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Accounting for Dietary Deprivations in Rural Africa

Poor Households, Poor Farms or Poor Food Environments?

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Abstract

Agricultural and food policies are increasingly asked to do more to improve the dietary quality of populations in lower and middle income countries (LMICs), especially severely malnourished rural populations. However, the appropriate strategy for improving diet quality remains an open question. Agriculture has traditionally focused on food security and poverty reduction, mostly through investments in staple crops, while social protection programs have also sought to improve diets through poverty reduction. Nutrition-sensitive agriculture programs traditionally emphasize farm-level diversification into nutrient-dense crops and/or livestock, combined with nutrition education. More recently, some researchers have moved beyond the farm to assess the role of market access and local food environments more generally, though little research has focused on food environments in rural Africa. In this study we explore the determinants of a new and improved measure of household diet deprivation(s) that measure consumption gaps for diets as a whole as well as gaps for individual food groups. Using national datasets for rural Nigeria, Ethiopia and Tanzania, we conduct a “racehorse” regression analysis that reveals strong support for the role of wealth in reducing dietary deprivation, evidence that livestock diversification is important but not crop diversification, and indications that local farming systems are also strongly associated with dietary outcomes, but market access indicators are not. While more research is needed, we conclude that the evidence supports strategies that combine income/wealth enhancement objectives with livestock diversification where possible. Evidence on the linkages between food environments and diet quality in rural areas of LMICs is currently too limited and warrants further research of the observational and experimental variety.

Keywords: Nutrition; agriculture; income; diversification; food markets; farming systems.

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1. Introduction

The potential for agricultural development to reduce poverty in low- and middle-income countries (LMICs) is long established; the potential for agricultural development to reduce malnutrition much less so (Headey and Masters, 2021). Most nutrition-sensitive agricultural programs have been implemented only at small scale (Ruel et al., 2018); crop diversification seems weakly associated with dietary diversity of farm households (Jones, 2017; Sibhatu and Qaim, 2018), and research on food markets and food environments more broadly is very limited for rural populations in LMICs (Headey et al., 2019). This study therefore agnostically seeks to assess support for three stylized strategies for improving agri-food systems for better diet quality in four sub-Saharan countries.

The first such strategy we consider is one we term *the income/wealth strategy*, whereby low incomes or wealth are assumed to be the main constraint to improving healthy diets, because nutrient-dense fruits, vegetables, and animal sourced foods (ASFs) are more expensive sources of calories than starchy staples (Headey and Alderman, 2019) and because global and regional evidence shows that the vast majority of LMIC populations cannot afford healthy diets (FAO et al., 2022b; Headey et al., 2023; Hirvonen et al., 2020). Facing severe income constraints, poor people consume very high levels of starchy staples (i.e., cheap calories), but switch to more nutrient-dense calories as income/wealth increases (Subramanian and Deaton, 1996).

While income fundamentalism is contentious in the nutrition literature (Alderman et al., 2015; Vollmer et al., 2013), there is certainly growing support for this view given influential new evidence on diet affordability problems. The 2022 State of Food Insecurity and Nutrition in the World (SOFI) report estimated that roughly 3 billion people cannot afford a healthy diet (FAO et al., 2022a). Using more granular household expenditure and food price data from national surveys in four East African countries, Headey et al. (2023) find that 70-90 percent of households cannot afford the EAT-Lancet diet. Yet as income grows, income elasticities reveal that African households do indeed spend more on ASFs and fruits, suggesting consumers will purchase much more of these foods than they will purchase additional starchy staples when incomes increase, though preferences for pulses, nuts, and vegetables are often much weaker (Choudhury et al., 2019; Colen et al., 2018; Headey et al., 2023). Moreover, while most healthy foods usually have high income elasticities, so too do many unhealthy, highly processed foods like sweetened beverages and snacks dense in sugar, fat, or salt (Colen et al., 2018). The income fundamentalist view may be partially correct, but income growth has still produced unbalanced diets and elevated obesity and non-communicable disease risks throughout LMICs (Popkin et al., 2020).

The second strategy for improving diets that we consider is *the farm-level diversification strategy*, which involves encouraging poor people to produce nutrient-dense foods, and appreciate their healthfulness, so that they can then eat those foods (or sell them for income gains that can then be used to buy other healthy foods). This approach assumes that consumers face both accessibility problems – in terms of low income and actual limited physical access to healthy foods in local markets – and nutritional knowledge constraints. Enhanced Homestead Food Production (EHFP) strategies, of the kind developed by Helen Keller International (HKI) in the late 1980s and 1990s, typically combine agricultural extension for nutrient-dense fruits and vegetables and small-scale livestock (mostly poultry) with nutritional knowledge interventions to raise caregiver awareness of the nutritional benefits of consuming these foods, and women's empowerment interventions to improve their control of key nutritional resources (Haselow et al., 2016). Encouragingly, program evaluations of these interventions have often found some dietary improvement and reduced micronutrient deprivation (Dulal et al., 2017; Iannotti et al., 2009; Murty et al., 2016; Olney et al., 2009; Osei et al., 2017; Osei et al., 2015; Schreinemachers et al., 2016; Talukder et al., 2010; Tesfamariam et al., 2018). However, this approach has an obvious theoretical and practical limitation: farm-level diversification for subsistence consumption is only likely to improve diets marginally because smallholders are far too constrained by land, labor, and capital limitations to produce sufficient nutrient-dense foods to close healthy diet gaps (and those gaps are large). Moreover, survey evidence from Africa suggest that consumers already purchase the vast majority of their nutrient-dense food consumption from markets, even in rural areas (Sibhatu and Qaim, 2017). Observational evidence also suggests weak associations between farm-level crop diversity and household diet diversity (Jones, 2017; Sibhatu and Qaim, 2018), though livestock production may be more strongly associated with consumption of ASF products, especially dairy (Choudhury and Headey, 2018; Hoddinott et al., 2015; Kabunga et al., 2017).

A third and emergingly popular approach is one that might be termed *the strengthening food environments strategy*. This much more nascent strategy assumes that food environments - the interface where people interact with the wider food system to acquire and consume foods - are influential in shaping dietary choices. However, while there is currently rapid growth in this research in LMICs, a 2020 scoping review found 70 studies on food environments in LMICs, but none in low income countries, and very few focused on rural populations (Turner et al., 2020). Poor food environments can refer to high or variable prices of nutrient-dense foods, limited diversity of foods, low quality of available foods, food safety, as well as packaging, marketing and advertising. This complexity makes food environments difficult to measure, especially at scale. Defining food environments in rural areas can also be challenging because of the varying or even shifting importance of consuming products from one's own farm, from one's neighbors, and from different kinds of markets and food vendors (Headey et al., 2019). Empirically, a major challenge is measuring food environment characteristics at scale. National “household” surveys rarely contain much information on food environment characteristics, and what data is collected (e.g. through community survey instruments) is rarely analyzed.

In this study we aim to provide several novel contributions to the literature on foods systems and diets.

