers lead to retail price rises that could place nutrient adequate diets out of reach for many consumers, especially the poorest.

In general, the largest plausible impact on consumer prices is twice the smallest plausible impact in percentage change terms. The actual range of impacts on consumer costs also depends on substitution among items. When an item's price increase (or decrease) is large enough, its quantity in the most affordable diet decreases (or increases) and is replaced by other items that can meet nutrient needs at a lower cost. For that reason, the actual impact of a given policy change on consumer prices at the upper bound is not always twice the lower bound, and a paradoxical reversal can occur when substitution shifts consumption from highly affected to less affected foods. In the cases of Benin, Sierra Leone, Ethiopia and Zimbabwe in 2008–2011, the change in diet cost at the upper bound is slightly smaller in absolute value than the change in diet cost at the lower bound of price transmission, because the upper bound triggers a large change away from items that are highly affected by trade policy towards items that are less affected.

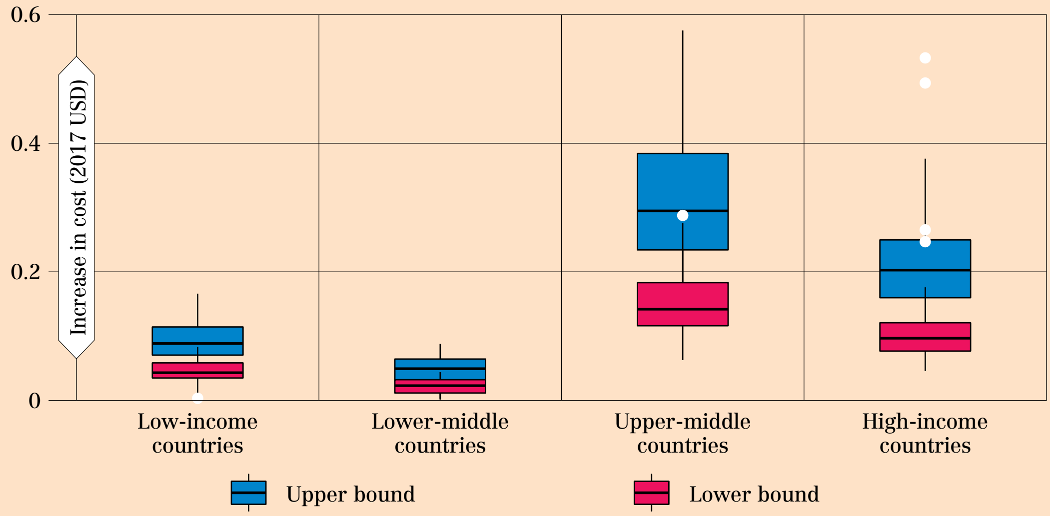
FIGURE 28 Change in cost of a nutrient adequate diet due to agricultural trade policy, 2008–2011



Notes: Data shown are median, 25th and 75th percentile range, and whiskers of 1.5 times that range for the effect of trade policy on daily retail cost of a nutrient adequate diet for an adult woman, in 2011 USD, under two scenarios: the upper bound applies to settings where wholesale costs affected by trade policy account for a large fraction of retail price, such as generic items sold in open markets; while the lower bound applies to settings where trade policy and wholesale costs are a smaller fraction of retail prices, such as supermarkets (as explained in the text and the methodological appendix). The following outliers are not shown: Japan (upper: 0.53) and Republic of Korea (upper: 0.74) in the high-income group.

Source: Authors' own elaboration.

FIGURE 29 Change in cost of a nutrient adequate diet due to agricultural trade policy, 2014–2017



Notes: Same as for Figure 28. Here, the following outliers are not shown: Bhutan (-0.2, -0.01), Mauritania (-0.01, 0), El Salvador (-0.15, -.08) and Sudan (-0.2, -0.12) in the lower-middle-income group; and Guinea (-0.07, -0.03), Comoros (-0.1, -0.08) and Chad (lower: -0.02) in the low-income group.

Source: Authors' own elaboration.

5.2 Impacts of transport cost reduction on the cost of nutrient adequate diets

This section considers the effect of within-country transport costs on the cost of nutrient adequate diets in 14 sub-Saharan African countries for which MAFAP collects agricultural commodity transport data. Estimates of potential decreases in farm-gate to wholesale transportation costs use as a reference point the country infrastructure of South Africa, the most efficient country in the region. Using the ratio of the infrastructure dimension of the World Bank's Logistics Performance Index in each country to that of South Africa, the MAFAP team calculated an adjusted transport cost for 21 commodity value chains (FAO, 2020a).

For this study, we compute an estimated transport cost reduction (*TCRij*) for each of the 21 commodities indexed i, in each of the 14 countries indexed j, in each year of observation t. Other models would be needed to take account of how a country's food system might adjust to changes in its farm-to-market transport costs; here we isolate only the transport cost change, holding all else constant, and apply the *TCR* for each product in each country to identify plausible changes in retail prices if farm-gate and traded product prices remained unchanged. For a price shock that can be compared directly to MAFAP's tariff-equivalent nominal rate of protection from trade policy, we express *TCRijt* as a fraction of the observed farm-gate price (*Pijt*), focusing on the cost difference between farm-to-market transport costs with reference-country infrastructure (*TiRt*) minus the observed farm-to-market transport costs (*Tijt*):

$$TCR_{ijt} = \frac{T_{iRt} - T_{ijt}}{P_{ijt}} \tag{1}$$

To apply farm-gate commodity-level shocks to retail prices, we average the shocks for ten food groups over the four years leading up to and including 2011 and 2017 – the ICP price collection years. Food groups vary in the number of countries and years for which transport cost estimates are available. Cereal grains have the most frequent transport cost data, with 128 observations across all 14 countries in each four-year period. Observations of nutrient-dense food groups such as dairy, fruits, poultry and eggs, red meat, and vegetables are relatively sparse, and often comprised of only one or two commodities from one or two countries.

As shown in Table 10, average shocks range from -0.68 percent for dairy in 2014–2017 to 6.75 percent for sweeteners in 2008–2011. In almost all cases, the shock in 2011 is greater, which would be consistent with countries in this region improving transportation infrastructure over time, so they are closer to cost levels in the reference country. Those groups for which the shock is based on only one product in one country are indicated by an asterisk.

We assume that the entirety of the transport cost reduction is passed on to the commodity price. Following the methodology of our trade policy simulation, we apply farm-gate-level food group price shocks to one quarter and one half of the retail prices, representing lower and upper bounds of impact (for details, see Annex 7). One key difference between the 2011 and 2017 simulations is the diversity of foods represented in the ICP retail data for the 14 countries studied here. In 2011, there were 259 foods in these countries compared to only 161 in 2017. This change in diversity may limit the sensitivity of the least-cost diet metric to individual country contexts.

TABLE 10 Transport cost changes used for simulation, by food group in 2008–2011 and 2014–2017

Food group	2008–2011	2014–2017
Dairy	-1.81%*	-0.68%*
Fruits	-5.98%*	-5.99%*
Grains	-5.16%	-3.12%
Nuts and oilseeds	-2.42%	-1.38%
Poultry and eggs	-3.32%*	-2.96%*
Pulses	-2.23%	-1.94%
Red meat	-3.09%	-2.49%
Roots, tubers and plantains	-6.32%	-3.03%
Sweeteners	-6.75%	-4.89%
Vegetables	-1.74%*	-2.06%*

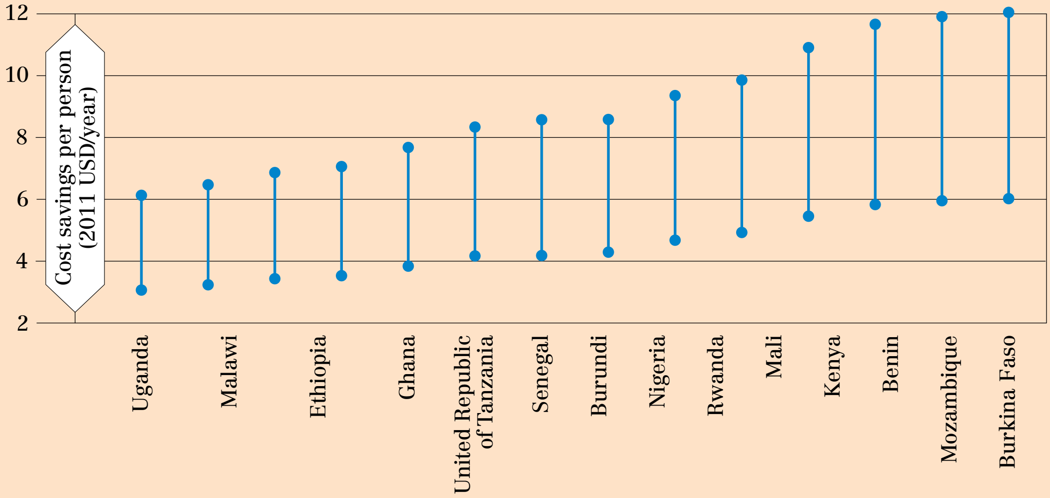
Note: Data shown are averages over all observations in each food group and time period.

Source: Authors' own elaboration.

Figure 30 and Figure 31 show the upper and lower bounds of annual cost savings for a least-cost nutrient adequate diet due to transport cost adjustment. In 2011, annual savings range from USD 2.80 to USD 11.06 per person, measured in 2011 USD at purchasing power parity (PPP). For Burkina Faso, Mozambique and Benin, the upper-bound effect is more than USD 10 per person per year, while Uganda and Malawi see relatively small savings of less than USD 6 at the upper bound. In 2011, we also see two alterations in the composition of the least-cost diet. The high transport shock adjustments for fruits and for roots, tubers and plantains make oranges a cost-efficient source of micronutrients in Burkina Faso and shift the least-cost diet in Burundi to include sweet potatoes rich in vitamin A.

In 2017, effects are more modest, ranging from USD 2.24 to USD 11.15 per person per annum, measured in 2017 USD at PPP. Potential savings amount to USD 7 per capita per year, on average, across the countries analyzed. Assuming an average household size of five members, these savings could amount on average to USD 35 per household, and up to USD 50 per household on an annual basis. Burkina Faso sees markedly higher savings compared to other countries, with savings per household amounting to USD 55 per year, while at the lower end of the effect range, Rwanda, Burundi, Malawi and Senegal all see annual cost savings of less than USD 6 per person at the upper bound. There are no changes in the composition of the least-cost diet in 2017. The lessened effect is consistent with the lower average shocks in each food group in 2017 and suggests that while infrastructure continues to improve in this region, there are still non-negligible costs of transportation inefficiency that may affect poorer consumers who struggle to access nutritious foods.

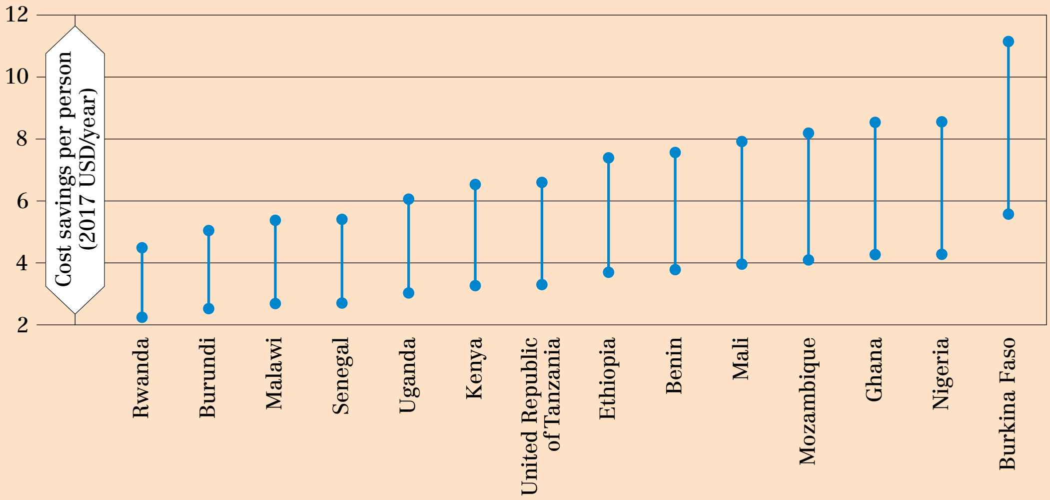
FIGURE 30 **Change in cost of the nutrient adequate diet from lower transport costs, 2008–2011**



Notes: Data shown are upper and lower bounds of estimated savings in annual cost of a nutrient adequate diet due to increased efficiency in transportation infrastructure, in 2011 USD. Upper bounds apply to settings where farm-gate to wholesale transportation costs account for a larger fraction of retail price, such as generic items sold in open markets, while lower bounds apply to settings where farm-gate to wholesale transportation costs are a smaller fraction of retail prices, such as supermarkets.

Source: Authors' own elaboration.

FIGURE 31 **Change in cost of the nutrient adequate diet from lower transport costs, 2014–2017**



Notes: Data shown are upper and lower bounds of estimated savings in annual cost of a nutrient adequate diet due to increased efficiency in transportation infrastructure, in 2017 USD. Upper bounds apply to settings where farm-gate to wholesale transportation costs account for a larger fraction of retail price, such as generic items sold in open markets, while lower bounds apply to settings where farm-gate to wholesale transportation costs are a smaller fraction of retail prices, such as supermarkets.

Source: Authors' own elaboration.

6 Applications of new food price metrics

KEY MESSAGES

- The metrics we use in this study are designed for use in current food price monitoring systems, to enable better use of food prices for understanding access to healthy diets. The metrics can be calculated and used by anyone (i.e. in government, international agencies, or research) with food price data covering a sufficient diversity of foods that constitute a healthy diet.
- The international poverty line of USD 1.90 per day is insufficient to maintain a healthy diet. This basic observation at the international level is echoed at the national level, as shown in the Myanmar case study. It calls for a re-evaluation of how food poverty lines are determined, and how they could be constructed in a way that accounts for nutritional needs.

6.1 Implications for food price monitoring

Food price data collection infrastructure

Measurement of cost and affordability in this study is made possible by the standardized collection of food prices by national governments and international agencies. Most of the price data we have used here, both through the ICP and national datasets, is collected by central statistical agencies for CPI calculations, using protocols developed for the United Nations System of National Accounts. Other price data are collected by agricultural agencies to track the prices of specific commodities, in market information systems (MIS) used to understand commercial opportunities. MIS data are collected at both retail and wholesale markets, targeting a variable and often limited number of high-volume commodities; they are not standardized across countries or uses.

How food prices are currently used

- CPI data is collected frequently (bimonthly at least) at retail markets to help countries track inflation, determine poverty lines, and measure economic activity over time.
- MIS data are collected frequently and primarily used to understand commercial opportunities. They sometimes contain data on diverse foods.
- Prices of staple foods are also used for vulnerability assessment and mapping, to monitor food price spikes and warn against potential calorie inadequacy.
- FAO or other agencies track global food prices, but these monitor only internationally traded commodities, which omits information about the many diverse foods on retail markets needed for a healthy diet.

- The ICP collects data from national governments on a standardized list of items that can be compared across countries, once every three to seven years, for the purpose of producing purchasing power parities (PPPs) and comparable price level indexes (PLIs).

Opportunities for using existing data better

Currently, food prices from all these sources are not tracked in a way that describes the price of adequate or healthy diets. However, the underlying data can be used for that purpose:

- Consumer price index (CPI) data are collected by almost all UN Member States. They aim to collect prices for a sufficient range of foods to represent national average food expenditures, typically including between 40 and 200 (and sometimes more) distinct foods and beverages which is usually enough diversity to measure the cost of nutrient adequate and healthy diets. To reliably capture the most affordable options, CPI data should include a range of fruits, vegetables, legumes, fish, eggs, dairy products and other nutrient-rich items that are locally available in markets used by low-income households. Prices for each food are typically collected monthly at multiple locations, then averaged to obtain annual or regional totals. The underlying prices for individual items are often treated as confidential but may be available to specialized researchers.
- Market information system (MIS) data are available for a limited range of countries and time periods, but in some countries can be diverse, frequent, and sufficiently high quality to be useful for calculating the cost of healthy diets. It is also sometimes possible to update MIS to include a wider range of more nutrient-dense items.
- The food price data contained in the ICP datasets have been underutilized for understanding the cost of diets; this analysis as well as Hirvonen *et al*. (2019) and Bai *et al*. (2020) reveal new insights across countries.

The metrics we use in this study are designed for use by a wide range of actors at diverse scales, from national governments and international agencies to programme implementers and academic researchers. Diet costs can be computed for people at any time and place where market prices are available for a sufficient diversity of foods. To reflect the cost of a healthy diet, a convenient rule of thumb would be to have prices for at least 60 items, including legumes, nuts and seeds, dark green leafy vegetables, other vegetables, deep orange vitamin A-rich fruits, other fruits, meat, fish, dairy, eggs and poultry as well as the most commonly consumed starchy staples. To reflect the most affordable healthy diets, price data should be collected for the lower-cost items in each food group at marketplaces that serve low-income people.

Governments and international agencies can use their food price data better to understand access to nutritious food by adopting metrics such as the cost of the healthy diet and NPI, as the Government of Ghana (Ghana Statistical Service) has announced they intend to do. Information on the cost and affordability of healthy diets, and identification of their most costly components, can then inform policies and interventions to improve food access. Interventions vary widely, and may include improving markets, on-farm own production, cash transfers, and other context-specific solutions. Projects/interventions can also use food price data in specific locations for programme design, monitoring and evaluation.

6.2 Implications for poverty estimation

It is clear from this analysis that the international poverty line of USD 1.90 per day is insufficient to allow access to a healthy diet. This basic observation at the international level is echoed at the national level, as shown in the Myanmar case study. It calls for a re-evaluation of how food poverty lines are determined, and how they could be constructed in a way that accounts for nutritional needs.

