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Measuring the cost of dietary diversity: Novel price indexes to monitor acces to nutriton diets

William A. Masters (Contact author - see below), Friedman School of Nutrition Science & Policy, Tufts University, USA
Yan Bai, Friedman School of Nutrition Science & Policy, Tufts University, USA
Anna Herforth, Friedman School of Nutrition Science & Policy, Tufts University, USA
Daniel Sarpong, Dept. of Agricultural Economics & Agribusiness, University of Ghana
Fulgence Mishili, Dept. of Agricultural Economics & Agribusiness, Sokoine University of Agriculture, Tanzania
Joyce Kinabo, Department of Food Science & Technology, Sokoine University of Agriculture, Tanzania
Jennifer C. Coates, Friedman School of Nutrition Science & Policy, Tufts University, USA

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William A. Masters
Professor, Friedman School of Nutrition Science & Policy, Tufs University
150 Harrison Avenue, Boston MA 02111 USA
+1.617.636.3751, email william.masters@tufts.edu,
https://nutrition.tufts.edu/profile/william-masters

ABSTRACT

This technical note describes a novel approach to measuring changes in the affordability of nutritious diets in low-income settings, using price indexes to monitor how trade policy or market infrastructure and other factors influence the cost of reaching a standard threshold of dietary diversity. We provide preliminary results for a new Cost of Diet Diversity (CoDD) price index in Ghana, contrasted with existing Cost of Nutrient Adequacy indexes as well as the standard Consumer Price Index concept for foods actually consumed, and world food price indexes for commodities that enter international trade.

INTRODUCTION

This technical note describes a novel approach to measuring changes in the affordability of nutritious diets in low-income settings, using price indexes to monitor how international trade, local markets and other factors influence the cost of reaching a standard threshold of dietary diversity. We provide the motivation and illustrative results for our new Cost of Diet Diversity (CoDD) price index in Ghana, contrasted with existing cost of nutrient adequacy indexes as well as older and more widely used measures based on relative costs of specific commodities and an overall Consumer Price Index (CPI).

Our new approach computes the minimum cost of reaching the Minimum Diet Diversity for Women of reproductive age (MDD-W), which measures whether at least five of ten specific food groups were consumed in the previous 24 hours (FAO and FHI360 2016). This method aggregates food prices in the same way that the MDD-W adds up foods consumed, thereby revealing changes in price within and across food groups on a seasonal and geographic basis. Preliminary results provide considerable insight beyond earlier indexes that focus only on staple commodities, or compute the minimum cost of meeting recommended daily intakes of specific nutrients, or provide a traditional cost-of-living measure that aggregates prices based on their share of actual consumption.

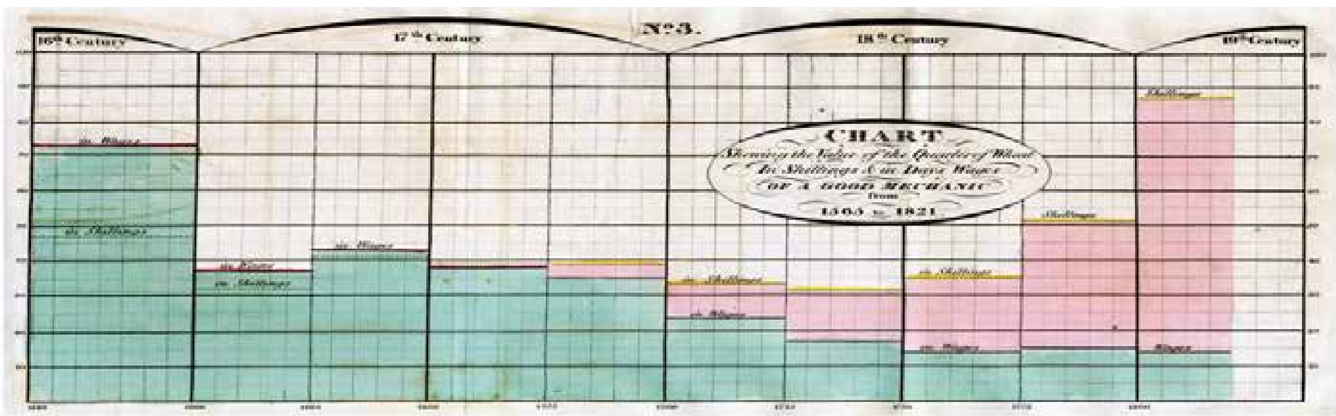
Consuming a diversity of foods helps ensure that the diet contains not only sufficient nutrients but also other attributes such as phytochemicals and prebiotics. Nutrition is a multidimensional domain that cannot be summarized by any single number, but the MDD-W is increasingly attractive to nutritionists because it measures important features of a healthy diet using data that are relatively easy to collect and communicate (Arimond and Ruel 2004, FAO and FHI360 2016). Most fundamentally, the MDD-W concerns dietary pattern in terms of food groups, such as green leafy vegetables or fish, rather than specific nutrients like iron or zinc. The indicator was validated by showing that women who had consumed at least 5 out of 10 food groups in the previous day were more likely to have consumed adequate nutrients.