First, while most studies focus on one of the strategies above, we try to assess empirical support for these strategies in a comparative framework, by attempt to run a fair “horse race” between alternative models. Such an approach comes with caveats. Conceptually, we do not claim that experts in any field unequivocally support a specific strategy to the exclusion of other strategies. Empirically, the fairness of the horse race may be limited by what can be measured in either household survey or geographic information systems (GIS) databases. Practically, whether policies derived from these strategies can cost-effectively improve dietary outcomes is a separate question we do not address, albeit one of great practical importance.

Second, we study the determinants of diet quality using a new household dietary deprivation index that compares actual household consumption of different food groups to recommended food intake levels (Pauw et al., 2023); in this case using the EAT-Lancet healthy reference diet (Willett et al., 2019). This index is a significant improvement over alternative measures like the Household Dietary Diversity Score (HDDS) or Food Consumption Score (FCS), because although it still captures the importance of diversity of food groups, it additionally incorporates quantitative data on the gaps between actual consumption and recommended consumption.

Third, unlike many analyses of the determinants of diets and food environment characteristics in urban areas in a given country or specific municipality, ours is a multi-country study, focusing on low-income countries that are still predominantly rural, and still heavily dependent on agriculture and underlying agro-climatic conditions, which may in turn shape local farming systems and food environments more broadly.

The remainder of this study is structured as follows. Section 2 describes our data and empirical approach. Section 3 presents our results, while Section 4 provides a brief summary of our key findings.

2. Data and Empirical Approach

2.1 Household Survey data

The dataset for this analysis combines multiple rounds of LSMS-ISA surveys from three African countries: Ethiopia (2015, n=1738), Nigeria (2012, 2015, 2018; n=5353), and Tanzania (2012, n=5885).[1] These surveys rounds were selected on the basis of availability of key agri-food system indicators, as not all LSMS-ISA rounds contain necessary indicators, particularly on food environment characteristics like market access.

2.2 Measuring Diet Quality

The outcome variable of our empirical analysis is a new dietary measure, termed the Reference Diet Deprivation (ReDD) index (Pauw et al., 2023). The ReDD index relates observed household diets to an ideal reference diet to construct a population-level, adjusted gap measure of household diet quality. The aggregate ReDD index is composed of three indicators that reflect the incidence, breadth, and depth of diet deprivation across multiple, nutritionally essential food groups. The first indicator is a headcount rate that gives the share of the population that is deprived in at least one of these food groups. The second indicator is the average deprivation share of the food-group-deprived persons, while, for each food group, all persons within a household are considered deprived, if the household consumes less than the reference intake for that food group. The third indicator is the average deprivation gap across all food groups, with a food group gap being calculated as the difference between the reference intake and the observed consumption amount (that is set equal to zero if a households' consumption exceeds the reference intake). The aggregate ReDD index is obtained by multiplying these three indicators, such the aggregate index falls within a range of [0,1], with higher numbers indicating greater deprivation.[2] An aggregate ReDD index equal to zero would suggest consumption of a fully healthy diet, while an index equal to one would suggest a diet that exclusively consist of (unhealthy) discretionary foods and hence lacks any nutritionally required food groups.[3]

The approach underlying the ReDD index construction is methodologically similar to, and draws motivation from, the Multidimensional Poverty Index developed Alkire and Foster (2011) where the "dimensions of deprivation" of the ReDD index are the essential food groups considered.[4] In this study we elect for these food groups to correspond to the EAT-*Lancet* healthy reference diet

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[1] See the following website for more details: https://www.worldbank.org/en/programs/lsms/initiatives/lsms-ISA#8
[2] To ease interpretation of our regression results below, we multiply the ReDD index values by 100.
[3] In the index's default setup (which is used in this study), equal weights are assigned to all food groups, because these food groups are all important for a healthy diet.
[4] For methodological details, see Pauw et al. (2021).

(Willet et al., 2019). This international reference diet is designed to meet most people's nutritional requirements and reduces the incidence of diet-related non-communicable diseases (such as cardiovascular diseases, type-two diabetes, and colorectal cancers), and preventable overall mortality. This reference diet (summarized in Appendix 1) consists of a balanced mix of 21 plant-based and animal-source food categories that belong to six major food groups (when aggregating cereals and stary roots and tubers into starchy staples), plus non-required, added sugars and other discretionary (and partly unhealthy) foods such as sugar-sweetened beverages, snacks, and condiments. We use this diet for convenience of comparisons across countries, but note that it remains controversial in terms of cultural acceptability, appropriateness for malnourished LMIC populations, and even its ability to achieve micronutrient adequacy (Beal et al., 2023). Moreover, even if imperfect, this diet is still far healthier than the typical diet currently consumed in LMICs (Headey et al., 2023; Sharma et al., 2020). Further details of the diet and the construction of REDD based on this diet are provided in Appendix A.

The ReDD index has three useful properties. First, since it measures deprivation at the level of the household, it recognizes that, even when national food supplies are adequate, there is inequality in the access and utilization of food (Barrett, 2010). Second, as a multidimensional (or multi-food group) diet deprivation measure, the ReDD index captures multiple aspects of diet quality in that it incorporates elements of both nutrient (in)adequacy and (a lack of) dietary diversity, in addition to dietary energy. Third, whereas dietary diversity scores are categorical indicators (e.g. the Household Dietary Diversity Index, HDDI), the information content in the ReDD index is much richer in that it incorporates information both on whether a food group is consumed and the quantitative extent of consumption shortfalls. Among the households in our dataset, the correlation between the ReDD index and HDDS is negative as expected, but only equal to -0.29, most likely because many households will have at least consumed small amounts of nutrient-dense foods in the past week, thus obtaining a high HDDS but still falling far short of meeting the EAT-Lancet reference targets for nutrient-dense foods. The HDDS alone is thus quite limited in the information it conveys as an overall indicator of diet quality as compared with the ReDD index.

2.3 Farming Systems

We also tested a more traditional set of farming system classifications developed Dixon et al. (2001) and updated by Dixon et al. (2020). Dixon et al. (2020) define a farming system as "…a population of farm households, generally of mixed types and sizes, that as a group have broadly similar patterns of resources, livelihoods, consumption, constraints and opportunities, and for which similar bundles of development strategies and interventions would be appropriate. Often, such systems share broadly similar agroecological and market access conditions." (p. 10) Key considerations in distinguishing farming systems include access to agricultural resources, resource endowments, and access to agricultural services. Dixon et al. (2020) identify 15 distinct farming systems in sub-Saharan Africa, 10 of which are represented in the LSMS samples from Ethiopia, Nigeria, and Tanzania (listed in Figure 2 and Appendix 2). While some degree of heterogeneity within farming systems is inevitable (e.g., farm types and sizes, variations in soils), these designations add a dimension of variation in our explanatory variables not captured by national boundaries. As described in the following section, we control for several specific key characteristics of production and marketing environments and use the binary farming systems indicators as added controls to assess robustness across regression specifications.

We had few specific hypotheses related to these farming systems, except that more pastoral systems in Eastern Africa would likely be associated with higher consumption of dairy products and perhaps other animal sourced foods.

2.4 Empirical Approach to explaining dietary deprivation

Following the discussion in the introductory section, we seek to test three distinct strategic perspectives on improving dietary quality in low-income rural settings, first controlling for basic household characteristics, and then adding wealth, farming characteristics and food environment factors.