Existing food poverty lines typically use what is called a "cost of basic needs" (CBN) approach. Our analysis suggests the potential to use healthy diets instead, following the healthy diet with food preferences method that rescales poverty line food baskets to attain levels of consumption needed for a healthy diet. This is important because for many actors in governments (specifically in national statistical organizations), one of the main purposes for household food consumption, price and quantity data is to determine poverty lines. The CBN approach for poverty line calculation uses food consumption data to determine the cost of a typical diet consumed by poor households scaled to meet basic energy needs, which may be quite different from a nutritional standard.[13]

CBN poverty lines are based on the actual consumption patterns of poor or nearly poor households. This approach depends on the concept that poor households are best able to determine how to allocate their resources and as such is an approach that is decidedly not paternalistic (Ravallion, 2016).[14] In other words, the CBN approach hinges on preferences of poor households. More specifically, the food poverty line is commonly constructed from a basket of foods, including associated average quantities, consumed by poor or nearly poor households. This food basket is scaled to meet energy requirements and then evaluated at median prices, which yields the food poverty line. The total poverty line is the sum of the food poverty line and an allowance to meet essential non-food needs.

Attaining sufficient energy intake is the most fundamental purpose of food consumption, and thus the CBN poverty line provides a measure of severe deprivation. Food poverty lines reflect the dietary preferences of households striving to meet their basic food needs given limited resources. However, relatively poor households are likely to consume disproportionate quantities of low-cost per calorie staple foods such as rice (see for example, Headey and Alderman, 2019). The over-representation of staples in the food basket relative to a healthy diet is apparent in the Myanmar case study (see Figure 21). As a result, the Myanmar poverty line food basket fails to meet the nutritional standards of key micronutrients (see Table 9). Consequently, poverty lines tied only to energy requirements underestimate the cost required to access a nutrient adequate diet. Food policy in low- and middle-income countries is shifting from meeting energy needs with a focus on staple crop production to diverse diets and food systems. As policy increasingly prioritizes meeting an array of nutrient requirements essential for good health, a food poverty line designed to satisfy nutrient requirements would provide a useful additional policy tool.

The healthy diet with food preferences method has a number of features that make it a convenient choice for a food poverty line that meets nutritional needs. First, as with the poverty line food basket, the cost is calculated using consumption patterns of a reference population and is in alignment with actual dietary norms. This method is analogous to the determination of food poverty lines in that the costs within food groups are based on consumption quantity shares observed in household surveys among poor households. But unlike poverty line food basket estimation, the healthy diet with food preferences method additionally requires that minimum food group-level proportional criteria be met in order to adhere to the FBDG. Thus, the resulting poverty line is consistent with consumption patterns among poor households *within* food groups while realigning consumption *between* food groups to meet nutritional standards. This realignment of consumption patterns between food groups is an important conceptual deviation from the CBN approach which, as noted, is designed to allow for food poverty lines to meet nutritional standards without being prescriptive.

13 See Ravallion (2016) for a comprehensive discussion of CBN poverty line estimation.

14 In some cases, such as Myanmar, food baskets exclude alcohol (MoPF and World Bank, 2017b).

Second, the healthy diet with food preferences method is based on FBDG which are national policy and education tools and thus provide a relevant and policy-coherent basis for setting food poverty lines that are consistent with cultural norms as well as existing policy. Developing a methodology that results in a higher poverty rate can be politically contentious. Aligning the methodology with existing and accepted government guidelines has a clear advantage. Finally, the healthy diet with food preferences approach is straightforward and requires no more computational ability or tools to implement than the existing CBN poverty line methodology.

One challenge with this new method relates to the imposed reallocation of food consumption between food groups in accordance with FBDG, which introduces a hypothetical scenario without observable household food preferences. A reallocation from the relatively cheap staple food group to nutrient-rich yet more expensive food groups would likely be accompanied by a reallocation toward cheaper items within those food groups. For example, a poor household striving to meet FBDG might shift some consumption within an animal source protein-rich food group away from relatively expensive meats toward eggs or cheaper varieties of fish. As a result, the cost of attaining a healthy diet given food preferences is likely overestimated.

However, poverty lines tied only to energy requirements clearly underestimate the cost of attaining a diet that meets nutritional needs. Combined with the existing non-food allowance of the CBN poverty line, a healthy diet with food preferences total poverty line can be constructed and compared to total household expenditure to calculate the nutrition-sensitive poverty headcount. Used in conjunction with the traditional CBN poverty line, this poverty line provides a complementary poverty measure that considers nutritional needs. In a sense, both poverty lines taken together provide bounds rooted in household consumption patterns. The latter results in a nutrition-sensitive poverty line higher than the CBN poverty line, with a greater proportion of expenditure required for food. This suggests a higher share of the population faces insecurity in attaining a healthy diet than suggested by the poverty rate.

Others have attempted to construct nutrition-based poverty lines based on nutrient needs. Allen (2017) introduces a linear programming approach to estimating international poverty lines based on three least-cost diets that satisfy three levels of nutrient requirements. Allen argues that a food poverty line should be based on the cheapest foods, as a poverty line "represents the cost of meeting basic needs, not a level of satisfaction, and should be set accordingly" (Allen, 2017, p. 3708). This is a considerable departure from the CBN approach which strives to estimate the cost of a bundle of foods that poor households would be willing to consume. Ravallion (2016) argues that attaining adequate nutrition is not the only purpose of food consumption and that ignoring established food culture risks setting a food poverty line at an expenditure level unrelated to what poor households actually spend. Importantly, the linear programming approach ignores the proportionality needed in healthy diets, which is reflected in FBDGs that are government policy documents intended for *all* citizens. Furthermore, the least-cost nutrient-based approach results in diets that are even less proportional than the current CBN method. Nutrient-only standards do not present an equitable and dignified approach to meeting nutritional needs.

In the Myanmar case study, we have demonstrated that food baskets used to construct standard CBN poverty lines fall short in meeting both nutrient and food group proportionality standards. We argue that it is time for nutritional needs to be considered as basic needs.

7 Policy options for improving affordability of healthy diets

KEY MESSAGES

- Public funding for agricultural research and development has made grains and starchy staples relatively more abundant and cheaper relative to nutrient-rich items such as vegetables, fruits, and pulses, which have received much less public support for research and development. That imbalance is a key factor explaining the relatively high cost of nutrient adequate and healthy diets, because productivity growth driven by public services that support private-sector innovation has been the primary driver of cost reduction over time. Research and investment have not sufficiently reduced barriers to productivity and profitability of non-staple foods.
- Our results show that trade restrictions are likely to be harmful in that they raise the cost of foods needed for nutrient adequate and healthy diets.
- The cost of nutritious food should be lowered by diversification of public investment and increased market access, not by externalizing true costs by subsidizing inefficient or environmentally harmful production methods. Agricultural and trade policies should align with diet quality goals, as well as environmental, social and economic sustainability.

There is currently enough food produced for all people to meet and exceed their dietary energy needs, but even if this food were to be equally distributed it would be impossible for all people to meet dietary recommendations. For example, most countries lack adequate supplies of fruits and vegetables for all people to meet the WHO recommendations of 400 g or more of fruits and vegetables per day (Siegel *et al.*, 2014). Other micronutrient-rich food groups, such as beans, nuts, and animal source foods are also far less available and affordable than starchy staples (Herforth, 2015).

We see this reality play out on a global scale in the results of this analysis, showing that a staggering number of people cannot afford even the lowest-cost form of healthy diets. The main cause is that nutrient-dense foods are the most expensive components of the diet and make up a large share of the cost required. The purpose of the least-cost diet calculation is to establish a bottom floor: i.e. the lowest possible cost that someone would need to spend to achieve the dietary guidelines – whereas we know (and demonstrate in the Myanmar case study) that adding in food preferences only increases the cost, and thus the number of people who cannot afford the diet.

The inability of people to afford healthy diets results in food insecurity and poor diets. Poor diet quality has major impacts on malnutrition on all its forms. In relation to overweight, obesity and diet-related non-communicable disease, the consumption of ultraprocessed foods of minimal nutritional value, such as sodas, instant noodles, and packaged sweet and salty snacks, has been rising in many countries experiencing nutrition transitions. The rise in consumption of these foods is based partly on the abundant supply and low prices of starchy staples, sugars and oils that constitute their main ingredients and make them relatively inexpensive, in addition to marketing which promotes these products as aspirational foods compared to traditional, minimally processed foods. The result is that basic starches make up too much of the diets of many people, whether in the form of monotonous, nutritionally inadequate diets or diets that promote obesity and non-communicable diseases.

Increasing access to healthy and sustainable diets will ultimately come from an interplay between supply-side and demand-side actions. Markets are a key arena where opportunities exist to affect both supply and demand of nutrition foods. A systems approach is needed to support increased supplies of vegetables, fruits, pulses, and sustainably produced animal source foods, including improvements in diversified and sustainable production, storage and transformation, and marketing.

Supply-side factors

The food environment – i.e. the kinds of food that are most available, affordable and convenient – is a major determinant of diets (Herforth and Ahmed, 2015). While consumer demand certainly influences what is produced, multiple supply-side factors do as well: for example, subsidies, standards at collection/trade points, quality of seed supply, pest resistance, transport and storage, and perishability. Supply-side policies and measures should align with diet quality goals, as well as environmental, social and economic sustainability.

Staple grains have been the focus of public investment in agriculture throughout human history, and particularly during the Green Revolution when more calories were urgently needed to avert famine. In almost all countries today, food and nutrition problems no longer call for just more calories, but for greater diversity in the food supply. Demand is increasing for diversified diets, but the supply response has been surprisingly low, partly due to risk for farmers and the other private-sector actors who supply each type of food (Pingali, 2015). Low productivity and high risk leave nutritious non-staple foods, such as fruits, vegetables and pulses, to remain out of reach for vast numbers of people.

Technological research and subsidies are needed to make more nutrient-rich, non-staple crops accessible. Growth in agricultural productivity is important and needed, but its traditional focus on agricultural commodities and export-led growth is not enough to improve nutrition or sustainability. Efforts and investments must be made in diversifying production with a focus on nutrient-dense foods such as fruits, vegetables, pulses, fish, dairy and eggs or other animal source foods. Furthermore, production methods need to be environmentally, socially and economically sustainable. It is critical to understand the ecological impact of production in choosing policies that support both human and environmental health. Integrated crop-livestock systems, including agroforestry, can help to ensure more sustainable use of natural resources (soil, water, biological diversity) as well as a supply of fuel for cooking and fodder for animals. The most sustainable solutions, considering human and environmental health as well as economics, will be context specific.

Nutrient-dense foods tend to be more perishable; therefore, improving post-harvest handling is a key area for action to improve their availability and affordability. Post-harvest measures can also improve the safety, quality and nutritional value of food. Development of pro-poor technologies and inputs can facilitate the transport, storage and safe preservation of more diverse foods, thereby reducing risk and loss which are barriers to increased production. Examples include drying of fruits, and cold chains for vegetables and dairy. Drying or freezing are processes that also protect the nutritional value of foods, while other processes such as food fortification and fermentation help improve their nutritional value.

Demand-side factors

Markets are where consumers interact with the food supply. They are a key arena for actions both in terms of promoting production (ensuring that production of nutrient-rich foods is economically viable for farmers and traders) and consumption (promotion of high-quality, nutritious, safe foods for consumers).

Nutrition-focused marketing can be a powerful tool to promote knowledge of and demand for nutritious foods. How retail outlets are organized physically and how foods are presented in the market can also significantly influence consumer choices. Geographical and sustainability indications on labels are another way that producers can leverage demand for diverse products and expand markets for traditional local foods that are sustainably produced.

There can be risks from food marketing as well, in particular with reference to children. The *Set of recommendations on the marketing of foods and non-alcoholic beverages to children* (WHO, 2010) aim to guide efforts by Member States in designing and/or strengthening policies to reduce the impact on children of marketing of highly processed foods that are high in saturated and trans fats, sugars and salt.

Nutrition education can be helpful in terms of selecting least-cost foods in order to improve access to healthy diets; often least-cost diets require substantial labour and knowledge to prepare. However, it is important to recognize that nutrition education will not result in the purchase of healthy diets among the poor until prices of those diets go down.

Removing distortions and other inefficiencies of food systems to increase affordability of healthy diets

Almost all people purchase some portion of their food, and the majority of smallholders are net buyers of food (that is, they buy more than they sell). Therefore, it is necessary to focus on what markets provide and the environments in which consumers live, in order to reach all people and reduce malnutrition in all its forms. A key area for action is linking producers to markets and improving rural infrastructure. Linking producers to markets is sometimes needed to ensure that economic opportunities are inclusive; for example, linking smallholder producers to larger markets that they have not been able to access on their own. Well-functioning market linkages can also serve to reduce food losses, for example of perishable fruits and vegetables, thereby increasing the overall supply of nutritious food. Finally, there is a need for trade policies that have co-benefits for nutrition, sustainability and equitable economic growth. Our results show that trade distortions are likely to be harmful in that they tend to raise costs of healthy diets.

8 Conclusions

Main three general takeaways from the analysis

1. Healthy diets are unaffordable for many people. The high cost of nutritious foods in places where low-income people live is a major obstacle to the achievement of global development goals.
2. Unaffordability of healthy diets is concentrated in Africa and Southern Asia. While these are known to be hot spots for malnutrition, insufficient attention has been paid to diet quality as a cause of malnutrition in all its forms. As the double burden intensifies in these regions, diet quality is becoming even more paramount.
3. Supporting nutrient adequate and healthy diets requires a combination of higher incomes and lower prices, particularly of diverse nutritious items, making a variety of healthier foods more widely available at lower cost. Where countries have national food-based dietary guidelines, there is often a lack of policy coherence on how to ensure the affordability of those diets recommended for nutrition and health. We found no definition of a healthy diet that would be globally affordable; all definitions result in similar conclusions.

Main three policy takeaways

1. Tracking the overall cost of a healthy diet highlights the disparity between dietary needs and what food systems actually produce. Food price data can be better used for nutrition, both globally and within countries:
   a. To understand where and when intervention is most needed, including which requirements are most costly and which foods can most effectively reduce the overall cost of healthy diets;
   b. To shift attention towards consumer prices and availability of all items required for healthy diets, in both rural and urban areas;
   c. To construct poverty lines that account for the cost of food in terms of meeting dietary needs, beyond only energy sufficiency.
2. Nutrition education and behaviour change will not substantially improve dietary consumption where nutrient adequate and healthy diets, even in their *cheapest* form, are unaffordable for the majority of the poor. A combination of social protection and food systems policies are needed to reduce prices and improve access to and consumption of healthy diets.
3. To make healthy diets cheaper, agricultural policies, research, and development need to shift toward a diversity of nutritious foods. Prices should not be reduced by discounting or externalizing real costs (such as reducing workers' wages, clearing forests, or intensive animal production that discounts animal welfare and water quality) or through trade protectionism. Rather, prices should be reduced through policies that support diversification and through market access that allows the flow of diverse products into markets.

Top ten take-home messages

1. People cannot live on bread alone. Food systems can and should focus on access to all elements of a healthy diet.
2. Nutrition education will not solve the problem of poor diets. Systemic changes in the food environment are also needed.
3. Healthy diets are often unaffordable for low-income people. Bringing healthy diets within reach requires higher incomes and expanded safety nets as well as lower prices for a variety of nutritious items.
4. Poverty lines need to be adjusted upward if they are meant to cover access to nutritious food that meets dietary needs. Poverty lines that are defined to include the cost of healthy diets would help align anti-poverty programmes with other global development goals, linking policies in agriculture and food security to health and human development.
5. Farm production and food markets complement each other. Homestead production of vegetables, legumes, dairy, poultry, small fish and fruits can be important forms of social protection and provide nutritious food in some settings, while markets can provide access to foods beyond what can be grown at each time and place.
6. Diversification in agriculture is needed. The innovations needed to lower diet costs differ by type of food. Moving beyond starchy staples to legumes, vegetables, fruits, nuts and seeds, as well as dairy, eggs, fish, and livestock calls for a wide range of actions including access to higher quality seeds, biotic and abiotic stress resistance (e.g. pests, drought), disease control, and management of natural resources around both crops and livestock, as well as better storage and transport, including cold chains and market infrastructure with product-specific steps to improve and maintain quality.
7. Diet costs and affordability vary significantly by region within countries, revealing geographic hotspots that are poorly served by the existing food system. The variability suggests that transport and storage networks are needed to stabilize prices and incomes over space and time, and to provide access to certain foods in places and times where they may be unavailable.
8. Protectionism in agricultural trade policy raises costs of nutrient adequate and healthy diets. It often helps influential interest groups while reducing job creation and wage growth for other people in the food sector. Reducing barriers between producers and consumers will lower diet costs while raising farm incomes.
9. Nutrient adequate and healthy diets can be achieved most affordably with small quantities of animal source foods, including dairy, eggs and small fish that complement nutrient-rich plant-based foods. It is important that efforts to reduce the cost of diets also internalize environmental costs, and therefore focus on both animal source and plant-based foods with the lowest environmental impact.
10. The highest-priority regions are Southern Asia and Africa, but poor affordability of healthy diets as well as heavy marketing of unhealthy options everywhere are driving malnutrition in all its forms all around the world.

References

Allen, L.H., Carriquiry, A.L. & Murphy, S.P. 2019. Proposed harmonized nutrient reference values for populations. *Advances in Nutrition*, 11(3): 469–483.

Allen, R.C. 2017. Absolute poverty: when necessity displaces desire. *American Economic Review*, 107(12): 3690–3721.

Anderson, K. 2016. *Agricultural trade, policy reforms, and global food security*. Amsterdam, Springer.

Bachewe, F. & Headey, D. 2017. Urban wage behaviour and food price inflation in Ethiopia. *The Journal of Development Studies*, 53(8): 1207–1222.

Bachewe, F., Headey, D., Bai, Y. & Masters, W. 2019. *Selected paper: Nutritional poverty in economic transition: measuring the affordability of nutrient adequacy and dietary energy in Ethiopia, 2001–2017*. 23 July 2019, Atlanta, USA, Agricultural & Applied Economics Association.

Bai, Y., Alemu, R., Block, S.A., Headey, D. & Masters, W.A. 2020. Cost and affordability of nutritious diets at retail prices: evidence from 177 countries. *Food Policy*, in press. https://doi.org/10.1016/j.foodpol.2020.101983

Bai, Y., Naumova, E. & Masters, W.A. 2020. Seasonality of diet cost reveals food system performance in East Africa. *Science Advances*, 6(49): eabc2162.

Bai, Y., Herforth, A. & Masters, W.A. (forthcoming). *Global variation in the cost of a nutrient adequate diet by population group*.

Chastre, C., Duffield, A., Kindness, H., LeJeune, S. & Taylor, A. 2007. *The minimum cost of a healthy diet: findings from piloting a new methodology in four study locations*. London, Save the Children.