BACKGROUND AND MOTIVATION

Research on the cost of meeting dietary needs goes back to the early 19th century if not earlier. At first studies focused only on basic staples, such as Playfair (1821)'s analysis of bread prices relative to workers' wages. In the late 19th century, overall cost-of-living indexes were developed to reflect the prices of foods in general, weighting each price by its share of current expenditure, thereby tracking the cost of what people actually buy or sell (Rippy, 2014). In the 20th century, soon after the nutrient composition of food was first measured, Stigler (1945) developed linear programming methods to identify the lowest-cost combination of different foods needed to meet recommended intake of each nutrient. Here we build on that literature to provide the motivation for a new cost of dietary diversity measure designed to use limited available market data in alignment with the FAO's MDD-W indicator.

Figure 1 shows the first widely-cited measure of food access, produced by William Playfair (1821) to reveal how the real cost of bread in England had stopped declining in the late 18th and early 19th centuries, as its monetary cost per shilling of British currency rose faster than nominal wages. The long tradition of focusing on relative prices for basic staples continues today, typically extended to other foods such the FAO's Cereal Price Index that includes rice and maize in addition to wheat (FAO 2017).

FIGURE 1. WILLIAM PLAYFAIR'S INDEX FOR THE AFFORDABILITY OF BREAD IN ENGLAND, 1565-1821



Source: Playfair (1821), https://commons.wikimedia.org/wiki/File:Chart_Shewing_the_Value_of_the_Quarter_of_Wheat_in_Shillings_&_in_Days_Wages_of_a_Good_Mechanic_from_1565_to_1821.jpg.

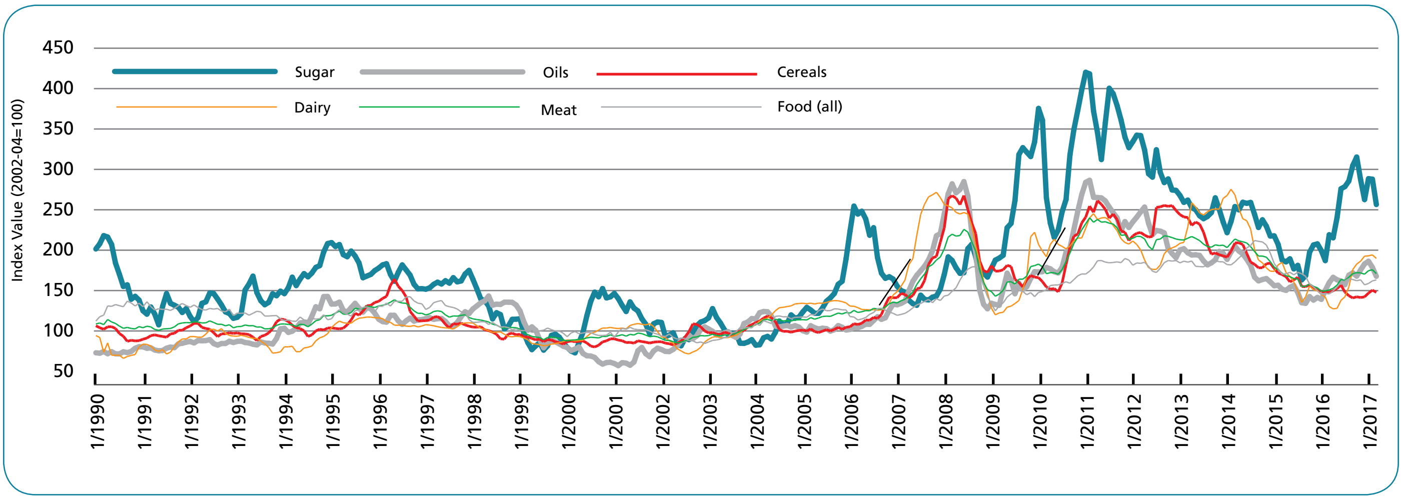
Figure 1 compares nominal to real prices of just one retail food item. Commodity-price indexes such as those used to monitor world food markets by FAO (2017) are designed to measure the real cost of basic products shipped internationally. Each price included in the index may be weighted equally, or counted in proportion to its share of international trade as shown in Figure 2, revealing how different kinds of commodities have quite different trajectories over time. As shown here, the price of meat is much less volatile than other prices, while the price of sugar is much more volatile, although periods of high versus low prices typically coincide.