Household characteristics (H) include household size, the age dependency ratio, age of the household head and whether the household head has completed primary school or secondary school relative to no education.

Wealth (W) is measured as a simple count of the number of key assets owned that is comparable across surveys and countries. We construct our count of household assets as the sum of indicator variables for roof material (excluding grass), floor material (excluding mud, dirt, straw), cooking on a stove, wall material (excluding grass and mud), and ownership of a flush toilet, radio, tv, bike, car or motorcycle, and internet access (for a maximum of 10). We exclude assets such as livestock, which are potentially direct sources of food, to clarify our analysis of the determinants of dietary deprivation.

Farming characteristics (F) include number of crops grown and the number of livestock types owned.

Agri-food environment characteristics (A) include having a market in the survey community and (when available) the distance to the market, travel time to major cities, local population density (to capture local urbanization and market "thickness") and the night lights intensity index to proxy for local economic development (Henderson et al., 2009). Our expectation is that better access to markets, and more urbanization and development should be associated with better dietary quality. Some specifications also include binary indicators for farming systems to address additional unobserved individual characteristics of production environments.

In terms of the regression analysis, our core specification is thus:

$$1) \qquad Y_{ijkl} = \beta_H H_{ijk} + \beta_W W_{ijk} + \beta_F F_{ijk} + \beta_A A_{jk} + \gamma_j + \gamma_k + \gamma_l + \varepsilon_{ijk}$$

Equation (1) states that REDD (Y) for household *i* in country *j*, observed in survey round *k*, is a function of:

$H_{ijk} = f(household\ size, dependency\ ratio, schooling\ \&\ age\ of\ head)$

$W_{ijk} = f(household\ assets)$

$F_{ijk} = f(crop\ diversity, livestock\ diversity)$

$A_{jk} = f(market\ access\ indicators, pop\ density, night\ lights\ )$

and $\gamma_j, \gamma_k, \gamma_l$ are dummy variables for country, survey round and farming system, respectively.

We estimate this equation by pooled ordinary least squares (with country-specific results included for comparison in Appendix 4). We test the specification with and without the farming systems indicators since these partly developed from other food environment type indicators (such as market access and length of the growing period). We also note that in order to facilitate inter-country comparisons, as well as to allow some degree of non-linearity, we break these independent variables into terciles and include indicators for the 2nd and 3rd terciles (measured against the excluded 1st tercile). Lastly, to maximize the available regression samples in the face of numerous missing observations, we employ "Missing-Indicator Method II" from Jones (1996), outlined in Appendix 3.

3. Descriptive results on dietary deprivation and agri-food system characteristics

Table 1 describes rural household characteristics by country. Dietary deprivation is highest in Tanzania and Ethiopia, where the diet deprivation index average exceeds 60%, but substantially lower in Nigeria (43%). There are clearly many households in all three countries with very poor diets (close to 100). Interestingly, however, the household dietary diversity score does not show the same variation across countries: Tanzania and Nigeria have very similar HDDS values despite Tanzania having much worse dietary deprivation than Nigeria. Moreover, the better quality of the diet in Nigeria is consistent with Nigeria having a much higher mean asset count (5.41 assets) compared to Tanzania (3.11 assets) or Ethiopia (just 1.53 assets). This suggests there is indeed value in incorporating food group quantities, not just counts, into household dietary indices.

There are some demographic differences of note (a high dependency ratio in rural Ethiopia), but household sizes are fairly large in all countries, on average. Secondary school completion is notably low in rural Ethiopia (5%), but somewhat higher in rural Tanzania (27%) and rural Nigeria (33%).

Table 1: Household Characteristics, by Country (Rural Sample)

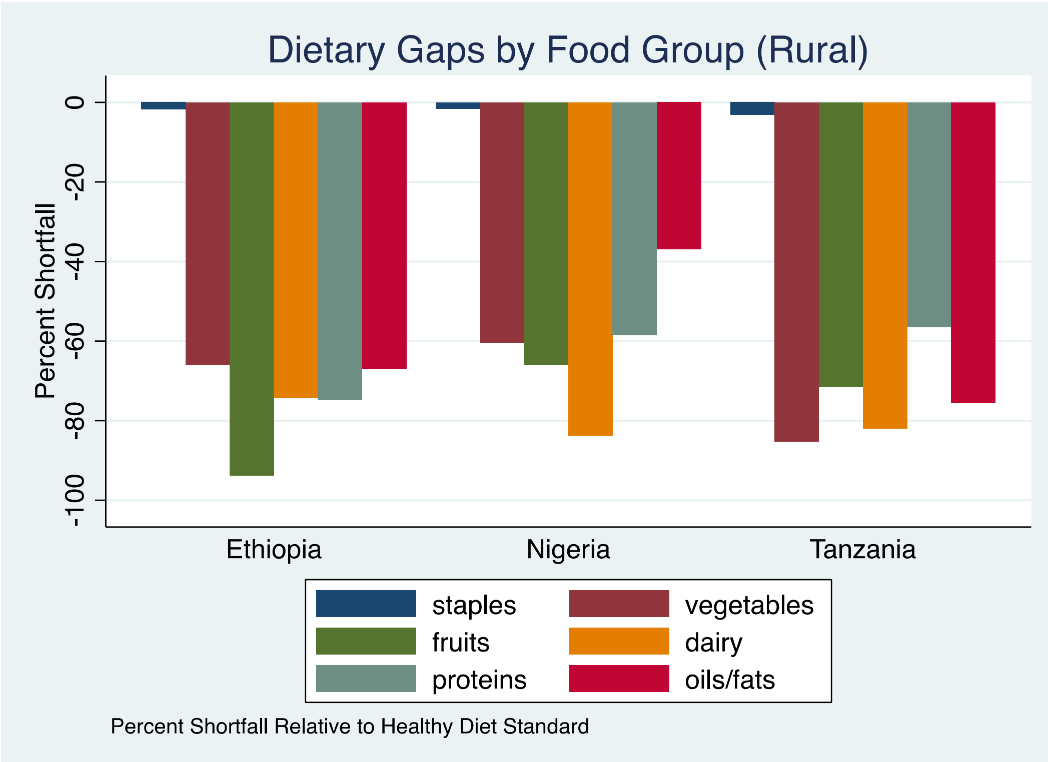
country:

Ethiopia	N	Mean	SD	Min	Max
Dietary Deprivation	1738	62.91	12.31	12.81	83.64
HDDS	1738	6.85	1.6	2	12
Household size	1738	7.2	2.32	2	17
Dependency Ratio	1738	1.31	.17	1	1.78
Age of head	1729	40.55	11.82	19	93
Head completed prim school	1738	.1	.3	0	1
Head completed sec school	1738	.05	.21	0	1
Assets	1738	1.53	1	0	6
Nigeria					
Dietary Deprivation	5353	43.03	14.78	0	82.06
HDDS	5353	8.3	1.9	1	12
Household size	5353	8.93	3.81	2	34
Dependency Ratio	5353	.66	.12	.17	1
Age of head	5332	44.31	11.27	19	100
Head completed prim school	4764	.6	.49	0	1
Head completed sec school	4764	.33	.47	0	1
Assets	5353	5.41	2.37	0	11
Tanzania					
Dietary Deprivation	5885	62.3	12.23	8.33	84.55
HDDS	5885	8.21	1.84	2	12
Household size	5885	7.81	5.22	2	55
Dependency Ratio	5885	.63	.14	.2	1
Age of head	5884	43.33	14.27	18	108
Head completed prim school	5885	.36	.48	0	1
Head completed sec school	5885	.27	.44	0	1
Assets	5885	3.11	1.61	0	8

Source: Authors' calculations from LSMS-ISA surveys, various rounds: Ethiopia (2015), Nigeria (2012, 2015, 2018), and Tanzania (2012).