Cornelsen, L., Green, R., Turner, R., Dangour, A.D., Shankar, B., Mazzocchi, M. & Smith, R.D. 2015. What happens to patterns of food consumption when food prices change? Evidence from a systematic review and meta-analysis of food price elasticities globally. *Health Economics*, 24(12): 1548–1559.

Dawe, D. & Lee, J. 2017. *Fruit and vegetable prices are rising in Asia and the Pacific*. Bangkok, FAO Regional Office for Asia and the Pacific.

Drewnowski, A. & Darmon, N. 2005. The economics of obesity: dietary energy density and energy cost. *The American Journal of Clinical Nutrition*, 82(1): 265S–273S.

FAO. 1996. *Rome Declaration on World Food Security and World Food Summit Plan of Action*. Rome.

FAO. 2020a. Database. In: *Monitoring and Analysing Food and Agricultural Policies (MAFAP)* [online]. Rome. [Cited January 2020]. www.fao.org/in-action/mafap

FAO. 2020b. Food-based dietary guidelines. In: *FAO* [online]. Rome. [Cited January 2020]. www.fao.org/nutrition/education/food-dietary-guidelines/home/en/

FAO. 2020c. Trade, Crops and Livestock Products. In: *FAOSTAT* [online]. Rome. [Cited May 2020]. www.fao.org/faostat/en/#data/TP

FAO, International Fund for Agricultural Development (IFAD), United Nations International Children's Emergency Fund (UNICEF), World Food Programme (WFP) & World Health Organization (WHO). 2019. *The State of Food Security and Nutrition in the World 2019. Safeguarding against economic slowdowns and downturns*. Rome, FAO. (also available at www.fao.org/3/ca5162en/ca5162en.pdf).

FAO, IFAD, UNICEF, WFP & WHO. 2020. *The State of Food Security and Nutrition in the World 2020. Transforming food systems for affordable healthy diets*. Rome, FAO. (also available at https://doi.org/10.4060/ca9692en).

Finaret, A.B. & Masters, W.A. 2019. Beyond calories: the new economics of nutrition. *Annual Review of Resource Economics*, 11: 237–259.

Federal Reserve Bank of St. Louis (FRED). 2020. *Inflation, consumer prices for the United States* [online]. [Cited 29 May 2020]. https://fred.stlouisfed.org/series/FPCPITOTLZGUSA

Green, R., Cornelsen, L., Dangour, A.D., Turner, R., Shankar, B., Mazzocchi, M. & Smith, R.D. 2013. The effect of rising food prices on food consumption: systematic review with meta-regression. *British Medical Journal (Clinical Research Edition)*, 346: f3703.

Headey, D. & Alderman, H. 2019. The relative caloric prices of healthy and unhealthy foods differ systematically across income levels and continents. *Journal of Nutrition*, 149(11): 2020–2033.

Herforth, A. 2015. Access to adequate nutritious food: new indicators to track progress and inform action. *In* D.E. Sahn, ed. *The fight against hunger and malnutrition: The role of food, agriculture, and targeted policies*, pp. 139–162. Oxford, UK, Oxford University Press. (also available at www.oxfordscholarship.com/view/10.1093/acprof:oso/9780198733201.001.0001/acprof-9780198733201-chapter-7).

Herforth, A. 2016. *Supply side policies and measures for diversifying food production and for increasing availability and affordability of healthy diets. Paper commissioned by FAO for the International Symposium on Healthy and Sustainable Diets*. Rome.

Herforth, A. & Ahmed, S. 2015. The food environment, its effects on dietary consumption, and potential for measurement within agriculture-nutrition interventions. *Food Security*, 7(3): 505–520.

Herforth, A., Arimond, M., Álvarez-Sánchez, C., Coates, J., Christianson, K. & Muehlhoff, E. 2019. A global review of food-based dietary guidelines. *Advances in Nutrition*, 10(4): 590–605.

Hirvonen, K., Bai, Y., Headey, D. & Masters, W.A. 2019. Cost and affordability of the EAT-Lancet diet in 159 countries. *Lancet Global Health*, 8(1): e59–e66.

Institute of Medicine (IOM). 2006. *Dietary reference intakes: the essential guide to nutrient requirements.* Washington, DC, National Academies Press.

Mahrt, K., Mather, D., Herforth, A. & Headey, D. 2019. *Household dietary patterns and the cost of a nutritious diet in Myanmar*. IFPRI Discussion Paper 1854. Washington, DC, IFPRI (International Food Policy Research Institute). (also available at https://doi.org/10.2499/p15738coll2.133344).

Masters, W.A., Bai, Y., Herforth, A., Sarpong, D., Mishili, F., Kinabo, J. & Coates, J.C. 2018. Measuring the affordability of nutritious diets in Africa: price indexes for diet diversity and the cost of nutrient adequacy. *American Journal of Agricultural Economics*, 100(5): 1285–1301.

Ministry of Health and Sports of Myanmar (MoHS). (no date). *Food-based dietary guidelines for Myanmar*. Nay Pyi Taw.

Ministry of Planning and Finance of Myanmar (MoPF) & World Bank. 2017a. *An analysis of poverty in Myanmar (Part 2). Poverty Profile*. Nay Pyi Taw.

MoPF & World Bank. 2017b. *Myanmar poverty and living conditions survey 2017. Technical Poverty Estimate Report.* Nay Pyi Taw.

National Academies of Sciences, Engineering and Medicine. 2019. *Dietary reference intakes for sodium and potassium*. V.A. Stallings, M. Harrison & M. Oria, eds. Washington, DC, National Academies Press.

Norton, G.W., Alwang, J. & Masters, W.A. 2014. *Economics of agricultural development: world food systems and resource use, 3rd edition*. New York, USA, Routledge.

Pernechele, V., Balié, J. & Ghins, L. 2018. *Agricultural policy incentives in sub-Saharan Africa in the last decade (2005–2016).* FAO Agricultural Development Economics Technical Study 3. Rome, FAO.

Pingali, P. 2015. Agricultural policy and nutrition outcomes – getting beyond the preoccupation with staple grains. *Food Security*, 7(3): 583–591.

Raghunathan, K., Headey, D. & Herforth, A. 2020. Affordability of nutritious diets in rural India. *Food Policy*, in press. https://doi.org/10.1016/j.foodpol.2020.101982

Ravallion, M. 2016. *The economics of poverty: history, measurement, and policy.* Oxford, UK, Oxford University Press.

Schneider, K. & Herforth, A. 2020. *Software tools for practical application of human nutrient requirements in food-based social science research*. Gates Open Research.

Scott, J. 2019. *Nutrient database for fish in Myanmar*. Yangon, Myanmar, WorldFish (unpublished).

Shaheen, N., Rahim, A.T.M.A., Mohiduzzaman, M., Banue, C.P., Bari, M.L., Tukun, A.B., Mannan, M.A., Bhattacharjee, L. & Stadlmayr, B. 2013. *Food Composition Table for Bangladesh.* Dhaka, University of Dhaka, Institute of Nutrition and Food Science.

Siegel, K., Ali, M.K., Srinivasiah, A., Nugent, R.A. & Venkat Narayan, K.M. 2014. Do we produce enough fruits and vegetables to meet global health need? *PLOS One*, 9(8): e104059.

United States Department of Agriculture (USDA). 2016. National Nutrient Database for Standard Reference, Release 28. Version Current: May 2016. In: *USDA* [online]. Washington, DC. [Cited July 2020]. www.ars.usda.gov/ba/bhnrc/ndl

USDA. 2020. Global Agricultural Trade System (GATS). In: *USDA* [online]. Washington, DC. [Cited May 2020]. https://apps.fas.usda.gov/gats

van't Erve, I., Tulen, C.B.M., Jansen, J., van Laar, A.D.E., Minnema, R., Schenk, P.R., Wolvers, D., van Rossum, C.T.M. & Verhagen, H. 2017. Overview of elements within national food-based dietary guidelines. *European Journal of Nutrition & Food Safety*, 7(1): 1–56.

Wang, S.S., Lay, S., Yu, H.N. & Shen, S.R. 2016. Dietary guidelines for Chinese residents (2016): comments and comparisons. *Journal of Zhejiang University SCIENCE B*, 17(9): 649–656.

Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., Garnett, T. *et al.* 2019. Food in the Anthropocene: the EAT-Lancet Commission on healthy diets from sustainable food systems. *The Lancet*, 393(10170): 447–492.

World Bank. 2020. PovcalNet. In: *World Bank* [online]. Washington, DC. [Cited July 2020]. http://iresearch.worldbank.org/PovcalNet

World Bank. 2020. Global Consumption Database – Food and Beverages. In: *World Bank* [online]. Washington, DC. [Cited 18 November 2020]. https://datatopics.worldbank.org/consumption/sector/Food-and-Beverages

WHO. 2010. *Set of recommendations on the marketing of foods and non-alcoholic beverages to children.* Geneva, Switzerland.

Annexes

Annex 1. Food-based dietary guidelines used for calculating the cost of a healthy diet

TABLE A1.1 Computing the cost of the healthy diet

FAO Region	FBDG country (or EAT-Lancet diet)	Date of FBDG	Number of groups (including subgroups)	Starchy staple	Protein-rich foods: Legumes	Protein-rich foods: Flesh/ eggs	Dairy	Vegetables	Fruits	Fat	Nuts and seeds	Discretionary/ sugars
Africa	Benin	2015	6	3–6 (adult woman, 3–5) servings; serving size: 185 g cooked maize paste, 220 g cooked rice, 160 g cooked pasta, 87.5 g bread, 185–200 g cassava, 60 g gari	2–3 servings; serving size: 75 g meat, 100 g fish, 80 g eggs (2), 200 g crabs (3 with shell), 100 g shrimp (including shell), 50 g dried fish, 140 g beans (cooked), 50 g soya cheese, 50 g peanut		1–2 servings; serving size: 125 g yogurt, 20 g powder, 50 g local cheese, 85 g concentrated milk (unsweetened). If milk products are not part of the diet, they can be replaced by other foods rich in calcium such as finfish, crustaceans, and dried fish	4–6 servings; serving size: 50 g leaves, 100 g other, 60 g carrots	2–3 servings; serving size: 100 g on average, or 3/4 cup juice	2–3 tablespoons, 15 g per tablespoon	(in protein-rich foods)	
Asia and the Pacific	China	2016	7*	250–400 g	120–200 g		300 g fluid milk equivalent	300–500 g	200–350 g	25–30 g	25–35 g nuts and tofu	
	India (moderate woman)	2011	6	9–20 (moderate woman, 11) servings; serving size: 30 g dry/uncooked (100 kcal)	2–4 (moderate woman 2.5) servings; serving size: 50 g meat/chicken/fish (100 kcal), 50 g eggs (85 kcal), 30 g dry pulses (100 kcal)		3 servings; serving size: 100 g (70 kcal)	3 servings (1 DGLV, 2 others; includes potatoes/roots and tubers); serving size: 100 g (28 kcal)	1 serving; serving size: 100 g (40 kcal)	4–8 (moderate woman, 5) servings; serving size: 5 g (45 kcal)	(none – nuts are discussed as additional in protein and fat; not clear)	

TABLE A1.1 (cont.) Computing the cost of the healthy diet

FAO Region	FBDG country (or EAT-Lancet diet)	Date of FBDG	Number of groups (including subgroups)	Starchy staple	Protein-rich foods: Legumes	Protein-rich foods: Flesh/ eggs	Dairy	Vegetables	Fruits	Fat	Nuts and seeds	Discretionary/ sugars
Asia and the Pacific	**Viet Nam**	2016	6	12–15 servings; each serving equivalent to 20 g of carbohydrates (examples: rice, bread, potato, sweet potato)	5–6 servings; each serving equivalent to 7 g of protein (examples: fish, meat, seafood, tofu, eggs, soybeans)		3–4 servings; each serving equivalent to 100 mg of calcium	3 servings; each serving 80 g	3 servings; each serving 80 g	5–6 servings; each serving equivalent to 5 g lipids	(in oil and fat)	
Europe	**Malta**	2015	6	4 servings; serving size: 40 g of breakfast cereals; 80–100 g of raw cereals, pasta and rice, preferably wholegrain or wholemeal; 80 g potatoes	Approx. 9–12 servings per week = approx. 1.5 servings per day; serving size: 115 g fish (raw), 70 legumes (raw), 21 g nuts and seeds, 1 egg, 100 g white meat (raw), 90 g red meat (raw)		2 servings; serving size: 250 ml milk, 1 tub (150 ml) yogurt, 30–40 g cheese, 45–50 g irkotta/ġbejna	3–5 servings; serving size: 80 g	2–3 servings; serving size: 80 g	1 serving; serving size: 1 tablespoon (15 ml)	(in protein-rich foods)	
	Netherlands	2017	7*	4–5 servings; serving size examples: 1 brown bread sandwich, 1 serving spoon of wholegrain products or potatoes	1 serving fish/pulse/meat; serving size: 100 g meat/fish		2–3 servings; serving size 150 ml milk, 40 g cheese. Includes soy drinks	250 g	200 g	40 g	25 g	

TABLE A1.1 (cont.) **Computing the cost of the healthy diet**

FAO Region	FBDG country (or EAT-Lancet diet)	Date of FBDG	Number of groups (including subgroups)	Starchy staple	Protein-rich foods: Legumes	Protein-rich foods: Flesh/ eggs	Dairy	Vegetables	Fruits	Fat	Nuts and seeds	Discretionary/ sugars
Latin America and the Caribbean	**Argentina**	2016	6*	4 servings; 606 kcal total + 270 kcal "optional foods" (876 kcal total)		1 serving (224 kcal total)	3 servings (310 kcal total)	400 g	300 g	2 servings (270 kcal total)	(in fats and seeds, also including dried fruits)	270 kcal optional foods
	Jamaica	2015	6	14 servings; serving size: 70 kcal (980 kcal total)	3 servings; serving size: 73 kcal (219 kcal total)		5 servings; serving size: 75 kcal if meat or whole milk, 40 kcal if skim milk (total of 374 kcal if no skim consumed)	3 servings; serving size: 36 kcal (108 kcal total)	3 servings; serving size: 40 kcal (120 kcal total)	6 servings (including avocado and coconut); serving size: 45 kcal (270 kcal total)	(in legumes)	
Near East	**Oman (at 2 300 kcal level)**	2009	7	0.95 servings whole, 3.7 refined; serving size: 28 g dry rice or pasta, or 1 cup cereal flakes	0.75 cup cooked lentils	91 g; serving size: 30 g lean meat, poultry or fish, 1 egg, 15 g oz nuts or seeds	0.6 servings; serving size: 1 cup equivalent = 1 cup milk or yogurt, 45 g natural cheese	3.4 servings; serving size: 1 cup raw vegetables, 2 cup leafy salad greens, 1/2 cup chopped, cooked or canned vegetables, 1/2 cup vegetable juice	3.95 servings; serving size: 1 cup raw fruits, 1/2 cup fruit juice, 1/2 cup chopped, cooked or canned fruits	66.5 g	(in protein-rich foods)	

TABLE A1.1 (cont.) Computing the cost of the healthy diet

FAO Region	FBDG country (or EAT-Lancet diet)	Date of FBDG	Number of groups (including subgroups)	Starchy staple	Protein-rich foods: Legumes	Protein-rich foods: Flesh/ eggs	Dairy	Vegetables	Fruits	Fat	Nuts and seeds	Discretionary/ sugars
Northern America	**USA (Vegetarian style at 2 300 kcal level)**	2015	6	8 oz-eq (half should be whole grain)	3.75 oz-eq (including eggs, legumes, tofu, nuts)		3 cup-eq; 1 cup milk, soymilk or yogurt = 1.5 oz cheese	3 cup-eq; 1 cup-eq = 1 cup reg-orange or other vegetables, 1 cup legumes, 2 cup DGLV, 1.5 cup potatoes	2 cup-eq; 1 cup-eq = 1 cup fresh, 1/2 cup dried, 3/4 cup 100% juice	30 g	(in protein-rich foods)	230 kcal
	USA (Mediterranean style at 2 300 kcal level)	2015	6	7.5 oz-eq (half should be whole grain)		7.25 oz-eq (including meat, fish, poultry, eggs, nuts, tofu)	2.25 cup-eq; 1 cup milk, soymilk or yogurt = 1.5 oz cheese	3 cup-eq; 1 cup-eq = 1 cup reg-orange or other vegetables, 1 cup legumes, 2 cup DGLV, 1.5 cup potatoes	2.5 cup-eq; 1 cup-eq = 1 cup fresh, 1/2 cup dried, 3/4 cup 100% juice	30 g	(in protein-rich foods)	230 kcal
	USA (American style at 2 300 kcal level)	2015	6	7.5 oz-eq (half should be whole grain)		6.25 oz-eq (including meat, fish, poultry, eggs, nuts, tofu)	3 cup-eq; 1 cup milk, soymilk or yogurt = 1.5 oz cheese	3 cup-eq; 1 cup-eq = 1 cup reg-orange or other vegetables, 1 cup legumes, 2 cup DGLV, 1.5 cup potatoes	2 cup-eq; 1 cup-eq = 1 cup fresh, 1/2 cup dried, 3/4 cup 100% juice	30 g	(in protein-rich foods)	230 kcal

TABLE A1.1 (cont.) Computing the cost of the healthy diet

FAO Region	FBDG country (or EAT-Lancet diet)	Date of FBDG	Number of groups (including subgroups)	Starchy staple	Protein-rich foods: Legumes	Protein-rich foods: Flesh/ eggs	Dairy	Vegetables	Fruits	Fat	Nuts and seeds	Discretionary/ sugars
N/A	**EAT-Lancet (flexitarian)**	2019	12	2 groups: 678 kcal cereal grains + 81 kcal starchy roots	254 kcal	4 groups: 14 kcal eggs + 38 kcal fish + 28 kcal poultry + 29 kcal red meat	90 kcal	96 kcal	95 kcal	405 kcal	180 kcal	95 kcal
	EAT-Lancet (pescatarian)	2019	10	2 groups: 678 kcal cereal grains + 81 kcal starchy roots	254 kcal	2 groups: 14 kcal eggs + 76 kcal fish	90 kcal	107 kcal	103 kcal	405 kcal	180 kcal	95 kcal
	EAT-Lancet (vegetarian)	2019	9	2 groups: 678 kcal cereal grains + 81 kcal starchy roots	317 kcal	14 kcal eggs	90 kcal	114 kcal	108 kcal	405 kcal	180 kcal	95 kcal
	EAT-Lancet (vegan)	2019	7	2 groups: 678 kcal cereal grains + 81 kcal starchy roots	387 kcal			133 kcal	124 kcal	405 kcal	180 kcal	95 kcal

Notes: * Argentina: fruits and vegetables are required subgroups. China: fruits and vegetables are subgroups; dairy and nuts are required subgroups. Netherlands: nominally four groups, but "fruits and vegetables" has two required subgroups; and "protein-rich foods" has three subgroups: protein, dairy and nuts.