The prices of food commodities entering international trade shown in Figure 2 may differ greatly from retail prices actually paid for food like Playfair's original price of wheat. To capture domestic market prices over many goods, governments have compiled CPI-type measures since the late 19th century, and also computed producer price indexes for intermediate goods sold on wholesale markets. These indexes aim to weight the price of each item by its share of consumer spending or producer revenue, so as to control for monetary inflation relative to all other goods and permit calculation of national accounts. Data for the United States from 1970 to 2016 are provided in Figure 3, comparing the wholesale prices paid to producers with retail prices paid by consumers.

The patterns shown in Figure 3 reveal how unprocessed commodities like wheat have the most volatility, while processed commodities like cheese have somewhat more stable prices, both moving in the characteristic U-shaped pattern of long valleys when goods are abundant followed by short peaks of temporary scarcity. In contrast, retail prices – especially for food away from home – have highly stable prices that include the cost of labor, equipment, facilities and other inputs beyond food commodities.

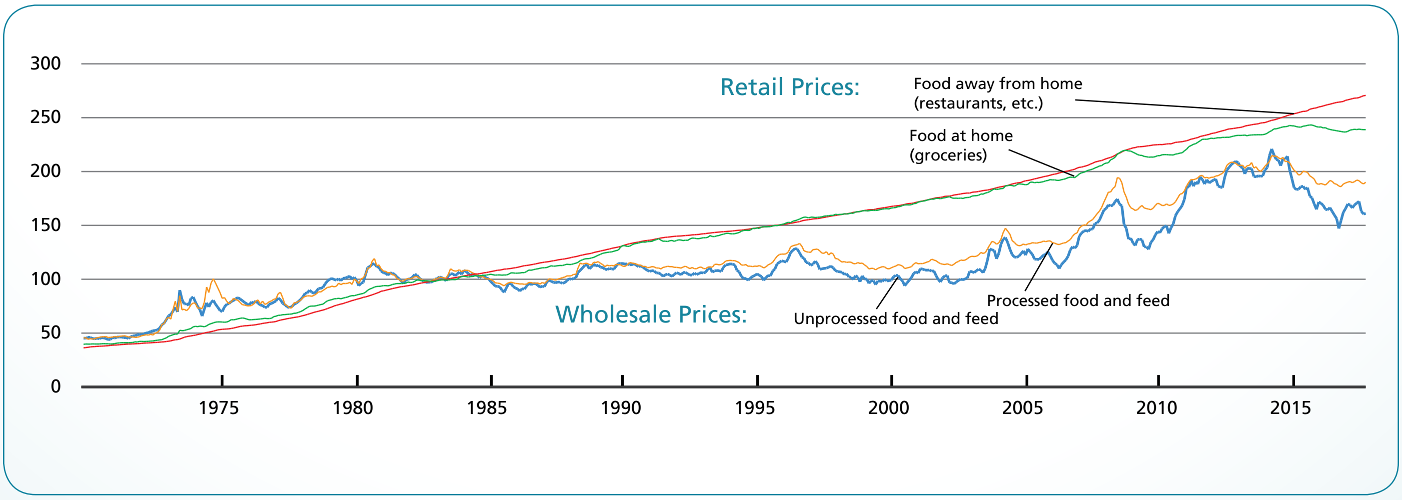
Price indexes designed to reflect just the cost of nutrients in food were introduced in the 1940s, building on Stigler (1945). The