The ReDD index is a composite index that incorporates the consumption shortfalls for the six required food groups, illustrated by country in Figure 1 in percentage terms relative to healthy diet standards. The patterns of shortfalls in consumption by food group are consistent across countries, with the smallest gaps in the consumption of staples and substantial gaps in the remaining – more nutrient-dense – food groups.

Figure 1. Dietary deprivation by food Group across countries



Source: Authors' calculations from LSMS-ISA surveys, various rounds: Ethiopia (2015), Nigeria (2012, 2015, 2018), and Tanzania (2012).

Table 2 summarizes data describing each country's observable key agri-food system characteristics: length of growing period, rural population density, travel time to a major city, distance to market, number of crops grown and number of livestock species owned, with these last two variables measured at the household level and all other variables measured at the community level. The two household level variables on number of crops and livestock species also have smaller samples sizes because they only apply to farm households.

The length of the growing period (LGP) is an important indicator of both the number of staple crop harvest that could be grown, but also water availability for fruit and vegetable production. The average LGP is not very different across countries, but there is large variation within countries, as from a maximum of roughly 300 days per year to just 41 days per year in Ethiopia, 75 in Nigeria and 126 in Tanzania. Thus, LGP is best captured by farming system indicators. Travel time to cities is much larger in Tanzania and Ethiopia compared to Nigeria, yet the distance to the nearest market is similar across all three countries. Market density, as indicated by the presence of a market in the community is somewhat greater in Ethiopia, where this is true for 46 percent of households compared with less than 40 percent of households in Nigeria and Tanzania.

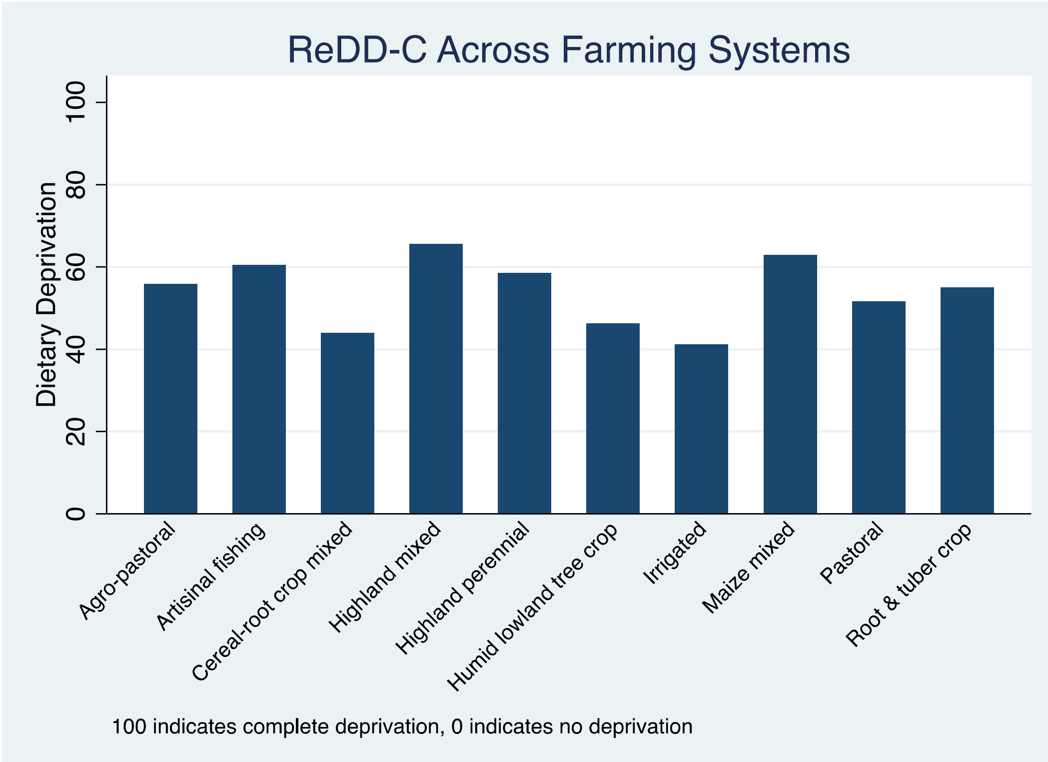
Table 2: Farm System Characteristics, by country

Ethiopia	N	Mean	SD	Min	Max
Have a market in community	6406	.46	.5	0	1
Population density/sqkm (rural)	6436	129.01	120.38	1.51	695.01
Median travel time (mins) to City	6436	115.88	99.48	4.27	587.13
HH Distance in (KMs) to Nearest Mkt	6436	72	55.02	.5	283.3
Number of crops grown by HH	6174	4.14	3.74	0	21
Length of Growing Period	6436	197.23	68.75	40.86	303.66
Nigeria					
Have a market in community	7541	.39	.49	0	1
Population density/sqkm (rural)	5682	184.34	197.68	0	1493.1
Median travel time (mins) to City	5682	39.02	33.98	0	281.52
HH Distance in (KMs) to Nearest Mkt	5682	71.46	39.64	.38	214.36
Number of crops grown by HH	6764	4.35	2.66	0	22
Length of Growing Period	5682	184.45	54.86	74.63	289.53
Tanzania					
Have a market in community	3398	.39	.49	0	1
Population density/sqkm (rural)	5980	117.85	293.19	0	4042.2
Median travel time (mins) to City	5980	128.76	103.73	0	644.82
HH Distance in (KMs) to Nearest Mkt	5980	86.87	52.16	1.7	257.1
Number of crops grown by HH	5857	1.92	1.51	0	11
Length of Growing Period	5980	212.24	29.04	126.00	302.43

Source: Authors' calculations from LSMS-ISA surveys, various rounds: Ethiopia (2015), Nigeria (2012, 2015, 2018), and Tanzania (2012).

Figure 2 illustrates mean levels of ReDD for each farming system. Dietary deprivation also varies widely by farming system. Irrigated systems exhibit the lowest level of dietary deprivation (42.5), while mixed maize and highland mixed systems exhibit the greatest levels of deprivation (61.7 and 61.3, respectively).

Figure 2. Dietary deprivation by farming system (rural sample)



Source: Authors' calculations from LSMS-ISA surveys, various rounds: Ethiopia (2015), Nigeria (2012, 2015, 2018), and Tanzania (2012).