Source: Authors' own elaboration.

Annex 2. Cost of the nutrient adequate diet using RDA compared to using H-AR

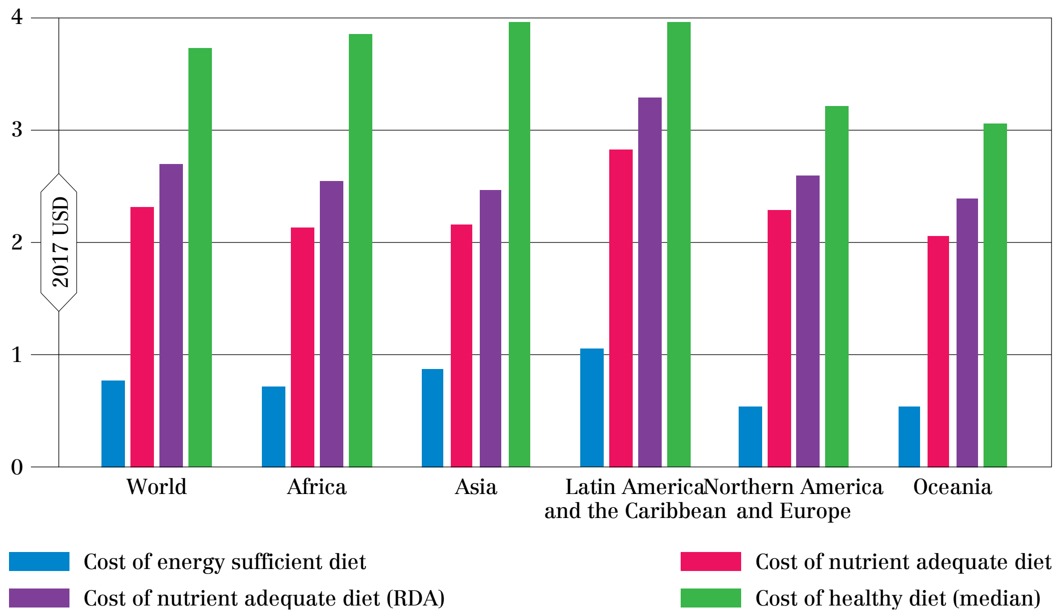
TABLE A2.1 Regional mean cost by macroregion for all cost of diet indicators (2017 international USD)

Macroregion	Energy sufficient diet	Nutrient adequate diet	Nutrient adequate diet (RDA)	Healthy diet (median)
Africa	0.73	2.15	2.56	3.87
Asia	0.88	2.18	2.48	3.97
Latin America and the Caribbean	1.06	2.83	3.30	3.98
Northern America and Europe	0.54	2.29	2.61	3.21
Oceania	0.55	2.07	2.39	3.06
World	**0.79**	**2.33**	**2.71**	**3.75**

Notes: To provide a sensitivity analysis, the Table compares the cost of the nutrient adequate diet calculated in this study using harmonized average requirements (H-ARs), harmonized upper levels of intake (H-ULs) and Acceptable Macronutrient Distribution Ranges (AMDRs) set by IOM (2006), with the cost of the nutrient adequate diet calculated using the IOM (2006) recommended dietary allowances (RDAs), or Adequate Intakes (AIs) if the latter is not larger than the H-ARs. For the methodology, see subsection 2.3.2.

Source: Authors' own elaboration.

FIGURE A2.2 Regional mean cost by macroregion for all cost of diet indicators (2017 international USD)



Source: Authors' own elaboration.

Annex 3. Average cost of each diet and national percentage of people who cannot afford each diet, by region and income level (simple average across countries)

TABLE A3.1 Average cost of each diet, by region and country income group (simple average across countries)

Regions	Energy sufficient diet	Nutrient adequate diet	Healthy diet
World	**0.79**	**2.33**	**3.75**
Africa	**0.73**	**2.15**	**3.87**
Northern Africa	0.75	2.90	4.12
Sub-Saharan Africa	0.73	2.06	3.84
Eastern Africa	0.61	1.98	3.67
Middle Africa	0.73	2.09	3.73
Southern Africa	0.86	2.29	3.99
Western Africa	0.80	2.05	4.03
Asia	**0.88**	**2.18**	**3.97**
Central Asia	0.84	2.04	3.39
Eastern Asia	1.27	2.63	4.69
South-eastern Asia	0.92	2.42	4.20
Southern Asia	0.80	2.12	4.07
Western Asia	0.74	1.87	3.58
Latin America and the Caribbean	**1.06**	**2.83**	**3.98**
Caribbean	1.12	2.89	4.21
Latin America	1.00	2.78	3.75
Central America	1.13	3.04	3.81
South America	0.91	2.61	3.71
Oceania	**0.55**	**2.07**	**3.06**
Northern America and Europe	**0.54**	**2.29**	**3.21**
Country income group			
Low-income countries	0.70	1.98	3.82
Lower-middle income countries	0.88	2.40	3.98
Upper-middle income countries	0.87	2.52	3.95
High-income countries	0.71	2.31	3.43

Notes: Data shown are the average cost (USD) per person per day of each diet. Methods and data sources are detailed in the text.

Source: Authors' own elaboration.

TABLE A3.2 Average national percentage of people who cannot afford each diet, by region and country income group (simple average across countries)

	Energy sufficient diet	Nutrient adequate diet	Healthy diet
Macroregion			
Africa	11.3%	51.0%	73.8%
Asia	0.4%	11.7%	36.6%
Latin America and the Caribbean	3.7%	18.1%	26.5%
Northern America and Europe	0.3%	1.7%	3.7%
Oceania	0.1%	5.0%	21.0%
Subregion			
Australia and New Zealand	0.2%	0.5%	0.7%
Central Asia	0.3%	11.0%	33.2%
Eastern Asia	0.3%	1.8%	15.6%
Eastern Europe	0.3%	1.7%	3.5%
Latin America and the Caribbean	3.7%	18.1%	26.5%
Melanesia	0.0%	9.6%	41.3%
Northern Africa	1.4%	29.2%	46.0%
Northern America	0.6%	1.0%	1.2%
Northern Europe	0.2%	0.4%	0.8%
South-eastern Asia	0.7%	20.7%	46.2%
Southern Asia	0.5%	17.9%	57.6%
Southern Europe	0.4%	3.8%	8.7%
Sub-Saharan Africa	12.5%	53.4%	76.9%
Western Asia	0.3%	3.8%	21.7%
Western Europe	0.1%	0.2%	0.3%
Country income group			
High-income countries	0.3%	0.9%	2.0%
Low-income countries	12.7%	61.4%	86.2%
Lower-middle countries	6.3%	33.1%	58.9%
Upper-middle countries	2.1%	11.5%	24.2%
World	**4.6%**	**23.3%**	**38.3%**

Notes: Data shown are the percentage of people in each region whose household income is below the total cost of the most affordable locally available items needed to meet each standard of diet quality, assuming that they can spend no more than 63 percent of their income on food. Average percentages are reported as in Table 8 of The State of Food Security and Nutrition in the World 2020 (FAO, IFAD, UNICEF, WFP and WHO, 2020). Methods and data sources are detailed in the text.

Source: Authors' own elaboration.

Annex 4. Lower- and upper-bound estimates of the number of people who cannot afford each diet type

The lower-bound estimate for the number of people who cannot afford each diet type is calculated assuming 100 percent of income spent on food; that is, the lower bound counts the number of people who have total daily income lower than the cost of a given diet (Table A4.1). By this calculation, 1.86 billion people would be unable to afford healthy diets.

Because people do not spend all of their income on food, our main estimate assumes 37 percent of income needs to be spent on non-food items such as housing and agriculture. However, many people need to spend more than this amount on non-food items, and would not be able to spend 63 percent of income on food, particularly in higher-income countries where food expenditures are typically lower than 30 percent and housing costs are high. Therefore, we calculate upper-bound estimates as the mean food expenditure share across countries within World Bank income groupings. The mean share of expenditure on food is 14.9 percent, 27.9 percent, 42.3 percent, and 50.2 percent for high-, upper-middle-, lower-middle- and low-income countries, respectively.[15] We define income needed as the income that would be required to afford both a healthy diet and other non-food needs, based on the cost of the healthy diet and holding the food/non-food share constant. We calculate income needed using the following formula: [Cost of the diet / food expenditure share in World Bank country income classification]. For example, if the cost of a healthy diet is USD 3 in a given low-income country, where food expenditures are on average 50 percent of total expenditures, income would need to be USD 6 to afford both the healthy diet and non-food needs. This upper-bound estimation is shown in Table A4.2. By this calculation, 4.75 billion people would not be able to afford healthy diets.

TABLE A4.1 Lower-bound estimate of the number of people (in millions) who cannot afford the cost of each diet, by region and country income group

	Energy sufficient diet	Nutrient adequate diet	Healthy diet
Macroregion			
Africa	59.62	413.55	754.34
Asia	2.81	184.05	1 050.71
Latin America and the Caribbean	4.24	31.02	49.41
Northern America and Europe	4.49	7.25	9.60
Oceania	0.06	0.13	0.24
Subregion			
Australia and New Zealand	0.06	0.12	0.12
Central Asia	0.01	0.44	2.43
Eastern Asia	1.52	3.14	53.93
Eastern Europe	0.24	1.23	2.24

15 The median food expenditure shares are 14 percent, 25 percent, 41 percent and 51 percent for the four income levels, which are quite close to the mean.

TABLE A4.1 (cont.) **Lower-bound estimate of the number of people (in millions) who cannot afford the cost of each diet, by region and country income group**

	Energy sufficient diet	Nutrient adequate diet	Healthy diet
Latin America and the Caribbean	4.24	31.02	49.41
Melanesia	0.00	0.01	0.12
Northern Africa	0.42	43.70	86.44
Northern America	3.25	4.15	4.24
Northern Europe	0.12	0.20	0.24
South-eastern Asia	0.28	43.13	182.28
Southern Asia	0.98	136.13	800.23
Southern Europe	0.86	1.60	2.58
Sub-Saharan Africa	59.20	369.85	667.90
Western Asia	0.01	1.21	11.84
Western Europe	0.03	0.07	0.31
Country income group			
High-income countries	5.71	8.36	11.00
Low-income countries	17.13	207.05	403.74
Lower-middle countries	40.82	373.21	1 316.69
Upper-middle countries	7.56	47.38	132.87
World	**71.22**	**636.01**	**1 864.30**

Notes: Data shown are the number of people in each region whose household income is below the cost of the most affordable locally available items needed to meet each standard of diet quality, assuming that they can spend 100 percent of their income on food. Methods and data sources are detailed in the text.

Source: Authors' own elaboration.

TABLE A4.2 Upper-bound estimate of the number of people (in millions) who cannot afford the cost of each diet, by region and country income group

	Energy sufficient diet	Nutrient adequate diet	Healthy diet
Macroregion			
Africa	267.12	866.74	1 081.54
Asia	199.94	1 684.12	3 033.55
Latin America and the Caribbean	39.14	224.31	304.14
Northern America and Europe	10.01	67.50	154.33
Oceania	0.16	0.88	1.43
Subregion			
Australia and New Zealand	0.12	0.36	0.68
Central Asia	0.27	6.68	19.31
Eastern Asia	26.00	258.23	886.97
Eastern Europe	0.94	23.20	68.02
Latin America and the Caribbean	39.14	224.31	304.14
Melanesia	0.04	0.52	0.75
Northern Africa	10.38	134.50	182.95
Northern America	6.77	17.16	32.69
Northern Europe	0.28	2.09	4.60
South-eastern Asia	40.01	283.15	463.27
Southern Asia	124.66	1 088.04	1 583.58
Southern Europe	1.93	21.48	39.15
Sub-Saharan Africa	256.74	732.23	898.59
Western Asia	8.99	48.02	80.42
Western Europe	0.09	3.57	9.87
Country income group			
High-income countries	23.35	101.88	212.17
Low-income countries	81.88	423.79	533.76
Lower-middle countries	327.06	1 755.80	2 497.58
Upper-middle countries	84.09	562.07	1 331.47
World	**516.38**	**2 843.54**	**4 574.98**

Notes: Data shown are the number of people in each region whose household income is below the cost of the most affordable locally available items needed to meet each standard of diet quality, assuming that they can spend the national average expenditure share of their income on food (14.9 percent, 27.9 percent, 42.3 percent and 50.2 percent for high-, upper-middle-, lower-middle- and low-income countries, respectively). Methods and data sources are detailed in the text.

Source: Authors' own elaboration.

Annex 5. Nutrient adequacy of the selected diets

The healthy diet results were analysed for mean adequacy ratio (MAR) across 20 nutrients that have a lower bound. For included nutrients, please refer to Table 1.

TABLE A5.1 Percent of nutrient needs met by healthy diets (mean adequacy ratio)

	MAR_HAR		MAR_RDA	
	mean	sd	mean	sd
Macroregion				
Africa	0.93	0.03	0.88	0.04
Asia	0.94	0.04	0.89	0.06
Latin America and the Caribbean	0.94	0.04	0.89	0.06
Northern America and Europe	0.94	0.03	0.89	0.04
Oceania	0.94	0.03	0.89	0.04
Food-based dietary guidelines				
Argentina	0.91	0.04	0.84	0.05
Benin	0.93	0.03	0.89	0.04
China	0.95	0.03	0.90	0.05
India (moderate woman)	0.93	0.04	0.87	0.05
Jamaica	0.93	0.04	0.88	0.05
Malta	0.91	0.04	0.85	0.05
Netherlands	0.94	0.03	0.89	0.04
Oman (at 2 300 kcal level)	0.93	0.04	0.88	0.04
USA (American style at 2 300 kcal level)	0.96	0.03	0.92	0.04
USA (Mediterranean style at 2 300 kcal level)	0.96	0.03	0.93	0.04
USA (Vegetarian style at 2 300 kcal level)	0.97	0.02	0.93	0.03
Viet Nam	0.93	0.03	0.88	0.04
World	**0.94**	**0.04**	**0.89**	**0.05**

Source: Authors' own elaboration.

Annex 6. Methodological note on constructing a nutritious food poverty line in Myanmar

In order to construct a healthy diet (CoRD) and healthy diet with food preferences (CoRD-FP) comparable to the 2015 Myanmar food poverty line and total poverty line, we closely adhere to the methodology and the following details outlined in the World Bank's poverty estimation technical report (MoPF and World Bank, 2017b): the reference poor population (households with expenditure within 10 percentage points of the poverty line); the food poverty line calorie target (2 238 calories); the composition of the food basket; the caloric content of foods; and wastage factors.

The CoRD is designed to reflect the cost of the cheapest foods within each food group and is typically constructed using data comprising commonly available foods. The CoRD-FP reweights food consumption patterns to meet dietary guidelines and as such places greater weight on non-staple food groups. The fish/meat/eggs, fruits, and vegetable food groups tend to have a wide variety of foods with a wide distribution of prices. To reduce the influence of atypically costly and/or rarely consumed foods, we limit the CoRD and CoRD-FP food baskets to items within the top 85 percent of total food expenditure within each food group.

For consistency with the 2015 Myanmar total poverty line, the World Bank non-food allowance of 436 kyat per capita per day is added to the CoRD-FP to yield a CoRD-FP poverty line (MoPF and World Bank, 2017a). Affordability of the World Bank, CoRD and CoRD-FP food baskets is assessed by comparing spatially adjusted per capita household food expenditure to the cost of each food basket. Official poverty and CoRD-FP poverty headcounts are assessed by comparing spatially adjusted per capita household total expenditure to each poverty line.

The World Bank poverty line food basket includes prepared foods purchased for consumption at home and food away from home (FAFH). Because it is not possible to classify prepared foods and FAFH into food groups, the CoRD-FP basket must exclude these items. In order to compare the composition of the poverty line food basket to the CoRD and CoRD-FP food baskets, a new poverty line basket is constructed, which excludes FAFH and is then rescaled to hit the 2 238 calorie target.

Annex 7. Data and methods to simulate impacts of policy change on diet costs

Data sources

Agricultural market distortions are modelled using estimates of nominal rates of protection for 62 countries and 58 food products. The nominal rate of protection (NRP) is calculated using the difference between observed border price and farm-gate price, after accounting for market access costs. This difference primarily represents international trade barriers, though other policies such as price interventions or exchange rate management may also play a role (Pernechele, Balié and Ghins, 2018). Nominal rates of protection are compiled, harmonized and published by the AgIncentives Consortium with data and input from the World Bank, Agrimonitor at the Inter-American Development Bank, the Monitoring and Analysing Food and Agricultural Policies (MAFAP) unit at FAO, and the Organisation for Economic Co-operation and Development.

Retail price data is from the 2011 round of the World Bank's International Comparison Project (ICP). The NRP values used to match 2011 and 2017 ICP retail prices are drawn from the four years leading up to and including each year. We have updated the publicly available NRP data using MAFAP file data, resulting in the addition of data for 2017 and several observations for poultry meat and sesame seed in Mozambique from earlier years. Additionally, there are several significant revisions to existing publicly available NRP data for sub-Saharan African countries. The final dataset includes 3 581 total observations across all eight years, with 2 154 observations in 2008–2011 and 1 427 observations for 2014–2017. One limitation of the 2017 simulation is that the AgIncentives NRP data extends only through 2016. 2017 observations come only from the MAFAP file data, which covers 14 sub-Saharan African countries.