FIGURE 2. FAO WORLD FOOD PRICE INDEXES, 1990-2017



Source: FAO (2017), The World Food Situation. Rome: FAO. http://www.fao.org/worldfoodsituation.
Note: Values shown are based on prices paid for internationally-traded bulk shipments of 3 cereals (wheat, rice and maize), 4 kinds of dairy products, 9 types of meat, 10 vegetable oils and sugar. Where possible each is weighted by its share of internationally traded food. All are deflated by the World Bank Manufactures Unit Value Index (MUV), and rebased to 100 in 2002-04.

FIGURE 3. CONSUMER AND PRODUCER PRICE INDEXES FOR ALL FOODS IN THE US, 1970-16



Source: Author's calculations from US. Bureau of Labor Statistics, downloaded 11 December 2017. Definitions and chart data are available at http://myf.re/g/aPV1.

concept of a least-cost diet, choosing the combination of foods needed to reach minimum requirements of various nutrients, was used for the United States Department of Agriculture's "Minimum-Cost Food Plan" to advise people facing extreme poverty (Cofer *et al*. 1962), and more recently for developing countries in the Optifood (2012) approach developed by the London School of Hygiene and Tropical Medicine and others with FANTA (2013). This same method can be used to track food prices in terms of nutrient adequacy, as in the "Cost of the Diet" approach developed by Save the Children UK (Deptford *et al*. 2017). Calculating least cost diets can be done based on nutrients alone, as in O'Brien-Place and Tomek (1983) for the U.S. and Omiat and Shively (2017) for Uganda, but this typically leads to diets whose other characteristics are quite unpalatable since actual diets are chosen in part for other reasons such as tradition, taste and convenience. To gain realism, Gerdessen and De Vries (2015) add palatability constraints tailored to European diets by imposing upper and lower limits on specific foods, while Deptford *et al*. (2017) aim for realism in developing countries by restricting choices to specific dishes actually observed being consumed in local household surveys. The diet-diversity method presented here focuses on cost of at least one item from each of the food groups defined in the MMD-W indicator, so as to use the more limited datasets typically available in developing countries.

DATA AND METHODS

To demonstrate the feasibility and insight generated by a new price index for the cost of dietary diversity, we provide illustrative results using national average monthly food prices in Ghana between January 2005 and December 2014. The data we use for the new Cost of Diet Diversity (CoDD) index were collected by the Ministry of Food and Agriculture in its market information system, and cover a total of only 28 distinct foods. To compute the CoDD index, we use no information beyond the price per gram of each item sold, its food group and dietary energy content using the West Africa Food Composition Table (Stadlmayr *et al*. 2012), the USDA National Nutrient Database for Standard Reference, the Food Nutrient Database of AUSNUT 2011–13 and other sources. Also, to measure the cost of each food group relative to all other prices in each country every year, we converted local currency units to international dollars of 2011 by applying the Purchasing Power Parity (PPP) conversion factor provided by the World Bank, as well as conversion between new and old currencies in Ghana. Prices for each item are averages over a variety of open air markets, covering Ghana's 10 regions (Accra, Central, Western, Eastern, Volta, Ashanti, Ahafo, Northern, Upper East and Upper West). Primary data collection was conducted by the Ministry of Food and Agriculture, and analysis was conducted by researchers at Tufts University and the University of Ghana. The overall project also involves data from Tanzania with colleagues from Sokoine University of Agriculture, and is funded by UK Aid (DFID) to improve Indicators of Affordability of Nutritious Diets in Africa (IANDA), as part of a larger initiative entitled Innovative Methods and Metrics for Agriculture-Nutrition Actions (IMMANA).