4. Regression Results

4.1 Determinants of aggregate dietary deprivation pooled across the three countries

Table 3 provides pooled cross-country results for equation (1).[5] Diet quality suffers in larger households with older heads and higher proportions of children and elderly. Primary education of the household head improves diet quality relative to no education, but surprisingly, secondary education has no statistical association with diet quality.

In regression 2 in Table 3 we compare middle and upper asset terciles to the omitted low asset tercile category. There is a moderately strong negative association with dietary deprivation. On average, households in the middle tercile category (in the fully-specified model) have a 2.5 lower deprivation index score while the high asset score households have a 3.7 lower deprivation index. Figure 3 underscores this result, illustrating the non-parametric association between diet quality improvements with greater asset ownership. The result seems mostly linear, with the very

[5] We provide country-specific results for these specifications in Appendix 4.

poorest households have deprivation scores of about 60 compared to 40 for the richest households.

Table 3. Determinants of Dietary Deprivation pooled across countries (rural sample)

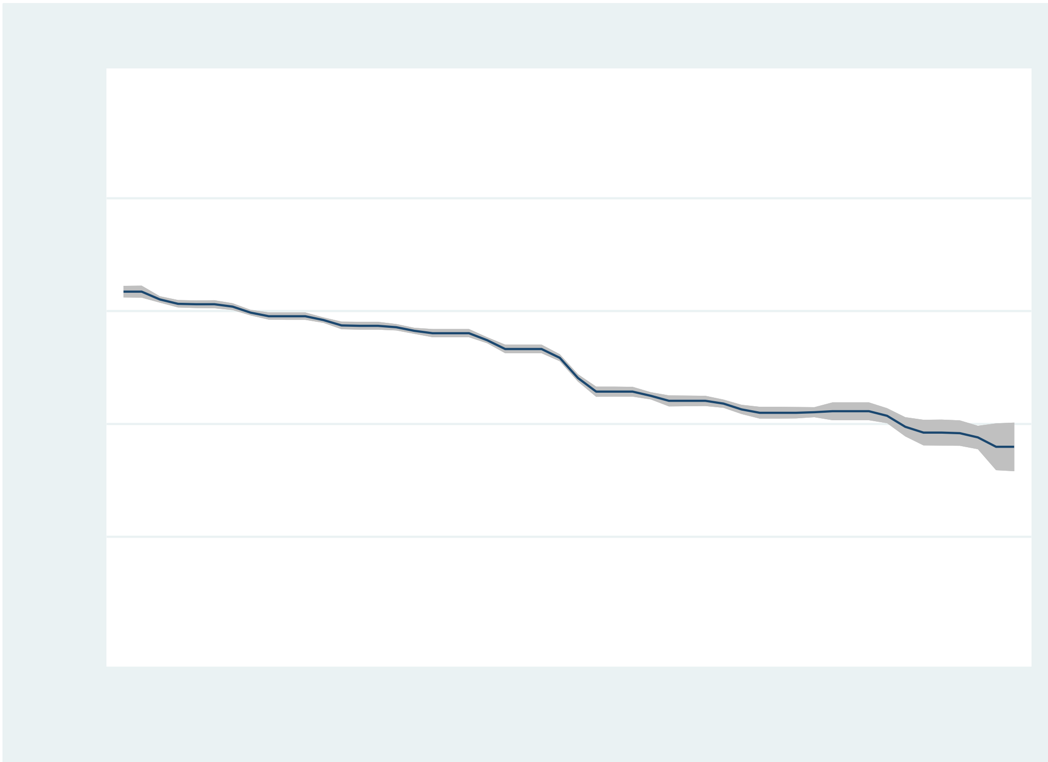
	(1)	(2)	(3)	(4)	(5)	(6)
			Household Controls			
Household Size	0.287***	0.338***	0.359***	0.272***	0.399***	0.416***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Dependency Ratio	8.558***	7.726***	8.983***	8.649***	8.277***	8.015***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Head Age	0.0643***	0.0685***	0.0681***	0.0660***	0.0740***	0.0659***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Primary Educ (head)	-1.040**	-0.699	-1.255***	-0.938**	-0.815*	-1.065**
	(0.022)	(0.122)	(0.006)	(0.041)	(0.075)	(0.019)
Secondary Educ (head)	0.468	0.0509	0.557	0.346	0.0323	0.0916
	(0.357)	(0.920)	(0.273)	(0.498)	(0.950)	(0.856)
			Wealth variables			
Asset count: med vs. low		-2.566***			-2.326***	-2.458***
		(0.000)			(0.000)	(0.000)
Asset count: high vs. low		-3.339***			-3.173***	-3.650***
		(0.000)			(0.000)	(0.000)
			Farm Diversification Variables			
Number of Crops: med vs. low			0.350		0.292	0.0757
			(0.345)		(0.430)	(0.838)
Number of Crops: high vs. low			0.453		0.389	0.165
			(0.282)		(0.361)	(0.702)
Number Lvstk Species: med vs. low			-1.645***		-1.684***	-1.275***
			(0.000)		(0.000)	(0.001)
Number Lvstk Species: high vs. low			-2.812***		-2.966***	-2.814***
			(0.000)		(0.000)	(0.000)
			Agro-Food Environment			
Has market in community				-0.498	-0.573*	-1.156***
				(0.121)	(0.075)	(0.000)
Time to City: med vs. low				0.0438	0.103	0.675
				(0.926)	(0.828)	(0.157)
Time to City: high vs. low				0.718	0.700	1.785***
				(0.205)	(0.218)	(0.002)
Distance to market: med vs low				0.588	0.596	-0.116
				(0.157)	(0.151)	(0.780)
Distance to market: high vs low				0.319	0.00662	-0.869**

	(1)	(2)	(3)	(4)	(5)	(6)
				(0.446)	(0.987)	(0.043)
Pop. density: med vs low				0.502	0.390	0.0998
				(0.171)	(0.286)	(0.799)
Pop. density: high vs low				-0.477	-0.553	-1.195**
				(0.314)	(0.242)	(0.025)
Night lights: med vs low				-0.542	-0.570	0.0154
				(0.147)	(0.126)	(0.967)
Night lights: high vs low				-0.234	-0.155	0.361
				(0.650)	(0.765)	(0.489)
Additional Geographic/Farming System Effects relative to agro-pastoral system						
Artisanal Fishing						-0.832
						(0.238)
Cereal-Root Crop Mixed						0.766
						(0.215)
Highland Mixed						3.142***
						(0.000)
Highland Perennial						-4.249***
						(0.000)
Humid Lowland Tree Crop						4.529***
						(0.000)
Irrigated						-1.776*
						(0.055)
Maize Mixed						-0.850*
						(0.087)
Pastoral						-11.46***
						(0.000)
Root & Tuber Crop						1.341**
						(0.030)
Observations	7178	7178	7178	7178	7178	7178
Adjusted R-squared	0.390	0.396	0.394	0.391	0.401	0.419
F	511.0	428.7	360.6	257.2	201.3	158.1

Source: Authors' calculations from LSMS-ISA surveys, various rounds: Ethiopia (2015), Nigeria (2012, 2015, 2018), and Tanzania (2012).