After compiling all available data, we impose a validity check on any negative NRP values in the dataset to retain only those values which could plausibly be sustained over time by export restrictions. We check that for each negative NRP for a given product in a given country, that country has had positive net exports of the product in that year or any one of the three years prior. Products are matched by FAO commodity list code to FAO export and import data (FAO, 2020c). In seven cases, where a product in the AgIncentives NRP dataset had no exact match in the FAO trade data, the closest match from that commodity group was chosen. In three cases where trade data was missing for a product with negative NRP values, products were matched to the corresponding HS-6 codes and UN Comtrade data was used to assess export and import levels (accessed through USDA, 2020). We assume that any negative NRPs where the country did not competitively export the product within the four years leading up to or including that year to be temporary outliers or measurement errors, and we trim these values to zero. In total, we trimmed 185 negative observations across the eight years considered in the study.

Countries and number of observations are listed in Table A7.1, which also shows 2011 and 2017 income classifications for results reported in the main text. We use World Bank country income classifications as the basis for four income groups. Income group is chosen over regional group because region classifications vary considerably in the heterogeneity of their components. Some, like Southern Asia, are relatively alike, while others, like East Asia and Pacific, are very diverse. Table A7.1 lists the 62 countries by income group and shows the total number of NRP observations for each time period for each country. Two-thirds (65.1 percent) of the data are from high-income and upper-middle-income countries. There are relatively few observations for low-income countries (13.1 percent), pointing to the need for better data on the implications of agricultural policies in these countries. Observations are particularly sparse for nutrient-dense food groups such as fruits, vegetables, and dairy.

Items in the price dataset are matched to one of nine functional food groups listed in Table A7.2. Table A7.2 lists all of the 58 foods in the dataset by food group classification. Analysing nutrient adequacy requires the use of nutritionally functional food groups. For example, vegetables are typically grouped into leafy green vegetables, red-orange vegetables, and other vegetables based on their differing micronutrient profiles. Palm oil, vegetable oils, and leguminous crops like peanuts and soybean would be treated separately as sources of saturated fat, unsaturated fat and protein, respectively. This analysis cannot capture such levels of nuance due to the limited number of foods in the NRP dataset. We classify foods based broadly on nutritional function, with some aggregations: all vegetables are grouped together, and oil crops that may be used to produce either oil or other food items, such as groundnuts and soybean, are grouped together as nuts and oilseeds. Though there are relatively few observations of eggs compared to other food groups, we treat them as a separate food group both due to nutritional differences between eggs and poultry meat and because the value chains for these products have significant differences. For low-income countries, we do not observe any NRPs for eggs, so we instead use the average NRP for eggs in the sub-Saharan Africa region. The low-income country group has a majority of countries from this region and may have similar policies due to regional trade agreements.

TABLE A7.1 Countries by income group and number of nominal rate of protection observations, 2008–2011 and 2014–2017

	2011		2017	
	countries	obs.	countries	obs.
High-income countries	Australia	60	Argentina	27
	Bahamas	16	Australia	45
	Barbados	8	Bahamas	8
	Canada	60	Barbados	8
	European Union	68	Canada	45
	Iceland	24	Chile	30
	Israel	60	European Union	51
	Japan	76	Iceland	18
	Republic of Korea	40	Israel	45
	New Zealand	40	Japan	57
	Norway	36	Republic of Korea	30
	Switzerland	44	New Zealand	30
	Trinidad and Tobago	22	Norway	27
	USA	52	Panama	20
			Switzerland	33
			Trinidad and Tobago	22
Total		**606**		**565**

TABLE A7.1 (cont.) Countries by income group and number of nominal rate of protection observations, 2008–2011 and 2014–2017

	2011		2017	
	countries	**obs.**	**countries**	**obs.**
Lower-middle-income countries	Belize	10	Ghana	21
	Bolivia (Plurinational State of)	16	India	57
	El Salvador	28	Indonesia	24
	Ghana	24	Kenya	31
	Guatemala	52	Nigeria	8
	Guyana	14	Philippines	33
	Honduras	9	Sri Lanka	7
	India	76	Ukraine	39
	Indonesia	48	Viet Nam	24
	Nicaragua	18		
	Nigeria	16		
	Pakistan	31		
	Paraguay	26		
	Philippines	44		
	Senegal	12		
	Sri Lanka	28		
	Ukraine	52		
	Viet Nam	32		
Total		**536**		**244**
Upper-middle-income countries	Argentina	36	Belize	10
	Brazil	36	Brazil	27
	Chile	40	China	42
	China	56	Colombia	33
	Colombia	44	Costa Rica	27
	Costa Rica	36	Dominican Republic	30
	Dominican Republic	40	Ecuador	18
	Ecuador	24	Guyana	5
	Jamaica	48	Jamaica	12
	Kazakhstan	48	Kazakhstan	36
	Mexico	56	Mexico	42
	Panama	20	Russian Federation	39
	Peru	32	South Africa	42
	Russian Federation	52	Suriname	9

▸▸

TABLE A7.1 (cont.) Countries by income group and number of nominal rate of protection observations, 2008–2011 and 2014–2017

	2011		2017	
	countries	obs.	countries	obs.
Upper-middle-income countries	South Africa	56	Turkey	42
	Suriname	36		
	Turkey	56		
	Uruguay	30		
Total		**746**		**414**
Low-income countries	Benin	8	Benin	10
	Burkina Faso	28	Burkina Faso	25
	Burundi	18	Burundi	18
	Ethiopia	36	Ethiopia	31
	Haiti	32	Malawi	12
	Kenya	36	Mali	25
	Malawi	11	Mozambique	21
	Mali	28	Rwanda	15
	Mozambique	18	Senegal	16
	Rwanda	15	United Republic of Tanzania	13
	United Republic of Tanzania	16	Uganda	18
	Uganda	20		
Total		**266**		**204**

Total observations across all countries 2008–2011: 2 154
Total observations across all countries 2014–2017: 1 427

Source: Authors' own elaboration.

TABLE A7.2 Summary of nominal rates of protection data by food group and product

Food group	Product	Nominal rate of protection 2008–2011				Nominal rate of protection 2014–2017			
		Obs.	Median	Min.	Max.	Obs.	Median	Min.	Max.
Dairy	Milk	160	6.1	-68.5	204.6	98	3.4	-56.0	361.7
Eggs	Eggs	110	8.2	-48.4	309.6	73	0.0	-13.3	346.2
Fruits	Bananas	56	0.0	-72.8	72.6	29	0.0	-58.8	109.7
	Grapes	26	0.0	0.0	199.5	18	0.0	0.0	140.6
	Apples	24	7.2	0.0	113.8	18	0.0	0.0	69.7
	Pineapples	20	0.0	-69.8	77.1	13	0.0	-59.8	113.7
	Oranges	19	0.0	0.0	235.5	10	0.0	0.0	287.7
	Mangoes	16	0.0	-23.6	16.4	7	0.0	-49.6	0.0
	Avocados	10	9.6	0.0	339.1	7	72.4	0.0	161.5
	Coconuts	10	-12.6	-32.5	38.0	5	-17.5	-32.3	42.4
	Grapefruit (including pomelos)	6	0.0	0.0	34.8	4	0.0	0.0	0.0
	Other melons (including cantaloupes)	4	-30.0	-37.1	-27.0	N/A	N/A		
	Pears	4	129.9	79.5	187.8	3	72.7	69.0	86.1
	Strawberries	4	15.5	6.0	24.9	3	11.7	8.1	11.8
	Tangerines, mandarins, clementines	4	88.5	31.2	117.7	3	41.8	29.6	42.9
	Papayas	2	4.2	-27.4	35.9	2	18.0	-0.5	36.5
Grains	Maize	165	0.0	-76.1	351.1	115	0.0	-67.9	189.2
	Rice	157	11.7	-54.6	258.6	107	29.8	-71.4	216.3
	Wheat	106	0.0	-43.9	95.9	76	0.0	-52.4	145.8
	Barley	63	0.0	-43.3	146.2	48	0.0	-30.1	248.1
	Sorghum	37	0.0	-85.0	156.0	27	0.0	-37.5	72.5
	Oats	28	0.0	-45.0	100.5	21	0.0	-25.2	83.7
	Rye	8	-7.5	-37.0	13.5	6	-9.6	-22.9	6.3
	Millet	4	3.4	-6.8	8.9	4	-2.5	-10.4	5.6
	Teff	4	-24.1	-50.4	-12.6	4	69.7	60.0	97.4
Nuts and oilseeds	Soybeans	57	0.0	-36.3	990.5	38	0.0	-40.4	478.7
	Groundnuts	36	0.0	-56.0	180.9	32	0.0	-47.5	108.0
	Sunflower seed	32	0.0	-43.1	19.6	24	0.0	-44.9	75.1
	Rapeseed	24	0.0	-24.2	159.2	18	0.0	-9.7	86.2
	Palm oil	18	0.0	-22.7	25.7	12	0.7	-11.5	41.8
	Cashew nuts	16	0.0	-22.6	34.6	13	-26.4	-54.2	71.2
	Sesame seed	8	3.0	-19.2	18.1	10	21.9	-33.7	118.7

▸▸

TABLE A7.2 (cont.) **Summary of nominal rates of protection data by food group and product**

Food group	Product	Nominal rate of protection 2008–2011				Nominal rate of protection 2014–2017			
		Obs.	Median	Min.	Max.	Obs.	Median	Min.	Max.
Pulses	Beans, dry	45	27.4	-12.7	186.3	26	2.6	-46.3	330.4
	Chickpeas, dry	8	0.4	0.0	1.9	3	8.0	0.0	10.7
	Lentils, dry	8	0.0	-13.0	97.5	7	0.0	0.0	90.7
	Peas, dry	4	0.0	0.0	0.0	3	0.0	0.0	0.0
	Pulses, not elsewhere specified	4	0.0	0.0	0.0	3	0.0	0.0	0.0
Poultry	Poultry meat	152	30.2	-19.2	512.2	99	15.1	0.0	484.5
Red meat	Bovine meat	166	0.0	-48.9	152.7	101	1.5	-41.7	231.5
	Pig meat	133	16.0	0.0	293.3	82	11.8	0.0	235.3
	Sheep meat	59	0.0	0.0	69.0	44	5.3	0.0	170.3
Roots, tubers and plantains	Potatoes	51	0.1	-48.7	599.5	33	0.0	-71.8	325.8
	Cassava	35	0.0	-28.8	153.6	24	10.7	-16.5	127.4
	Yams	13	0.0	-37.0	62.5	5	0.0	-71.3	112.5
	Plantains	12	7.1	-10.6	38.2	8	28.8	0.0	54.8
	Sweet potatoes	11	36.0	0.0	137.0	4	145.8	0.0	173.4
Sweeteners	Sugar	116	12.4	-71.6	208.8	77	26.1	-61.8	147.5
	Honey	6	-16.9	-40.3	108.8	2	206.4	179.4	233.4
Vegetables	Tomatoes	37	0.0	-48.0	129.1	21	0.0	-57.8	29.6
	Onions	22	18.5	-47.3	342.3	15	5.0	-42.3	239.4
	Cabbages and other brassicas	8	126.2	27.0	314.1	6	126.5	27.0	245.2
	Chillies and peppers	8	125.2	0.0	403.9	4	183.8	-32.3	187.8
	Beans, green	4	-40.5	-65.6	-26.1	2	-54.5	-55.1	-53.8
	Cucumbers and gherkins	4	17.5	3.0	52.6	3	3.0	3.0	3.0
	Spinach	4	3.0	3.0	3.0	3	3.0	3.0	3.0
	Asparagus	2	0.0	0.0	0.0	N/A	N/A		
	Pumpkins, squash and gourds	2	42.3	-43.0	127.7	2	-25.9	-38.3	-13.6
	Vegetables: fresh, not elsewhere specified	2	223.6	136.9	310.3	2	122.7	58.7	186.6

Source: Authors' own elaboration.

Data analysis

We first collapse the NRP observations from 2008–2011 and 2014–1207 for all countries and products into a set of mean protection rate by income level for each food group. Because the NRP is measured at the farm-gate level and our price data is at the retail level, we assume 100 percent as a lower bound of markup from farm gate to retail and 300 percent as an upper markup bound. Assuming that the rate of protection applies only to the farm-gate portion of the retail price, we compute a reference price for each retail food item as follows:

$$P_r' = m\left(\frac{P_r}{1+m}\right) + \frac{P_r}{(1+\tau)(1+m)} \tag{1}$$

where:

m = assumed markup from wholesale to retail

τ = nominal rate of protection (NRP)

P_r = observed ICP retail price.

We calculate a wholesale price (Pw) based on observed retail price and assumed markup:

$$P_w = \frac{P_r}{1+m} \tag{2}$$

Assuming the additional cost due to markup remains constant as a cost of retail supply, $P_s = mP_w$, we can adjust the P_w to reflect a zero-distortion scenario as follows:

$$P_w' = \frac{P_w}{1+\tau} \tag{3}$$

then add the constant cost of retail supply to obtain an adjusted retail price, which we label a reference price:

$$P_r' = P_s + P_w' \tag{4}$$

Substituting equations 2 and 3 into equation 4, we obtain equation 1. Because we do not have an observed wholesale price, we keep the component of the price attributed to the markup from wholesale to retail (Ps) constant for the purposes of this simulation. We calculate two reference prices based on an income-group NRP imputation at 100 percent and 300 percent markup for each of the 159 and 170 countries in the ICP datasets for 2011 and 2017, respectively. Reference prices are then used to calculate a new cost of nutrient adequacy for each country.

9

FAO AGRICULTURAL DEVELOPMENT ECONOMICS TECHNICAL STUDY

Price and affordability are key barriers to accessing sufficient, safe, nutritious food to meet dietary needs and food preferences for an active and healthy life. In this study, the least-cost items available in local markets are identified to estimate the cost of three diet types: energy sufficient, nutrient adequate, and healthy (meeting food-based dietary guidelines). For price and availability the World Bank's International Comparison Program (ICP) dataset is used, which provides food prices in local currency units (LCU) for 680 foods and non-alcoholic beverages in 170 countries in 2017. In addition, country case studies are developed with national food price datasets in United Republic of Tanzania, Malawi, Ethiopia, Ghana and Myanmar.

The findings reveal that healthy diets by any definition are far more expensive than the entire international poverty line of USD 1.90, let alone the upper bound portion of the poverty line that can credibly be reserved for food of USD 1.20. The cost of healthy diets exceeds food expenditures in most countries in the Global South. The findings suggest that nutrition education and behaviour change alone will not substantially improve dietary consumption where nutrient adequate and healthy diets, even in their cheapest form, are unaffordable for the majority of the poor. To make healthy diets cheaper, agricultural policies, research, and development need to shift toward a diversity of nutritious foods.

The FAO Agricultural Development Economics Technical Study series collects technical papers addressing policy-oriented assessments of economic and social aspects of food security and nutrition, sustainable agriculture and rural development.

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ECONOMICS

Seasonality of diet costs reveals food system performance in East Africa

Yan Bai, Elena N. Naumova, William A. Masters*

Seasonal fluctuations in food prices reflect interactions between climate and society, measuring the degree to which predictable patterns of crop growth and harvest are offset by storage and trade. Previous research on seasonality in food systems has focused on specific commodities. This study accounts for substitution between items to meet nutritional needs, computing seasonal variation in local food environments using monthly retail prices for 191 items across Ethiopia, Malawi, and Tanzania from 2002 through 2016. We computed over 25,000 least-cost diets meeting nutrient requirements at each market every month and then measured the magnitude and timing of seasonality in diet costs. We found significant intensity in Malawi, Tanzania, and Ethiopia (10.0, 6.3, and 4.0%, respectively), driven primarily by synchronized price rises for nutrient-dense foods. Results provide a metric to map nutritional security, pointing to opportunities for more targeted investments to improve the year-round delivery of nutrients.

INTRODUCTION

High food prices limit consumption and harm well-being for low-income people (*1*–*3*). This study addresses the predictable component of price fluctuations, focusing on recurring seasonal peaks of consistent timing and intensity (*4*). All kinds of food price volatility may affect nutrition and health (*5*–*8*), but seasonality is of particular interest because it measures the degree to which people have improved agriculture and food systems sufficiently to overcome predictable climate fluctuations. Improvements in storage and transport have helped stabilize prices over time (*9*, *10*), but there remains significant seasonality in wholesale prices at many market locations in Africa (*11*). This study measures seasonal variation in retail prices across all food groups and diet costs in a way that allows substitution among items to meet nutrient needs.

Our study uses government file data on monthly retail prices and harmonic regression analysis to measure the timing and intensity of seasonality in three East African countries, Tanzania, Malawi, and Ethiopia, chosen because of their vulnerability to malnutrition and also variation in geography north and south of the equator, as well as variation in altitude and distance from ocean ports or land transport routes. The inclusion of these three countries is also due to availability of relatively high quality of food price data. From Tanzania, we have prices for 61 foods at 21 market locations from 2011 through 2015; in Malawi, we have 48 foods at 29 markets from 2007 through 2016; and in Ethiopia, prices are for 82 foods at 120 markets from 2002 through 2016. The total number of market-month observations is 3480 in Malawi, 1236 in Tanzania, and 20,806 in Ethiopia. Our harmonic model uses sine and cosine functions to estimate smooth, symmetric fluctuations of each item's price or diet costs over time, in this case, with one cycle each year reflecting the region's unimodal rainfall (Fig. 1A). The seasonal intensity of price variation is the difference between its annual peak and nadir normalized to a unit-free percentage of the nadir. This approach allows us to measure the magnitude and timing of peaks for different combinations of foods at different locations, using 95% confidence intervals (CIs) around the estimated intensity to test for statistical significance.

Friedman School of Nutrition Science and Policy, Tufts University, Boston, MA 02111, USA.
*Corresponding author: Email: william.masters@tufts.edu

The prices we use were originally collected to measure inflation for each country's consumer price index and are repurposed here to track the least-cost sources of 21 essential nutrients and dietary energy in the proportions needed for an active and healthy adult woman. We and others focus on diet costs for women of reproductive age because they are often at risk of malnutrition, with severe consequences for themselves and for child health (*12*). To allow for substitution among foods in delivering nutrients, we computed the least-cost combination of foods at each place and time needed to meet all requirements, and compared that to bare subsistence cost of daily energy from starchy staples only (*13*, *14*). Each food list includes a wide variety of nutrient sources, including starchy staples, pulses/nuts/seeds, animal foods, fruits/vegetables, oils/fats, and sweets. Not all foods are available at each market every month, but only 102 of the 25,522 market-months in our study had an insufficient variety of foods to meet all nutrient needs, and all of those were in Ethiopia. After computing least-cost diets, we used harmonic regression to extract the seasonal component of variation in cost of nutrients and daily energy at each location, and report differences in timing and intensity as a metric of food system performance and vulnerability to climatic fluctuations. Our method would also be useful to identify price anomalies due to disruptions such as armed conflict or disease outbreaks.