In the CoDD, we measure the cost of diet diversity by converting reported prices for each food to cost per unit of weight of edible matter, and then per unit of dietary energy, expressed in a common currency and adjusted for inflation in other prices to obtain purchasing-power parity (PPP) values. We then classify foods using the MDD-W guidelines into one of ten mutually exclusive food groups, described in the guidelines as 1. Grains, white roots and tubers, and plantains, 2. Pulses, 3. Nuts and seeds, 4. Dairy, 5. Meat, poultry and fish, 6. Eggs, 7. Dark green leafy vegetables, 8. Vitamin A-rich fruits and vegetables, 9. Other vegetables, and 10. Other fruits (FAO and FHI360 2016). The actual items for which prices are reported varies by country and time period; in Ghana there were no prices at all for dark green leafy vegetables or dairy, so only 8 of 10 possible food groups were actually represented. The IANDA project that sponsored this research is actively pursuing expansion of data collection to include a wider variety of foods, so as to compute price indexes that include more diverse potential contributors to nutritious diets.

Our central innovation is to introduce price indexes that aggregate foods in the same way as the MDD-W, counting the most affordable way to acquire at least some of each food group. The MDD-W and other dietary diversity measures posit that foods within a group have similar characteristics for human health, while different food groups bring other attributes. The distinguishing feature of a *minimum* dietary diversity indicator is its focus on reaching the threshold number of food groups, with the MDD-W achieved when at least one item from five or more different groups are consumed. To aggregate over groups, we provide two distinct measures: one counts only the least-cost way to reach a fifth group, while the other counts the least-cost way to acquire any combination of food groups, formally defined as:

$$\text{CoDD1} = \text{min5}\{\min\{p_{i1}\}, \min\{p_{i2}\}, \ldots, \min\{p_{im}\}\} \quad (1)$$

$$\text{CoDD2} = \text{ave}\{\min\{p_{i1}\}, \min\{p_{i2}\}, \ldots, \min\{p_{im}\}\} \quad (2)$$

For CoDD1, min5 denotes the fifth lowest of all m food groups, and p_{ij} is the price of item i in the jth food group. This formula corresponds to a literal interpretation of the MDD-W, returning the marginal cost of reaching the threshold. For questions that involve diet diversity more generally, CoDD2 uses the average cost of including at least one item from any number of different food groups. When using the MDD-W classification there could be a maximum of m=10 groups, but due to missing historical data in Ghana for green leafy vegetables and dairy our empirical results actually have a total of eight.

The first cost of diet diversity index is specific to the MDD-W indicator, tracing the price of just the one food needed to include the fifth lowest-cost group. The second index counts the cost of acquiring other groups, each weighted equally, and so corresponds to diet diversity scores that track the total number of groups consumed. Both indexes are constructed without reference to quantities consumed. This approach is designed for use in data-scarce settings, based only on classifying items into food groups. Adding information about quantities and nutrients leads to an index for the Cost of Nutrient Adequacy (CoNA), following Stigler (1945) and most recently Omiat and Shively (2017) and Deptford *et al*. (2017):

$$\text{CoNA} = \text{Min}\textstyle\sum_i p_i q_i \text{ , subject to } a_{ij} q_i >= EAR_j \text{ and } a_{ie} q_i = E \quad (3)$$

Here, the quantity of the jth nutrient in food i is denoted a_{ij}, which multiplied by its quantity consumed (q_i) must meet the population's estimated average requirement (*EAR*) for nutrient *j*, at lowest total cost given all prices (p_j) within the further constraint of overall energy balance ($a_{ie}q_i = E$).

The CoDD and CoNA indexes reflect only the cost of diversifying among food groups or reaching required levels of nutrients, which are not the only goals for healthy diets. These are not positive descriptions of what people actually eat, or normative prescriptions for what people should consume. Other aspects of desirable diets can be specified by limiting foods to what is actually consumed, as in Optifood (2012) and Deptford *et al*. (2017), or by reference to recommended dietary patterns or dietary guidelines. We refer to that type of index as the Cost of Recommended Diets (CoRD):

CoRD = $\sum_j p_{ij} q_j$, where $p_{ij} = \min\{p_{ij}\}$ and q_j = recommendation for $j=\{1,\ldots, m\}$ categories (4)

In this formulation, the dietary guideline recommendation is a specific quantity, and the formula can readily be generalized to allow maximum and minimum quantities of specific food categories.