Notes: All specifications include country and survey round indicators. *p<.10 **p<.05 ***p<.01
dietary deprivation is measured on a scale from 0 to 100, where 100 indicates complete deprivation. Thus, positive coefficient estimates indicate increased deprivation.

Figure 3. Dietary deprivation as a function of household asset holding in a local polynomial smoothing regression with 95% confidence intervals



Source: Authors' calculations from LSMS-ISA surveys, various rounds: Ethiopia (2015), Nigeria (2012, 2015, 2018), and Tanzania (2012).

In regression 3 we add the two farm diversification variables, the number of different crops grown and the number of livestock species owned. Crop diversification, conditional on this specification (and in particular, conditional on livestock diversification) has no statistically detectable effect on dietary deprivation. In contrast, diversity in livestock holdings has a much larger and increasing marginal reduction in dietary deprivation.

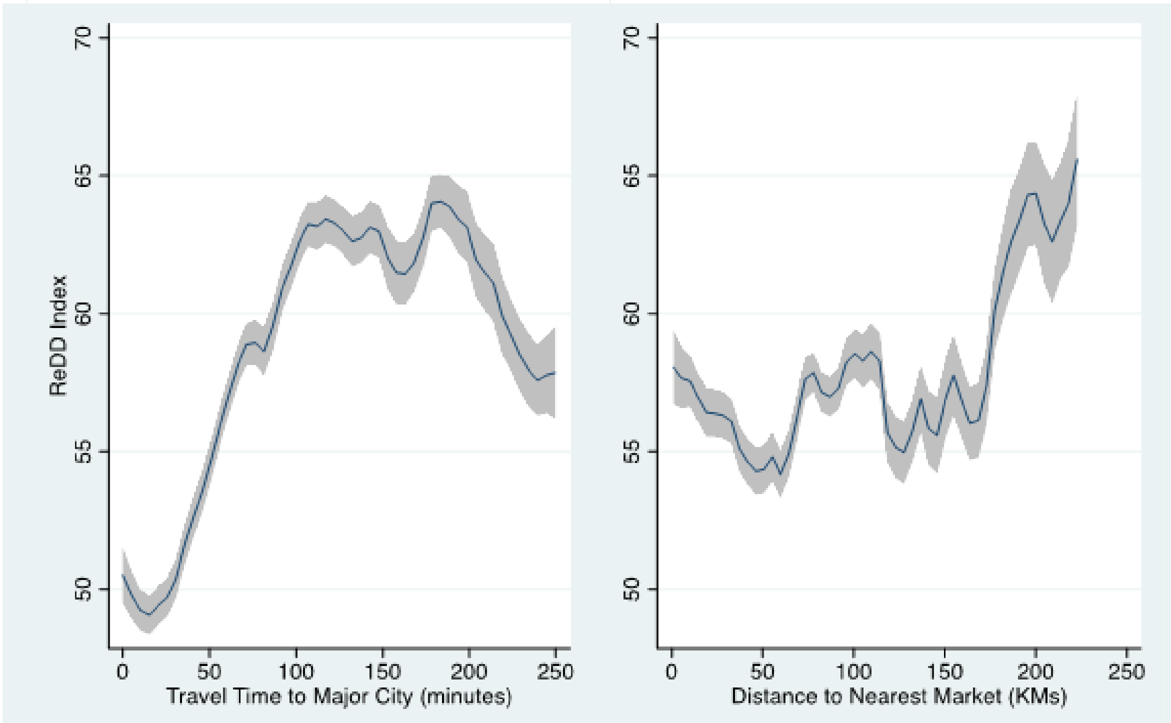
Column 4 introduces our agri-food system characteristics. The associations between diet quality and market access are clear. The existence of a community market has a small but statistically robust association with reduced deprivation. The tercile with the longest travel time to cities has a marginally significant association with greater dietary deprivation, suggesting the longest travel times to cities is moderately harmful to diet quality. Yet, there is weakly suggestive evidence that moderately distant households fare worse than the farthest, suggesting the latter may have adapted to remoteness.

Our three indicators of market access (existence of a community market, distance to major markets, and travel time to cities) appear together in these specifications. Running specifications (not shown) of the model in Table 3 that include these three indicators one at a time and then together yields similar results to those in regression 4 (the only difference being that the high vs low comparison for distance to markets loses significance when distance is included separately). The most robust of these three indicators remains the existence of a community market, though the effect size is small.

We interpret rural population density as a proxy for market density and find small but statistically significant and increasing marginal improvements in diet quality in the most densely populated communities. From a resilience perspective, these findings underscore the community-level contribution of market access to households' capacity to absorb shocks to their food system. Regression 6 adds indicators for each farming system, to capture system-specific effects beyond those controlled individually. These farming system indicators remain jointly significant (F = 10.25, P = 0.000).

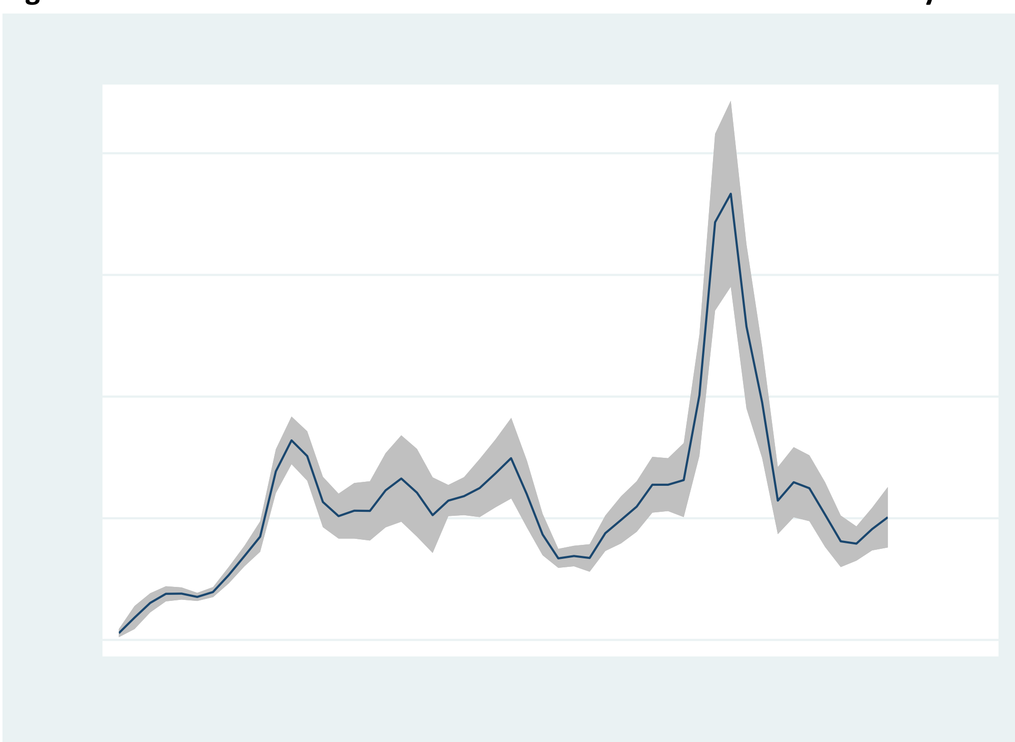
Figure 4 provides a nonparametric counterpart to these results, demonstrating rapidly increasing deprivation for travel times to cities up to approximately 100 minutes. Households with the longest travel times to cities demonstrate some improvements in diet quality – a counterintuitive result possibly reflective of their greater need for self-sufficiency, or greater livestock ownership and higher animal sourced food consumption; indeed, Figure 5 shows a sharp spike in the numbers of cattle owned among more remote households. Individually, this spike in cattle ownership occurs at similar levels in both Nigeria and Tanzania, while Ethiopia exhibits a more gradual increase in cattle ownership as a function of travel time to cities. In Figure 4 we also find strongly increasing deprivation among households residing farthest (in kilometers) from cities. This sharp upturn reflects the experience of approximately the farthest 10 percent of the sample households.