Measuring seasonality in the cost of nutrients over all major food groups, allowing for substitution among items as their relative prices change, allows us to compare the ability of local farmers and traders to deliver year-round access to all essential nutrients in the proportions needed by people. This permits us to quantify the nutritional performance of local agroecosystems, distinguishing nutrition security from food security, and identify how each type of food contributes to seasonal variation so as to guide interventions that could improve year-round access to a nutritious diet.

RESULTS

Seasonality of individual food prices

The timing of harvest leads to seasonality in prices at each market location, if not offset by storage and trade with other places. Figure 1A reveals the national average pattern in rainfall and temperature over each calendar year. Tanzania and Malawi have a cooler dry season

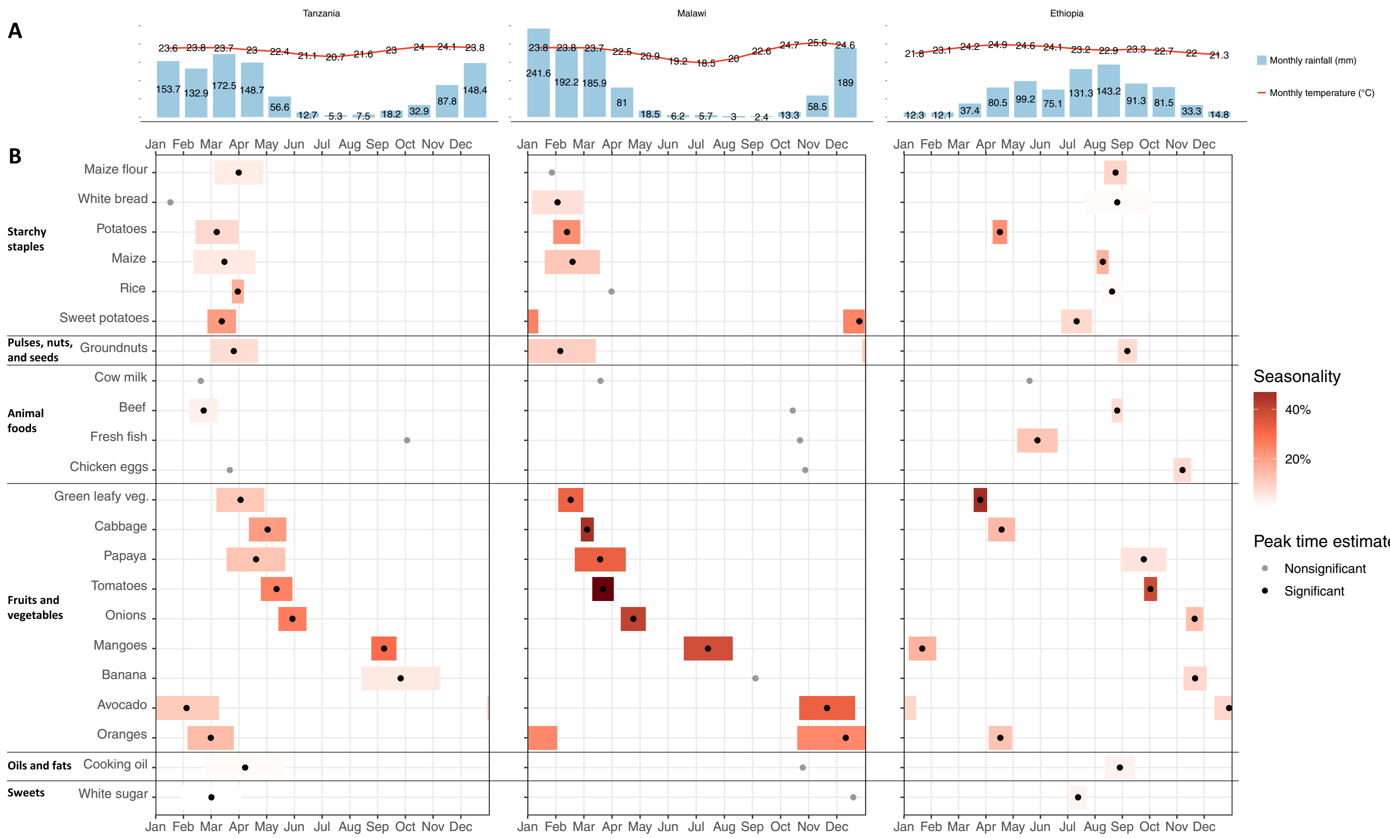

Fig. 1. Intensity and timing of seasonality in market prices for commonly consumed foods in Tanzania, Malawi, and Ethiopia. (**A**) National average monthly rainfall (in millimeters) and temperature (in degrees Celsius) between 1991 and 2016 (*32*). (**B**) Ninety-five percent confidence intervals (CIs) around the peak month for each food, shown as a black dot, with the magnitude of intensity shown by the color gradation of each bar. Gray dots show the peak month for foods without statistically significant harmonic seasonality. Price variation is estimated from data in local currency units (LCUs) per item, on average over all market locations in each country shown.

approximately from May to October, and Ethiopia, located north of the equator, has a dry season from November to March. We found that these recurring cycles lead to statistically significant seasonality in most food items in all three countries (36 of 61 items in Tanzania, 31 of 48 items in Malawi, and 72 of 82 items in Ethiopia; tables S1 to S3).

To visualize these data in Fig. 1B, we show the estimated seasonal intensity and peak timing for 22 standard items from six major food groups. Fruits and vegetables generally have stronger seasonality than other food groups, especially in Malawi. For example, tomatoes have a high seasonal intensity of 25.8% (18.7%, 33.3%) in Tanzania, 60.3% (46.1%, 75.9%) in Malawi, and 38.7% (31.7%, 46.2%) in Ethiopia. High seasonal intensities were also found in prices of locally representative dark leafy vegetables, notably 12.8% (7.5%, 18.4%) for mchicha (amaranth leaves) in Tanzania, 32.7% (22.2%, 44.2%) for rape leaves and 20.7% (10.7%, 31.6%) for pumpkin leaves in Malawi, and 46.9% (38.0%, 56.4%) for kale in Ethiopia. Potatoes and sweet potatoes also have high seasonality in their prices, while cereal grains and pulses, nuts, and seeds have less seasonal fluctuation, and animal-sourced foods have little or no seasonality in these data. Seasonal peaks in Tanzania and Malawi were synchronized for starchy staples and pulses/nuts/seeds in the late rainy seasons before harvesting, while fruits and vegetables have diverse price peaks that could help to stabilize diet costs if they offer similar nutrients, allowing substitution among them over the course of each year.

Seasonality of diet costs

The ability of local food systems to deliver all nutrients needed for health is revealed by the cost of nutrient adequacy from all foods, which we abbreviate CoNA. We compare that to the cost of caloric adequacy from starchy staples, abbreviated CoCA, which is what would be needed for bare subsistence at each location every month. National average levels of CoNA over the period of observation were TZS (Tanzanian shilling) 912.1 [$1.50 in 2011 USD (U.S. dollar) at purchasing power parity (PPP) prices] in Tanzania, MWK (Malawian kwacha) 129.6 ($1.21) in Malawi, and ETB (Ethiopian birr) 6.74 ($1.34) in Ethiopia. These costs were 2.41, 3.11, and 3.49 times the country's average level of CoCA required for subsistence (tables S4 to S6).

Seasonal fluctuation in the overall cost of all nutrients is large and statistically significant. As shown in Fig. 2A and tables S4 to S6, seasonality was much stronger in Malawi with a seasonal intensity of 10.0% (5.7%, 14.6%), compared to 6.3% (3.7%, 9.0%) in Tanzania and 4.0% (2.5%, 5.5%) in Ethiopia. Seasonal intensities in CoCA were significant in all three countries. The intensity was strongest at 13.9% (12.2%, 15.6%) in Ethiopia, and 8.0% (1.5%, 14.9%) in Malawi and 5.9% (0.8%, 11.3%) in Tanzania. The premium for nutrients above dietary energy, measured by the gap between CoNA and CoCA, also has significant seasonality with an intensity of 6.3% (2.4%, 10.4%) in Tanzania, 9.0% (2.7%, 15.6%) in Malawi, and 5.3% (3.8%, 6.8%) in Ethiopia.

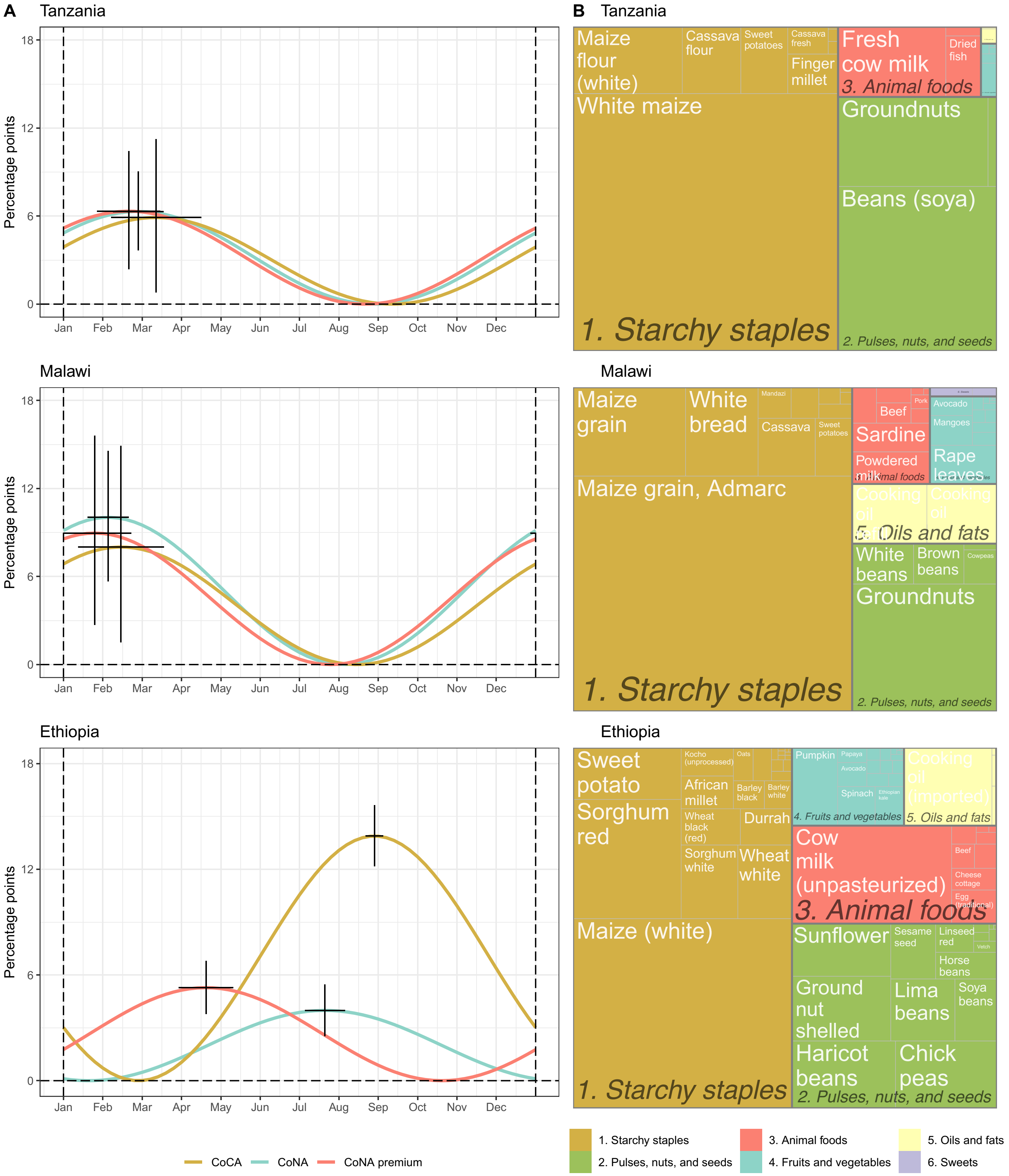

Fig. 2. Seasonality in diet costs and composition of least-cost nutrient adequate diets in East Africa. (**A**) Estimated harmonic seasonality over a 1-year cycle for the three indicators, with error bars showing 95% CIs around the magnitude of seasonal intensity along the vertical axis and peak month along the horizontal axis. (**B**) Average energy composition by food group and item of the least-cost diet selected for CoNA over all observations in each country. CoCA is a least-cost diet that meets energy needs using only starchy staples. The CoNA premium is the cost of meeting nutrient requirements beyond daily energy, defined as CoNA-CoCA, in LCUs per day.

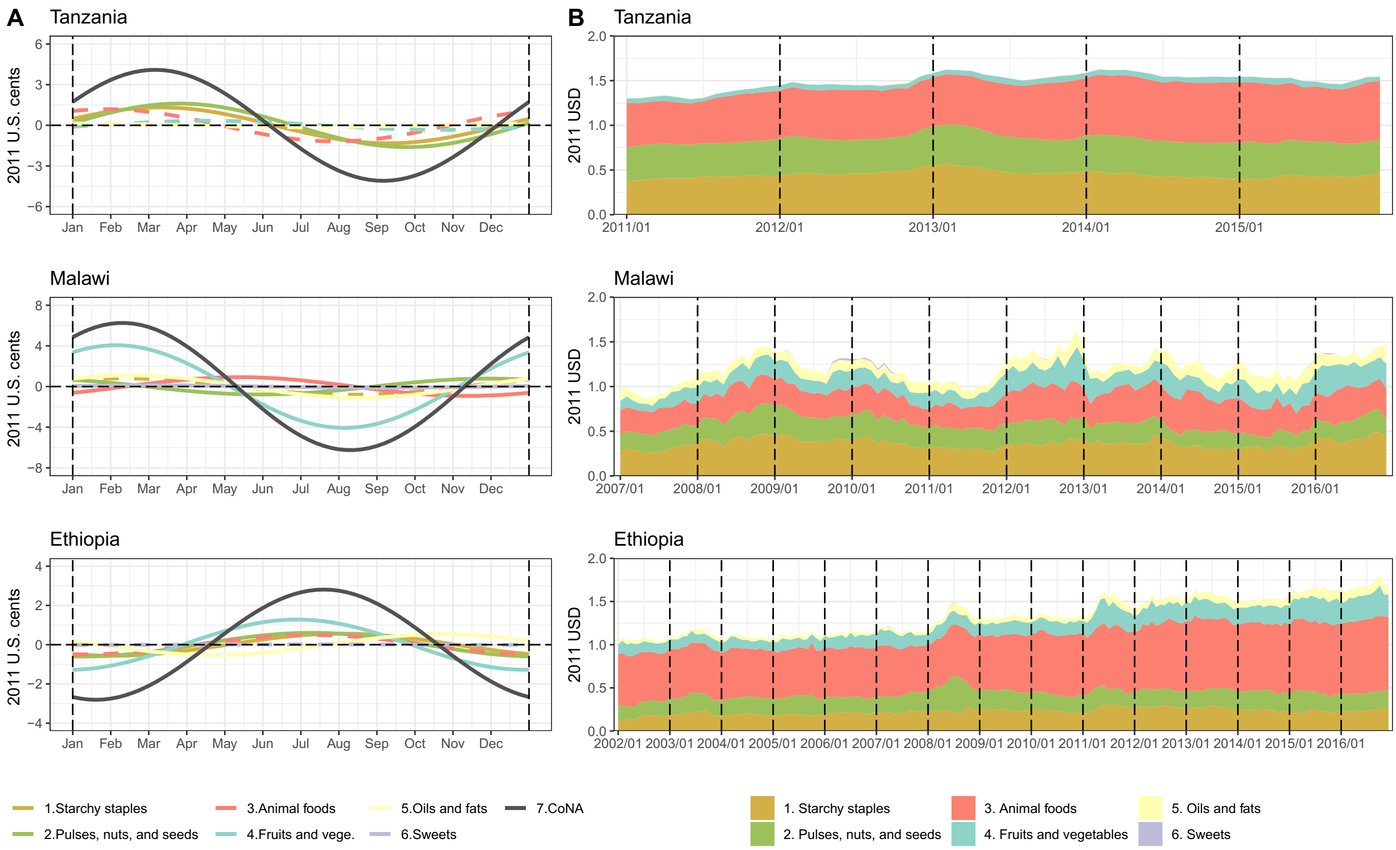

Fig. 3. Seasonality in diet costs by food group over time. (**A**) Estimated harmonic seasonality over a 1-year cycle for the overall CoNA and for the selected components of that diet from each of the six food groups. Dashed lines are not statistically significantly different from zero. (**B**) Contribution of each food group to the CoNA each month, averaged over all marketplaces in the country shown. Diet costs are converted to USD at PPP exchange rates.

Peak timings of the three indicators in Malawi and Tanzania were estimated to be about 3 months before the harvest season starting in May. In Ethiopia, although CoCA was estimated to peak in late August, which is about 2 months before the start of harvest season in November, CoNA and CoNA premium peaked earlier in late July and mid-April, respectively. The timing and magnitude of these peaks reflect the limited degree to which different foods can substitute for each other to deliver all required nutrients around the year. As shown in Fig. 3A, the cost of each food group in a least-cost diet varies over time, with high levels of overall seasonality in Malawi driven by its seasonality in fruit and vegetable prices. A different view of these substitutions is presented in Fig. 4, as each food group's contribution of total calories, which has significant seasonality in Malawi and Ethiopia but not in Tanzania. In Malawi, energy intake from starchy staples in CoNA becomes minimum before the harvest season and, therefore, more energy from fruits and vegetables, animal foods, and sweets. Figure 3B also reveals time trends in CoNA, for which the national averages increased from \$1.31 to \$1.56 over the 2011–2015 period in Tanzania, from \$0.96 to \$1.46 over the 2007–2016 period in Malawi, and from \$1.04 to \$1.68 over the 2002–2016 period in Ethiopia. In both Malawi and Tanzania, seasonality in the cost of fruits and vegetables contributed the most in the seasonality of CoNA (Fig. 3A), although fruits and vegetables do not take a large portion in total cost or energy of CoNA (Figs. 2B and 4B and tables S4 to S6).