All of the "nutrition-sensitive" price indexes listed above can be contrasted with a standard consumer price index (CPI), defined as:

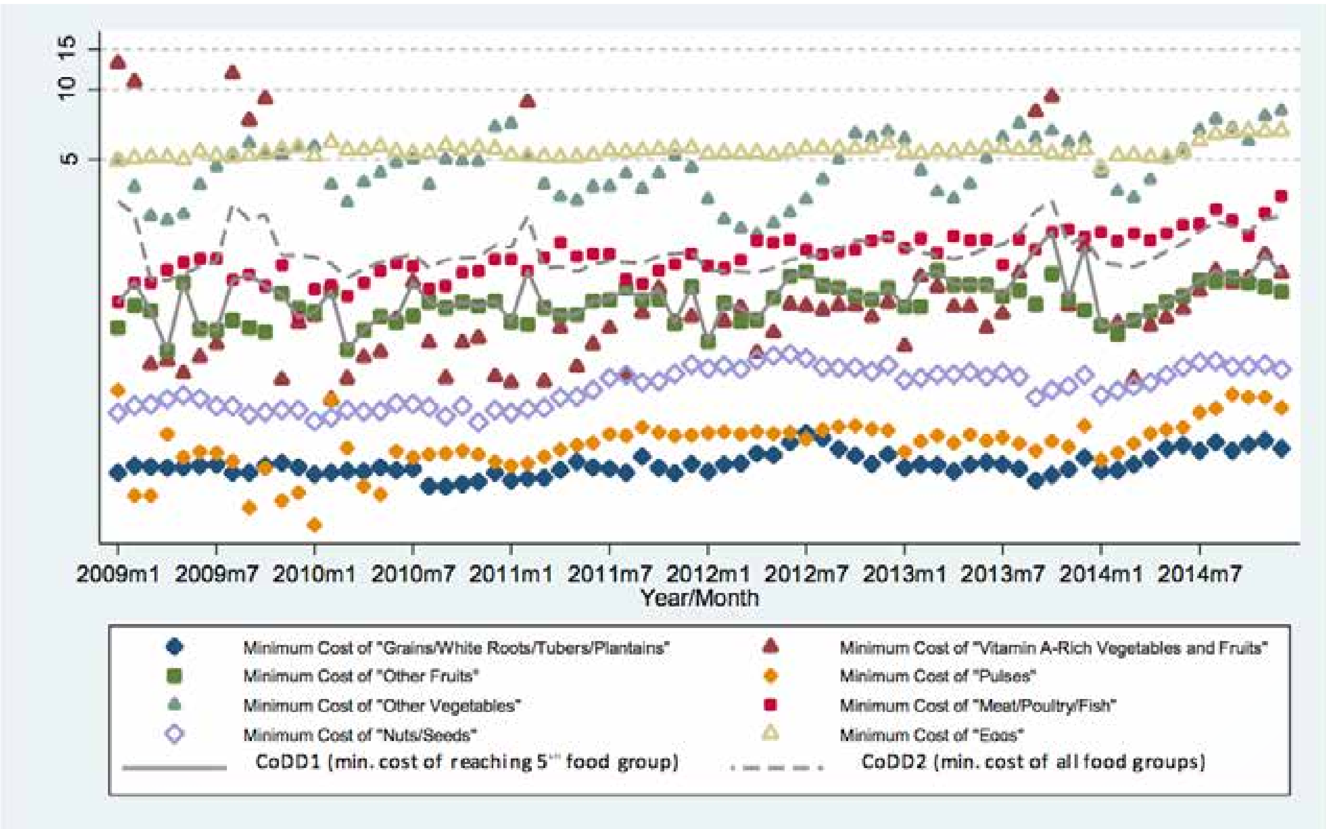
CPI = $\sum_i p_i q_i$, where p_i and q_i are actual average prices and quantities consumed (5)

For a producer price index (PPI) or the world market price index shown in Figures 2 and 3, prices and quantities reflect actual quantities sold or traded. For each type of index, the calculation of percentage changes over time or differences across locations involves specifying which observation is the base year or location. With our nutritional indexes (CoDD, CoNA and CoRD), quantities do not change but for the CPI and other traditional market price indexes, Laspeyres-type indexes use quantities from the initial time period as the base, while Paasche-type indexes us quantities from the ending time period.