Figure 4. Diet deprivation as a function of travel time to city and distance to market



Source: Authors' calculations from LSMS-ISA surveys: Ethiopia (2015), Nigeria (2012, 2015, 2018), and Tanzania (2012).

Figure 5. Number of Cattle Owned as a Function of Travel Time to City



Source: Authors' calculations from LSMS-ISA surveys: Ethiopia (2015), Nigeria (2012, 2015, 2018), and Tanzania (2012).

In regression (5) of Table 3 we specify all these sets of explanatory variables together. There are some changes in coefficients – wealth associations weaken marginally, for example – but mostly it seems that different kinds of factors influence dietary deprivation independently. Finally, regression (6) adds farming system characteristics that are, by construction, partially correlated with other variables such as market access and population density. Intriguingly, compared to the omitted agro-pastoral groups, several farming system characteristic categories have statistically significant coefficients. Humid lowland tree crop households have much more dietary deprivation than the agro-pastoral base, while highland perennial and pastoral households have much less deprivation. Joint F-tests of country indicators and of farming system indicators in column 6 of Table 3 are both statistically different from zero.

We thus find evidence in support of at least some aspects of all three stylized strategies for improving diet quality outlined above. Yet, within these categories, we find both non-linearities and differences within categories. For example, within the production diversity category, we find stronger contributions of livestock than for crop diversity in reducing dietary deprivation. While jointly significant, individual dimensions of agri-food systems vary in their significance.

4.2 Determinants of Consumption Gaps by Major Food Group

The summary diet deprivation index aggregates the degree of deprivation across major food groups. While that broad view of dietary quality is our core focus, it is additionally informative and potentially more conducive to policy recommendations to consider the predictors of consumption gaps for individual food groups. Table 4 uses the fully-specified model in equation (1) for each major food group. Among household controls, age of household head is consistently associated with increased deprivation, with the only exception being dairy. Education has weak associations with food group specific deprivation. In contrast, households with more assets substantially reduce percentage shortfalls across all food groups. These associations are highly non-linear for fruits, dairy, proteins, and oils/fats – food groups typically found to have especially high income elasticities of demand. These results are broadly consistent with recent studies from sub-Saharan Africa showing high income or wealth elasticities for animal sourced foods and fruits (Colen et al. 2018; Choudhary et al. 2017; Headey et al., 2023). Figure 6 underscores the effect of asset accumulation in reducing consumption shortfalls relative to healthy diet standards across food groups.

The results for crop diversification differ across food group outcomes. We find significant and increasing marginal benefits of crop diversification for consumption of vegetables, fruits, and proteins; yet the results suggest a possible tradeoff between those groups and dairy. However, livestock diversity has a large and increasing marginal association with dairy consumption, and a more modest association with protein consumption. This result is consistent with previous studies from East African countries especially (Rawlins et al., 2014; Hoddinott et al. 2015; Kabunga et al. 2017).

Associations for community markets are quite modest, being somewhat important for consumption of proteins and fruits, but not strongly associated with other deprivations. (It is not clear why presence of a community market would increase deprivation in dairy.) There are likewise positive and negative coefficients associated with distance to markets. Remoteness from cities is associated with lower vegetable and oils/fats consumption. Higher rural population density appears to increase stress on the supply of staples, but the associated market density has beneficial effects for the consumption of more perishable goods such as fruits in particular. Night light intensity is also associated with more fruit consumption, but curiously is also associated with reduced consumption of vegetables.

Table 4. Determinants of Food Group-Specific Deprivations in Household Diets

	(1) Staples	(2) Vegetables	(3) Fruits	(4) Dairy	(5) Proteins	(6) Oils/Fats
			Household Controls:			
Household Size	0.0195	0.812***	0.760***	-0.129	0.690***	0.743***
	(0.503)	(0.000)	(0.000)	(0.173)	(0.000)	(0.000)
Dependency Ratio	1.376*	13.93***	-1.590	5.733**	10.59***	16.46***
	(0.086)	(0.000)	(0.570)	(0.026)	(0.000)	(0.000)
Age of head	0.0368***	0.121***	0.0416	0.00393	0.109***	0.140***
	(0.000)	(0.000)	(0.183)	(0.892)	(0.000)	(0.000)
Head completed primary school	0.174	-1.843**	-0.325	-0.716	-1.350	-1.078
	(0.594)	(0.019)	(0.787)	(0.520)	(0.190)	(0.242)
Head completed secondary school	0.166	0.278	0.372	-2.799**	-0.720	-0.102
	(0.647)	(0.751)	(0.780)	(0.024)	(0.530)	(0.921)
			Wealth Strategy:			
Assets tertile 2 vs 1	-0.552**	-2.220***	-3.190***	-2.422***	-2.061**	-7.663***
	(0.033)	(0.000)	(0.001)	(0.004)	(0.012)	(0.000)
Assets tertile 3 vs 1	-1.239***	-2.230***	-6.648***	-6.879***	-5.604***	-10.33***
	(0.000)	(0.004)	(0.000)	(0.000)	(0.000)	(0.000)
			Farm Diversification Strategy:			
Number of Crops: med vs. low	-0.303	-1.589**	0.491	2.146**	-0.463	1.781**
	(0.254)	(0.013)	(0.604)	(0.013)	(0.582)	(0.018)
Number of Crops: high vs. low	-0.0700	-2.108***	-3.226***	3.404***	-3.936***	4.645***
	(0.821)	(0.005)	(0.004)	(0.001)	(0.000)	(0.000)
Number Lvstk Species: med vs. low	-0.447	0.0686	0.189	-7.391***	-0.117	0.618
	(0.109)	(0.919)	(0.851)	(0.000)	(0.894)	(0.432)
Number Lvstk Species: high vs. low	-0.546*	0.598	0.639	-16.63***	-1.075	-0.936
	(0.057)	(0.388)	(0.538)	(0.000)	(0.236)	(0.248)