Seasonal intensity in CoNA also presents great regional variations within countries. Regional results are shown in Figs. 5 and 6, where 12 of 21 regions in Tanzania, 14 of 25 districts in Malawi, and 27 of 57 zones in Ethiopia showed significant results. In Tanzania, the inland region of Singida and the west border region of Kigoma showed strong seasonality in CoNA with an intensity of 24.7% (8.2%, 43.7%) and 18.2% (9.9%, 27.2%). In Malawi, five districts suffered severe seasonality with an intensity of more than 20%, among which the Dowa district, close to the capital of Lilongwe City, showed a seasonal intensity of 35.2% (15.5%, 58.2%), and its peak timing was estimated approximately 1 month earlier than the national estimation. In Ethiopia, three zones had unusual higher seasonality in CoNA than the rest of the country, which are Kemashi with an intensity of 25.2% (16.9%, 34.1%) and Agnuak with an intensity of 27.7% (3.4%, 57.8%) on the west borders to Sudan and South Sudan, as well as Yem, a special woreda in the Southern Nations, Nationalities, and Peoples' Region, with a seasonal intensity of 36.7% (22.7%, 52.3%). Last, we note the role of variation in individual dietary requirements, which affects the level of cost but has little effect on seasonality. For example, a higher level of physical activity would require 12% more daily energy, which raised CoNA by about 4% but led to negligible differences in the timing or intensity of seasonality.

DISCUSSION

This paper introduced a combination of techniques to characterize spatiotemporal variation in food prices across three countries in East Africa, measuring the ability of local farmers and traders to

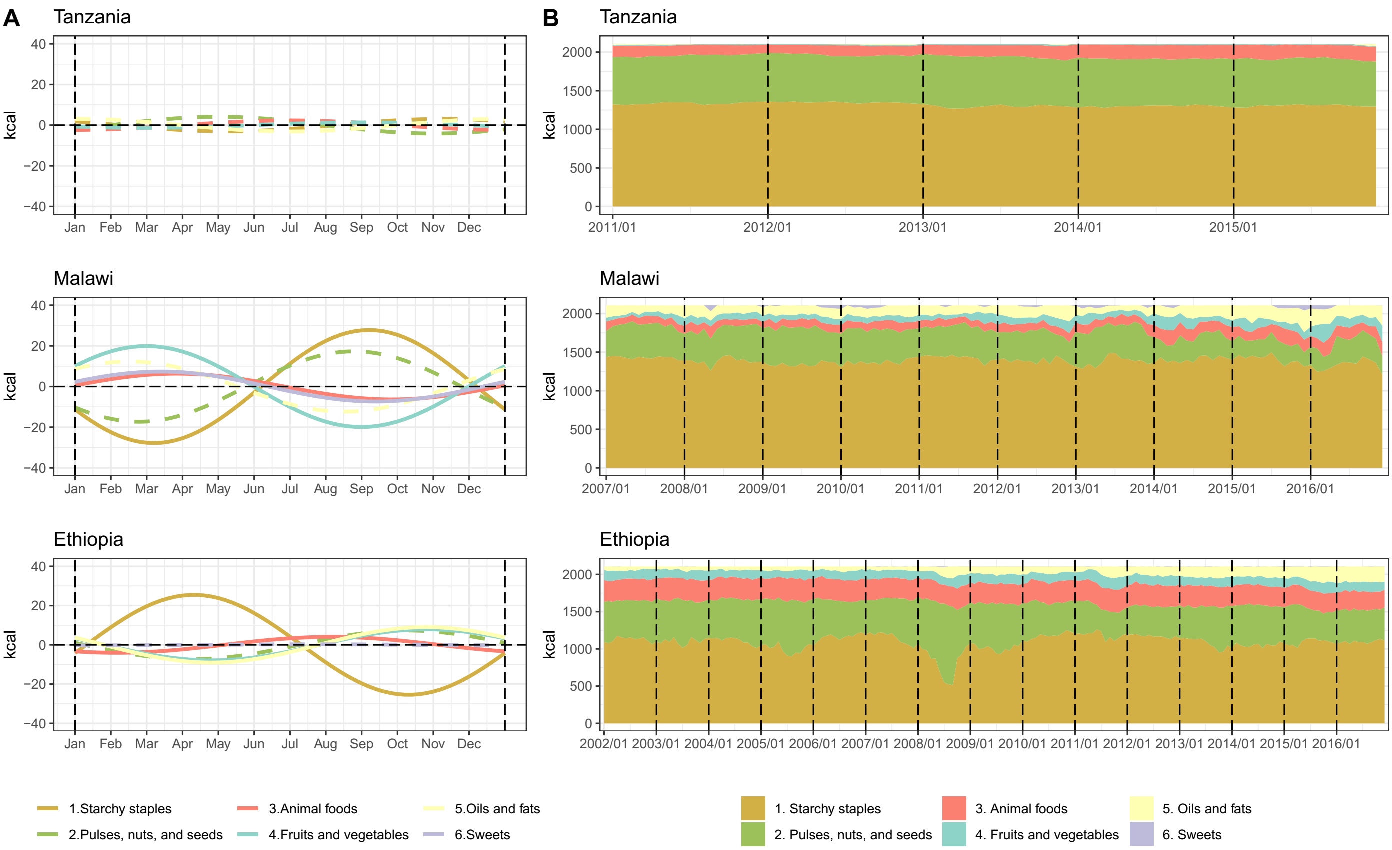

Fig. 4. Seasonality in the composition of least-cost diets by food group over time (in kilocalories per day). (**A**) Predicted seasonal curves over a year cycle of energy intakes in kilocalories from six food groups; the dashed line means insignificant result. (**B**) Average energy compositions of CoNA over markets contributed by six food groups. The total daily energy intake is 2107.6 kcal, required by a woman between 19 and 30 years old under low active physical activity level with a height of 163 cm and a weight of 57 kg.

achieve year-round delivery of all essential nutrients at low cost despite climatic fluctuations. We used government file data on a total of 191 items at 170 locations in various years from 2002 through 2016, solved for the least-cost combination of foods needed to meet requirements for 21 essential nutrients and dietary energy at each of 25,522 market-months, and then applied harmonic regression to estimate seasonal intensity and peak timing of diet costs at each location. Three important findings were found:

First, most individual foods have significant seasonality in retail prices, extending previous observations about major commodities to all food categories. Fruits and vegetables have the largest seasonal price variations, which averages over 20% for 7 of 21 items in Tanzania, 14 of 17 items in Malawi, and 8 of 24 items in Ethiopia. Items such as carrots, mangoes, papaya, oranges, avocado, tomatoes, green peppers, and onions are important not only for the essential nutrients they provide but also for other aspects of diet quality and local livelihoods. Foods that are more easily stored and transported, such as cereal grains and pulses, nuts, or seeds, have lower levels of seasonality than the highly perishable fruits and vegetables. We also find that seasonality in the prices of widely traded grains is lower on retail markets than previous studies had found in wholesale prices on commodity markets (*11*), implying that wholesale-to-retail margins help stabilize consumer prices. Nonetheless, peak times for various food groups tend to be synchronized before harvests in all three countries, limiting year-round access to all essential nutrients.

Next, even after allowing for substitution among foods, overall diet costs using the least-cost sources of nutrients and energy fluctuate seasonally in ways that are statistically and nutritionally significant. Substitution away from fruits and vegetables worsens diet quality during the lean season (*15*), and we find that scarcity of nutrient-dense foods typically precedes scarcity of calories from starchy staples as the peak timing for CoNA is earlier than the peak for CoCA. We also find large regional variation in the seasonality of diet costs, revealing how local food systems differ in their ability to deliver low-cost nutrients around the year. Reducing and stabilizing the cost of acquiring a nutritious diet is important not only for those who buy all their food but also for farmers who use markets to complement what they grow. Purchased foods from local markets contribute substantially to the diets of agricultural households in Africa (*16*) and are especially important in lean seasons and for diet diversity beyond what can be produced and stored on the household's own farm (*17*, *18*).

Our third major finding is that prices for animal-sourced foods had the least seasonality. This is one reason why the CoNA had less seasonality in Tanzania and Ethiopia than in Malawi, since their least-cost nutrient sources included more animal products. Overall, these findings point to opportunities for further improvement in low-cost, relatively stable supplies of animal-sourced foods, in addition to improvements in market access that would help people overcome seasonality in local production of plant-based foods.

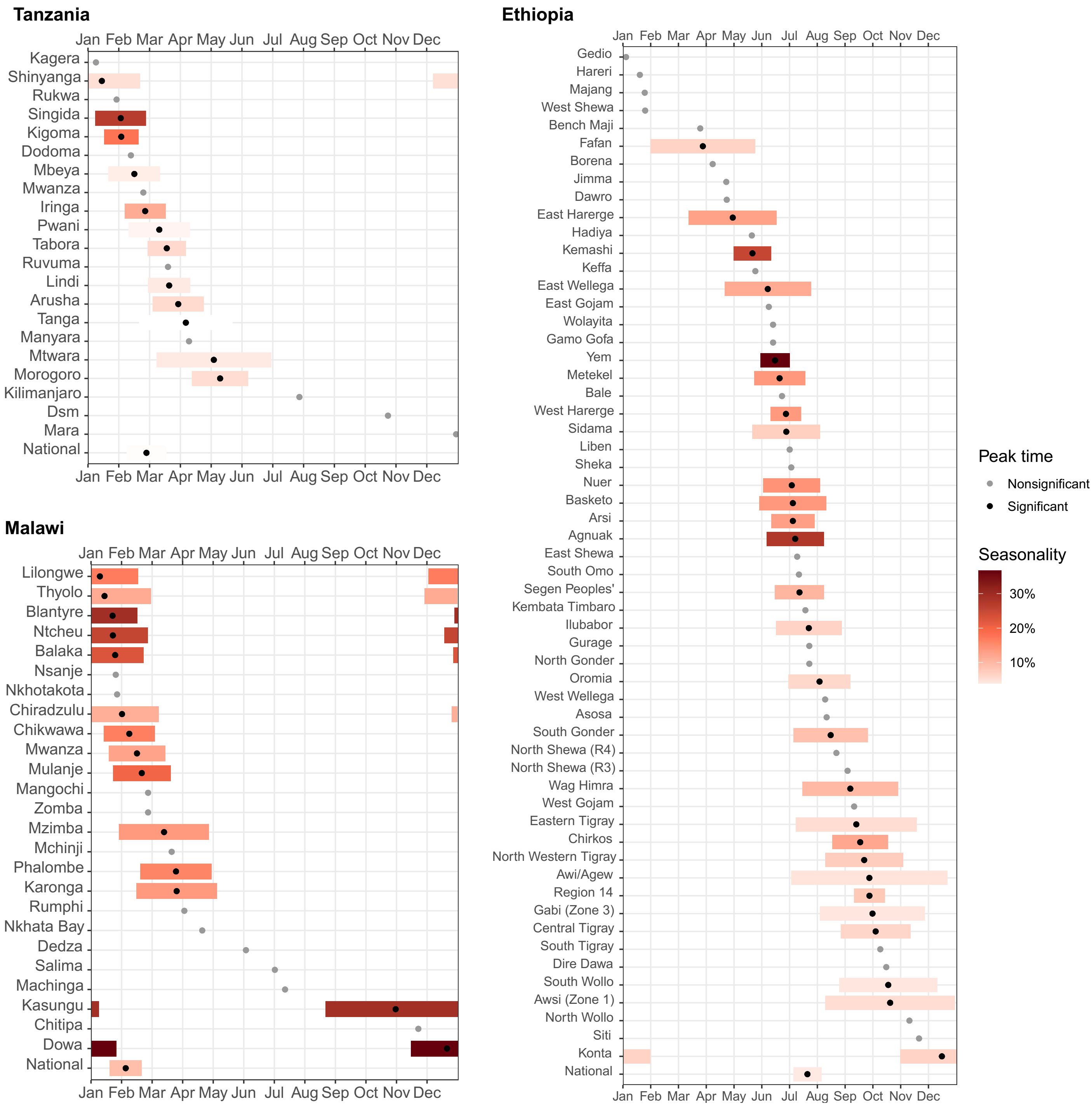

Fig. 5. Intensity and timing of seasonality in diet costs across 21 regions of Tanzania, 25 districts of Malawi, and 57 zones of Ethiopia. Data shown are 95% CIs around the peak month in each location, shown as a black dot, with the magnitude of intensity shown by the color gradation of each bar. Gray dots show the peak month in locations without statistically significant seasonality in diet costs, as measured by the CoNA.

Our analysis reveals the potential for high-frequency, high-density price observations to reveal the ability of local agroecosystems and food markets to deliver nutritionally complete diets at low cost, using data on food composition to compute the least-cost combination of foods that meet all essential nutrient requirements at each time and place. Protocols and software tools to automate the computation of least-cost diets allow us to extract nutrient costs from food price data over a total of 25,522 market-months, thereby measuring food system performance in ways that directly inform efforts to improve year-round access to nutritious diets in both rural and urban areas. Future studies may apply this method to identify the causes of differences in seasonality including local agricultural calendars, trade

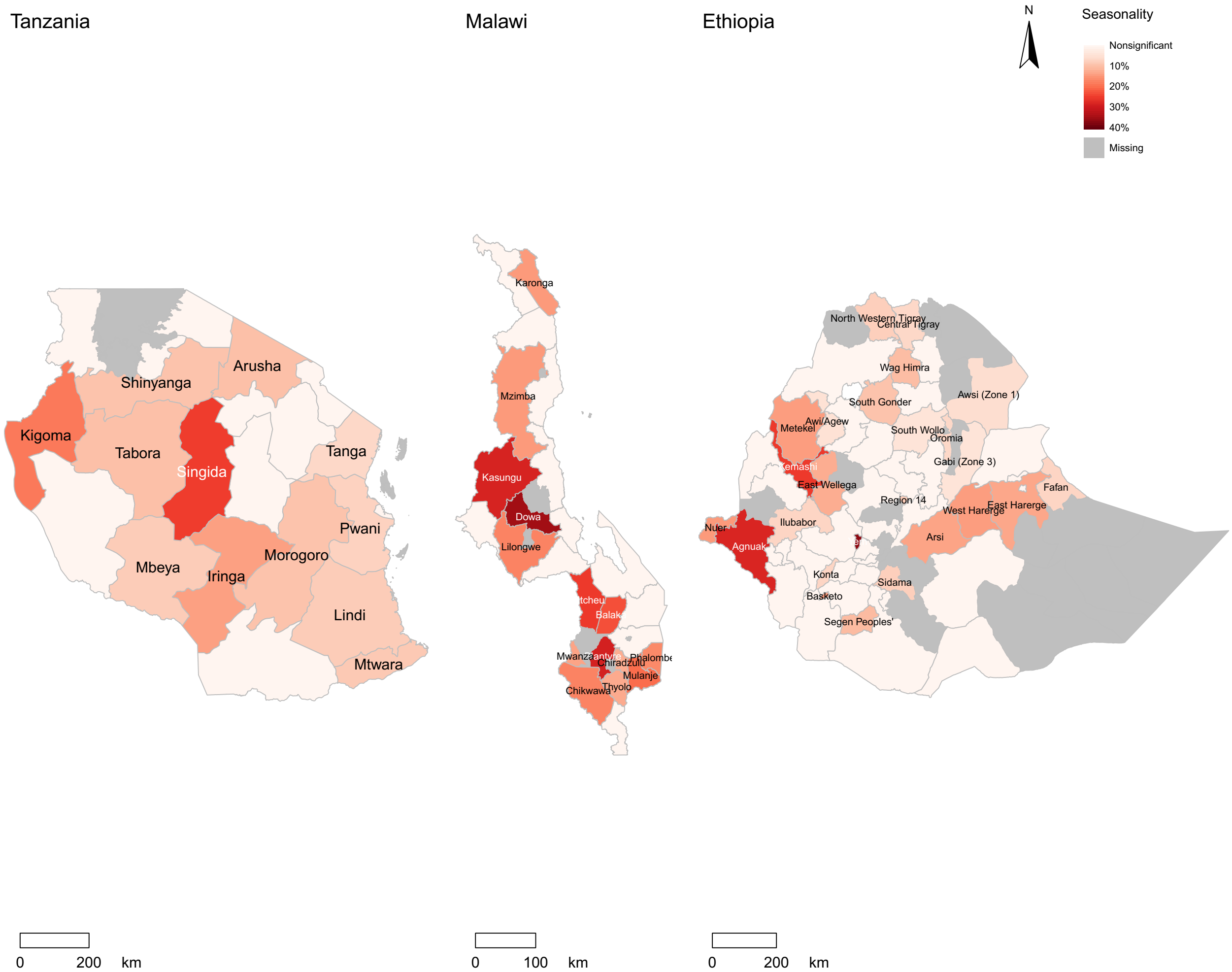

Fig. 6. Geographical distribution of seasonality in diet costs within Tanzania, Malawi, and Ethiopia. Color gradations show the magnitude of estimated seasonal intensity in the CoNA.

opportunities, and storage costs interacting with consumer demand, affecting both peaks in diet costs that harm consumers and seasonal lows that affect farm income and farming-dependent populations.

One key limitation of these analyses is that governments may not collect prices for all foods that could be low-cost sources of essential nutrients, at the times and locations where they are needed by people at risk of malnutrition. Other limitations include variation in the nutrient composition of each food especially after cooking, variation in peoples' nutrient requirements, and variation in retail prices within the month at each market, all of which are subject to further research. Last, our measure of seasonality in this paper is limited to harmonic fluctuations, which is just one component of all variation. Future work could address different kinds of price differences and identify ways to improve agricultural production, storage, and transport to stabilize diet costs and improve year-round affordability of nutritious diets.

MATERIALS AND METHODS

Data sources

The food prices used in this study are historical file data provided by national statistical services in each country. Prices were originally collected for the purpose of measuring inflation using a consumer price index, based on a list of all goods and services needed to represent national average per capita consumption in that country over an entire year. Since individuals can substitute foods seasonally, and observed diets may not actually meet their nutritional needs, to address the impact of climate fluctuations on cost of nutrients, we link food prices with the nutrient composition of each item and model the least-cost combination of foods needed to meet human requirements of each nutrient.