ILLUSTRATIVE RESULTS

The CoDD results of equations (1) and (2) are illustrated in Figure 4, showing the real price of the lowest-cost food in each group, and then index numbers reflecting either the cost of the fifth group (CoDD1) or the average of all groups (CoDD2), per unit of dietary energy. Which specific foods are the lowest-cost item in each group varies seasonally and across years. For example, among vitamin-A rich fruits and vegetables, the least-cost item alternates between mangoes and papaya, and from mid-2012 to mid-2014, cassava prices were unusually high but maize prices remained low, stabilizing the cost of starchy staples. The comparison between maize and cassava reveals the importance of comparing prices per unit of dietary energy rather than weight, given the very high moisture content of cassava.

FIGURE 4. ILLUSTRATIVE RESULTS FOR THE COST OF DIET DIVERSITY OVER TIME IN GHANA, 2009-14



Source: Author›s calculations

As shown by Figure 4, the lowest-cost food groups per unit of dietary energy are consistently starchy staples, pulses (beans), nuts (groundnuts), vitamin A-rich vegetables and fruits, and other fruits. Very occasionally, some form of meat, poultry or fish replaces "other fruits" as the fifth group. The price of other vegetables and eggs never fall low enough to be included in a least-cost diet with at least five food groups, so do not enter our basic cost of diet diversity measure (CoDD1). A price index that includes other food groups (CoDD2) is considerably more expensive, especially at times when vitamin A-rich fruits and vegetables and other vegetables are out of season in a bad year, and are therefore not included in CoDD1. Overall, both CoDD indexes reveal that the cost of diet diversity in Ghana had no clear trend from 2009 through 2014, but had substantial season variation with peaks in the later months of each year especially the last two years of this series.

The ranking of groups in Figure 4 reflects the market value of each type of food. Starchy staples are the least expensive per unit of energy in part because they contain the least desirable attributes beyond dietary energy. Pulses (beans) are only slightly more expensive per unit of energy, as they bring additional protein and other nutrients. Nuts/seeds (groundnuts) are even more costly, offering additional but more expensive attributes including oil for palatability in stews and other dishes. Ranking foods by cost per unit of energy thus reveals the market price of reaching each threshold level of diet quality as defined in terms of dietary diversity. Our CoDD index is intended for use in settings with relatively limited data, such as the prices for only 28 different foods from 8 food groups used for the illustrative results in Figure 4. One purpose of the IANDA project was to demonstrate the value of obtaining price data for additional, more nutrient-dense foods. The most recent price surveys in Ghana include many more foods, permitting calculation of the CoNA index and the quantities of each food needed to achieve nutrient adequacy.

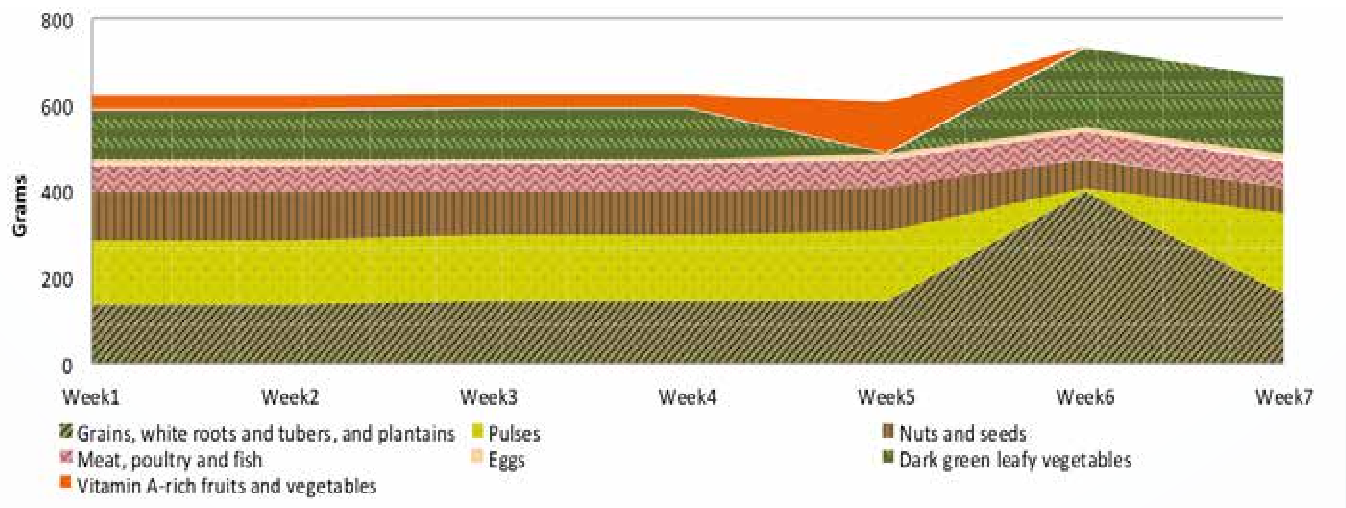
To illustrate our CoNA results, Figure 5 presents the quantities from each food group needed to reach estimated average requirements for protein plus 18 micronutrients in a 2000 calorie diet, at least total cost using prices and nutrient composition for 61 distinct foods whose prices were collected at weekly intervals from November 19th to December 31st 2017 at Techiman municipal market. Ten items from seven of the MDD-W food groups are ever included in the lowest-cost diet during this time period; these are cassava and maize (in the starchy staple group), soybean (in the pulse group), groundnut (nuts and seeds), mackerel (from the meat, poultry and fish group), egg (from the egg group), amaranth and taro leaves (dark green leafy vegetables), and papaya and carrots (from the vitamin A-rich fruit and vegetable group). The CoNA index itself, which is the total cost of these foods in 2011 US dollars per day at PPP prices, is $0.41, 0.39, 0.46, 0.49, 0.48, 0.46 and 0.47 in each successive week.