For Tanzania, the National Bureau of Statistics collected monthly retail food prices of 71 food and nonalcoholic beverage items from all 21 regions of mainland Tanzania between January 2011 and December 2015. Price data are collected from different types of outlets, including open markets, supermarkets, neighborhood shops, groceries, shopping centers, and other retail outlets. The monthly price surveys are conducted in urban regional headquarters in all 21 regions in approximately four outlets per item. For nonprocessed food items, price collectors go to the shops/markets on three consecutive days for price collection and retain the median of those three observations.

In Malawi, the National Statistical Office assembled monthly price data for 55 food items in 29 market locations across 25 administrative districts between January 2007 and December 2016. Unlike the Tanzania dataset, all 29 markets in this dataset are in rural towns, 17 of which are the district capitals known as "boma" markets, and the remaining 12 are in other towns. The data are collected during the first 2 weeks of each month usually from three retail shops preselected by the National Statistical Office or vendors subject to data collectors' judgement. They retain the geometric mean of the three observations. To reduce the disproportional effect of extreme values on model results, we have winsorized outliers beyond the top 1% of all ratios between reported price and the median for each item, replacing those outliers with the cutpoint value for that item.

The Ethiopia prices were obtained from the Consumer Price Survey, collected by the Central Statistical Agency (CSA). Monthly retail food prices considered in this study cover 97 food items in 120 markets from 57 zones of 11 administrative regions between January 2002 and December 2016 of 15 years. Like the dataset in Tanzania, the surveys are conducted in towns and cities. To ensure the survey to be nationally representative, the CSA also assigns the number of markets in each region to be proportional to the region's share of total urban population in Ethiopia. CSA enumerators collect three price quotations from traders, retailers, and consumers in the first 15 days of each month. They retain the median of those three prices and, before our receipt of the data, also trimmed outliers below the 1st and above the 99th percentile of each item.

After assembling each country's archival price data, we converted their units of measure to local currency per kilogram of edible matter (LCU/kg), and matched the item's description to entries in local food composition tables (*19–21*) where available. To fill gaps where no local composition data are available, we used the U.S. Department of Agriculture National Nutrient Database for Standard Reference (SR28) (*22*). For data visualization and analysis, we also converted food prices to LCU per 100 kcal and classified foods on the basis of an adjusted form of the Minimum Dietary Diversity for Women guidelines (*23*) into six major mutually exclusive food groups: (i) grains, white roots and tubers, and plantains ("starchy staples"); (ii) pulses, nuts, and seeds; (iii) dairy and eggs, meat, poultry, and fish ("animal foods"); (iv) fruits and vegetables; (v) oils and fats; and (vi) sweets. Last, we dropped food items that have nutrients but would not be included in substantial quantities for adult meal plans such as infant foods and condiments. There are finally 61, 48, and 82 food items included in the analysis for Tanzania, Malawi, and Ethiopia, respectively, representing all six major food groups. Descriptive statistics and numerical results are reported in the annex of extended data.

Computation of least-cost diets

To identify the most affordable sources of all essential nutrients, we automate the computation of least-cost diets at every time and place using linear programming approaches that were originally formulated to solve this and related problems during the Second World War (*24*). With each food's market price and nutrient composition as fixed parameters, we obtain the quantity of each food that delivers all nutrients within fixed lower and upper bounds at the lowest total cost. This least-cost diet for all nutrients is defined as the solution to

$\min\{C = \Sigma_i p_i \times q_i\}$, subject to six kinds of constraint:

(i) $\Sigma_i a_{ij} \times q_i \geq \mathrm{EAR}_j$.

(ii) $\Sigma_i a_{ij} \times q_\mathrm{i} \leq \mathrm{UL}_j$.

(iii) $\Sigma_i a_{ij} \times q_i \leq \mathrm{AMDR}_{j,\mathrm{upper}} \times E/e_j$.

(iv) $\Sigma_i a_{ij} \times q_\mathrm{i} \geq \mathrm{AMDR}_{j,\mathrm{lower}} \times E/e_j$.

(v) $\Sigma_i a_{ie} \times q_i = E$.

(vi) $q_1 \geq 0, q_2 \geq 0, q_3 \geq 0, \ldots, q_i \geq 0$.

The objective is lowest diet cost given the price of each food (p_i), choosing quantities (q_i) to meet or exceed the population's estimated average requirement (EAR) for nutrient j given the quantity of nutrient j in each food n_{ij}, within the further constraint of overall estimated energy needs (E), while remaining below upper levels (UL) for most micronutrients and the chronic disease risk reduction (CDRR) upper bound for sodium, and within a range for macronutrients determined by acceptable macronutrient distribution ranges ($\mathrm{AMDR}_{\mathrm{lower}}$ and $\mathrm{AMDR}_{\mathrm{upper}}$) as percentages of daily energy needs (E). The reference number e_j is the energy density of macronutrients, which is 4 kcal per gram of protein and carbohydrate and 9 kcal per gram of lipid. In the analysis, we included 21 nutrients, including 3 macronutrients (protein, fat, and carbohydrate), 8 minerals (calcium, iron, magnesium, phosphorus, zinc, copper, selenium, and sodium), and 10 vitamins (vitamin C, thiamin, riboflavin, niacin, vitamin B6, folate, vitamin B12, vitamin A, retinol, and vitamin E). Using this same framework, we also computed the CoCA for daily subsistence, using only starchy staples to meet the constraint of energy needs alone.

All the dietary reference intakes applied in our analysis include the most updated EAR, UL, AMDR, and estimated energy requirement developed by the U.S. Institute of Medicine (*25*), and we used healthy, not pregnant and lactating women of 57 kg and 163 cm between 19 and 30 years old with low active physical activity level as the reference population group. EAR is the amount of nutrient intake value meeting the requirement of half healthy population. For nutrients other than sodium, the upper limit indicates the UL, which is the highest level of daily nutrient intake that is likely to pose no risk of adverse health effects for the general population; for sodium, we used the CDRR developed in 2019 as the UL considering the beneficial effect of reducing sodium intake on cardiovascular disease risk, hypertension risk, systolic blood pressure, and diastolic blood pressure (*26*). The AMDR provides a range of intakes for macronutrients that is associated with reduced risk of chronic disease.

To automate computations, we call the lpSolve package in R (*27*) to return solutions for each location every month. Those computations are done in nominal local currency terms to reflect choices at each place and time. Then, for comparison over time and across countries, we converted each diet cost into constant USD using 2011 PPP exchange rates provided by the World Bank (*28*). Since local inflation occurs from month to month but PPP conversion factors are reported for each calendar year, we smooth over 12 months using the least squares technique as implemented in Stata using the -denton- command (*29*).

Measurement of seasonality

We extracted the magnitude and timing of seasonal fluctuations using harmonic regression, also known as a trigonometric model. This approach uses sine and cosine functions over time, offering a parsimonious representation using just two parameters to estimate smooth, symmetric rise and fall of a variable. The harmonic approach has been shown to be more efficient than traditional monthly indicator models that estimate one coefficient for each month, and the harmonic form offers a closer fit for many seasonal patterns than other functional forms (*11*). The model specification is shown below

$$\ln(C_{kt}) = \beta_0 + \beta_s \times \sin(2\pi\omega t) + \beta_c \times \cos(2\pi\omega t) + \beta_T \times T(t) + \beta_y \times Y_t \quad (1)$$

where C_{kt} is the monthly time series of food price or diet cost, in market k at month t. Coefficients of sin and cos terms, β_s and β_c, measure the magnitude (A) and peak timing (P) of seasonality where ω is a constant equal to $^1/_{12}$, indicating 12 months per annual cycle. $T(t)$ is a cubic polynomial term of t, controlling the trend of time series. Y_t controls the fixed effect of crop years. In Tanzania and Malawi, the first month of a crop year is May, while it is October in Ethiopia (*30*).

Seasonal intensity is defined as the difference between annual peak and nadir prices normalized to a unit-free percentage of the nadir price, expressed as $\exp\{(2A) - 1\}$, where A is the amplitude of the seasonality. Therefore, the seasonality is comparable across different food items, price indicators, and countries, and over time. The estimates of amplitude (A) and peak timing (P) and their variances are calculated using the δ method and the equations below (*4*)

$$A = \delta\sqrt{\beta_s^2 + \beta_c^2}, \text{where } \delta = 1, \text{if } \beta_c > 0, \text{and } \delta = -1, \text{if } \beta_c < 0 \text{ and} \tag{2}$$

$$\mathrm{Var}(A) = \left(\sigma_s^2\beta_s^2 + \sigma_c^2\beta_c^2 + 2\sigma_{sc}\beta_s\beta_c\right) / \left(\beta_s^2 + \beta_c^2\right) \tag{3}$$

$$P = \frac{12\left(1 - \frac{\varphi}{\pi}\right)}{2}, \text{where } \varphi = -\arctan\left(\beta_s/\beta_c\right) \tag{4}$$

$$\mathrm{Var}(\varphi) = \left(\sigma_s^2\beta_c^2 + \sigma_c^2\beta_s^2 + 2\sigma_{sc}\beta_s\beta_c\right) / \left(\beta_s^2 + \beta_c^2\right)^2 \tag{5}$$

where σ_s, σ_c, and σ_{sc} are the SDs of β_s and β_c parameters, and their joint covariance. We also calculated the 95% CIs for A and P using a standard constant from a t-distribution of 1.96. The 95% CI of the amplitude is from $A - 1.96\sqrt{\mathrm{Var}(A)}$ to $A + 1.96\sqrt{\mathrm{Var}(A)}$. The harmonic regression models allow for assessing the significance of seasonal components, e.g., the significance of β_s and/or β_c parameters (for sin and cos terms, respectively). Thus, the peak timing estimates can be formally compared. If the 95% CI does not contain the value of zero, then seasonality will be determined significant (*31*).

For the seasonality analysis of energy intake compositions and cost components of CoNA contributed by different food groups, we applied a different harmonic model specification

$$I_{kt} = \beta_0 + \beta_s \times \sin(2\pi\omega t) + \beta_c \times \cos(2\pi\omega t) + \beta_T \times T(t) + \beta_y \times Y_t \tag{6}$$

where I_{kt} is the energy intake compositions of CoNA in kilocalories and the cost components of CoNA from each food group in k market and time t. In this analysis, seasonal intensity is defined as the average absolute difference between the peak and nadir values in a yearly cycle, or simply the double of amplitude, $2A$, estimated from Eq. 6.

We compared results from both harmonic regression and traditional monthly indicator models, for diet costs and individual food items across three countries, and the comparison results are shown in figs. S1 to S4. The model specification for the harmonic model followed Eq. 6 above, and the specification for the indicator variable approach is shown in Eqs. 7 and 8 below

$$I_{kt} = \beta_0 + \Sigma_m \beta_m \times M_m + \beta_T \times T(t) \tag{7}$$

$$\ln(C_{kt}) = \beta_0 + \Sigma_m \beta_m \times M_m + \beta_T \times T(t) \tag{8}$$

where I_{kt} is the diet costs or food prices in the kth market at month t. M_m is the dummy variable for calendar months, and we selected November as the base month in the analyses.

We used a multivariate mixed-effects model in estimations where observations are from multiple markets, with random intercepts and coefficients on the seasonal terms (sin and cos terms) by markets. If an estimation was based on observations from a single market, an ordinary least squares model was applied instead. All regression models were run in Stata/SE 15.1.

SUPPLEMENTARY MATERIALS

Supplementary material for this article is available at http://advances.sciencemag.org/cgi/content/full/6/49/eabc2162/DC1

View/request a protocol for this paper from *Bio-protocol*.

REFERENCES AND NOTES

1. H.-J. Brinkman, S. de Pee, I. Sanogo, L. Subran, M. W. Bloem, High food prices and the global financial crisis have reduced access to nutritious food and worsened nutritional status and health. *J. Nutr.* **140**, 153S–161S (2010).
2. H. E. Bouis, P. Eozenou, A. Rahman, Food prices, household income, and resource allocation: Socioeconomic perspectives on their effects on dietary quality and nutritional status. *Food Nutr. Bull.* **32** (Suppl. 1), S14–S23 (2011).
3. R. Green, L. Cornelsen, A. D. Dangour, R. Turner, B. Shankar, M. Mazzocchi, R. D. Smith, The effect of rising food prices on food consumption: Systematic review with meta-regression. *BMJ* **346**, f3703 (2013).
4. E. N. Naumova, I. B. MacNeill, Seasonality assessment for biosurveillance systems, in *Advances in Statistical Methods for the Health Sciences*, J.-L. Auget, N. Balakrishnan, M. Mesbah, G. Molenberghs, Eds. (Birkhäuser, 2007), pp. 437–450.
5. M. Stelmach-Mardas, C. Kleiser, I. Uzhova, J. L. Peñalvo, G. La Torre, W. Palys, D. Lojko, K. Nimptsch, A. Suwalska, J. Linseisen, R. Saulle, V. Colamesta, H. Boeing, Seasonality of food groups and total energy intake: A systematic review and meta-analysis. *Eur. J. Clin. Nutr.* **70**, 700–708 (2016).
6. K. Hirvonen, A. S. Taffesse, I. Worku Hassen, Seasonality and household diets in Ethiopia. *Public Health Nutr.* **19**, 1723–1730 (2016).
7. J. Kaminski, L. Christiaensen, C. L. Gilbert, Seasonality in local food markets and consumption: Evidence from Tanzania. *Oxf Econ Pap.* **68**, 736–757 (2016).
8. E. Becquey, F. Delpeuch, A. M. Konaté, H. Delsol, M. Lange, M. Zoungrana, Y. Martin-Prevel, Seasonality of the dietary dimension of household food security in urban Burkina Faso. *Br. J. Nutr.* **107**, 1860–1870 (2012).
9. P. Brenton, A. Portugal-Perez, J. Regolo, Food prices, road infrastructure, and market integration in Central and Eastern Africa, in *Policy Research Working Paper Series 7003* (The World Bank, 2014).
10. G. Shively, G. Thapa, Markets, transportation infrastructure, and food prices in Nepal. *Am. J. Agric. Econ.* **99**, 660–682 (2017).
11. C. L. Gilbert, L. Christiaensen, J. Kaminski, Food price seasonality in Africa: Measurement and extent. *Food Policy* **67**, 119–132 (2017).
12. Women's Dietary Diversity Project (WDDP) Study Group, Development of a dichotomous indicator for population-level assessment of dietary diversity in women of reproductive age. *Curr. Dev. Nutr.* **1**, cdn.117.001701 (2017).
13. R. C. Allen, Absolute poverty: When necessity displaces desire. *Am. Econ. Rev.* **107**, 3690–3721 (2017).
14. W. A. Masters, Y. Bai, A. Herforth, D. B. Sarpong, F. Mishili, J. Kinabo, J. C. Coates, Measuring the affordability of nutritious diets in Africa: Price indexes for diet diversity and the cost of nutrient adequacy. *Am. J. Agric. Econ.* **100**, 1285–1301 (2018).
15. K. Hirvonen, Y. Bai, D. Headey, W. A. Masters, Affordability of the EAT–*Lancet* reference diet: A global analysis. *Lancet Glob. Health* **8**, e59–e66 (2020).
16. C. Romanik, *An Urban-Rural Focus on Food Markets in Africa* (The Urban Institute, 2016).
17. K. T. Sibhatu, M. Qaim, Rural food security, subsistence agriculture, and seasonality. *PLOS ONE* **12**, e0186406 (2017).
18. J. C. Fanzo, Decisive decisions on production compared with market strategies to improve diets in rural Africa. *J. Nutr.* **147**, 1–2 (2017).
19. Z. Lukmanji, E. Hertzmark, N. Mlingi, V. Assey, G. Ndossi, W. Fawzi, *Tanzania Food Composition Tables* (Muhimbili University of Health and Allied Sciences (MUHAS) and Tanzania Food and Nutrition Centre (TFNC), and Harvard School of Public Health (HSPH), 2008).
20. Ethiopian Health and Nutrition Research Institute, *Food Composition Table for Use in Ethiopia, Part IV* (EHNRI, 1995).

21. B. Stadlmayr, U. R. Charrondiere, V. N. Enujiugha, R. G. Bayili, E. G. Fagbohoun, B. Samb, P. Addy, I. Barikmo, F. Ouattara, A. Oshuag, I. Akinyele, G. A. Annor, K. Bomfeh, H. Ene-Obong, I. F. Smith, I. Thiam, B. Burlingame, *West African Food Composition Table* (FAO, 2012).
22. USDA Agricultural Research Service, *Composition of Foods Raw, Processed, Prepared USDA National Nutrient Database for Standard Reference, Release 28* (Nutrient Data Laboratory, 2016).
23. M. Arimond, D. Wiesmann, E. Becquey, A. Carriquiry, M. C. Daniels, M. Deitchler, N. Fanou-Fogny, M. L. Joseph, G. Kennedy, Y. Martin-Prevel, L. E. Torheim, Simple food group diversity indicators predict micronutrient adequacy of women's diets in 5 diverse resource-poor settings. *J. Nutr.* **140**, 2059S–2069S (2010).
24. G. J. Stigler, The cost of subsistence. *J. Farm Econ.* **27**, 303–314 (1945).
25. Institute of Medicine, *Dietary Reference Intakes: The Essential Guide to Nutrient Requirements* (National Academies Press, 2006).
26. National Academies, Engineering, and Medicine, *Dietary Reference Intakes for Sodium and Potassium* (National Academies Press, 2019).
27. M. Berkelaar, *lpSolve: Interface to "Lp_solve" v. 5.5 to Solve Linear/Integer Programs* (2015); https://CRAN.R-project.org/package=lpSolve.
28. World Bank, *Metadata Glossary: PPP Conversion Factor, Private Consumption (LCU per International $), Series PA.NUS.PRVT.PP* (The World Bank, 2020).
29. F. T. Denton, Adjustment of monthly or quarterly series to annual totals: An approach based on quadratic minimization. *J. Am. Stat. Assoc.* **66**, 99–102 (1971).
30. FAO, *GIEWS—Global Information and Early Warning System* (Food and Agriculture Organization of the United Nations, 2020).
31. J. B. Wenger, E. N. Naumova, Seasonal synchronization of influenza in the United States older adult population. *PLOS ONE* **5**, e10187 (2010).
32. World Bank, *Climate Change Knowledge Portal: Historical Data* (The World Bank, 2020).

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