The contrast between our CoDD index in Figure 4, the more complex CoNA index illustrated in Figure 5, the CPI and earlier kinds of price indexes shown in Figures 1-3 demonstrate the increasing levels of nutritional detail captured by these indicators. Each index reflects a different aspect of diet quality, with the new CoDD index filling an important gap in the literature on the cost of nutritious diets.

CONCLUSIONS

Our novel index for the cost of dietary diversity (CoDD) uses market price data for various items in each food group to compute the cost of meeting daily energy needs in a diverse way, with just the lowest-cost groups (CoDD1) or the average of all available groups (CoDD2). The concept could be used for any classification, and is applied here to diet quality as defined by the indicator of Minimum Dietary Diversity for Women (MDD-W). Our CoDD results reflect the MDD-W's classification of foods into one of ten mutually exclusive groups (starchy staples, pulses, nuts/seeds, dairy, meat/poultry/

FIGURE 5. FOOD GROUP INTAKE NEEDED FOR NUTRIENT ADEQUACY IN GHANA, NOVEMBER-DECEMBER 2017



Source: Authors calculations

fish, eggs, dark green leafy vegetables, vitamin A-rich fruits and vegetables, other vegetables, and other fruits). Our CoDD1 metric is the price of including the fifth group, providing a strictly literal interpretation of the MDD-W indicator, using a minimum of data to measure the cost of reaching that nutritional standard. Our CoDD2 measure is broader, and reflects the cost of including any of the food groups for which we have prices. In each case, the concept embodied in this measure is that of dietary diversity itself, namely that foods within a group can substitute for each other, while each successive group brings distinct and increasingly valuable attributes up to the level needed for a minimally healthy diet.

The new CoDD index, like the MDD-W indicator of diet quality, is designed for use in data-scarce settings. Unlike standard food price indices such as the Cost of Nutrient Adequacy (CoNA), it uses no information on quantities actually consumed or traded. The weight of each food is either zero or one, based purely on whether it is the least-cost item in each food group as established by the MDD-W. Like the MDD-W indicator, this allows the measure to make effective use of the limited information available in situations such as Ghana's price series for 28 foods in 8 food groups shown in Figure 4.

Future work will validate the CoDD relative to CoNA, and compare them to CPI values to determine change in access to nutritious diets across local food environments. We also aim to use these indexes to test the degree to which improvements in market access and agricultural production can reduce and stabilize the cost of nutritious diets, which in turn can improve food security, diet quality and nutrition outcomes. With increasing availability of data on a wider variety of nutritious foods, these indexes could permit significant improvements in how food environments are measured, leading to more informative monitoring, evaluation and ultimately more effective interventions to change food systems for the better.

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