	(1) Staples	(2) Vegetables	(3) Fruits	(4) Dairy	(5) Proteins	(6) Oils/Fats
			Agro-Food Environment:			
Community Market Exists	-0.0899	-1.321**	-1.687**	1.551**	-1.172	-0.947
	(0.698)	(0.018)	(0.036)	(0.037)	(0.109)	(0.148)
Distance to Mkt tertile 2 vs 1	0.733**	-0.655	-2.430**	0.549	-3.032***	3.700***
	(0.014)	(0.363)	(0.022)	(0.572)	(0.001)	(0.000)
Distance to Mkt tertile 3 vs 1	-0.00795	-0.730	-1.895*	-0.109	-4.809***	3.927***
	(0.979)	(0.328)	(0.084)	(0.914)	(0.000)	(0.000)
Travel Time to City tertile 2 vs 1	0.194	2.072**	0.475	-0.00334	-0.503	1.473
	(0.571)	(0.013)	(0.712)	(0.998)	(0.642)	(0.128)
Travel Time to City tertile 3 vs 1	0.833**	6.098***	-1.579	-0.629	-2.721**	5.576***
	(0.044)	(0.000)	(0.294)	(0.651)	(0.037)	(0.000)
Pop Density (rural) tertile 2 vs 1	1.288***	-1.199*	-5.064***	4.568***	-1.535*	3.731***
	(0.000)	(0.077)	(0.000)	(0.000)	(0.084)	(0.000)
Pop Density (rural) tertile 3 vs 1	1.644***	-1.831**	-7.944***	3.500***	-5.517***	1.451
	(0.000)	(0.047)	(0.000)	(0.005)	(0.000)	(0.178)
Night Lights (mean) tertile 2 vs 1	0.631**	1.255*	-3.101***	0.163	0.119	0.716
	(0.018)	(0.051)	(0.001)	(0.853)	(0.887)	(0.342)
Night Lights (mean) tertile 3 vs 1	0.588	2.577***	-3.453**	-3.767***	3.049***	-1.060
	(0.116)	(0.004)	(0.010)	(0.002)	(0.010)	(0.316)
			Additional Geographic/Farming System Effects:			
Agro-pastoral (excluded)						
Artisinal Fishing	2.175***	6.589***	-31.52***	8.735***	-3.359**	11.75***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.035)	(0.000)
Cereal-Root Crop Mixed	1.015**	4.580***	-7.258***	2.808*	0.238	10.42***
	(0.022)	(0.000)	(0.000)	(0.081)	(0.865)	(0.000)
Highland Mixed	0.261	4.060***	-6.828***	14.85***	-0.0277	5.206***

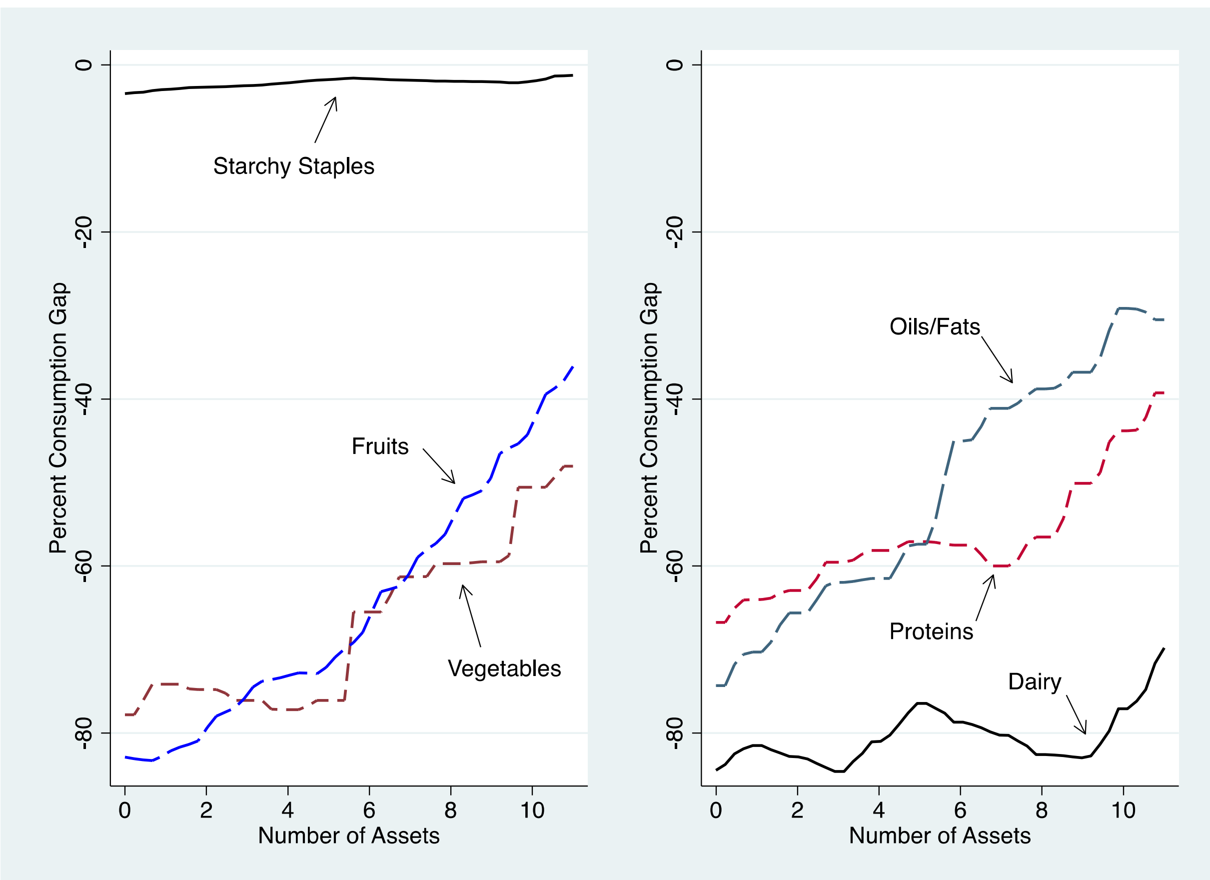
	(1) Staples	(2) Vegetables	(3) Fruits	(4) Dairy	(5) Proteins	(6) Oils/Fats
	(0.605)	(0.001)	(0.000)	(0.000)	(0.986)	(0.000)
Highland Perennial	3.492***	-3.546***	-27.96***	4.977***	-7.163***	4.545***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Humid Lowland Tree Crop	3.908***	9.696***	-29.38***	-1.334	6.885***	19.42***
	(0.000)	(0.000)	(0.000)	(0.500)	(0.000)	(0.000)
Irrigated	-1.062	-1.379	4.935*	3.606	-2.285	-3.745**
	(0.110)	(0.397)	(0.069)	(0.131)	(0.275)	(0.046)
Maize Mixed	0.579	0.817	-18.79***	9.304***	1.218	1.100
	(0.104)	(0.342)	(0.000)	(0.000)	(0.279)	(0.275)
Pastoral	7.023***	-5.535**	-14.35***	-31.71***	2.146	-26.02***
	(0.000)	(0.030)	(0.000)	(0.000)	(0.520)	(0.000)
Root & Tuber Crop	3.679***	5.256***	-20.66***	5.747***	0.0120	8.967***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.993)	(0.000)
Observations	7178	7168	6497	6562	7165	7173
Adjusted R-squared	0.055	0.266	0.265	0.164	0.105	0.416
F	13.75	79.78	71.85	40.06	26.50	156.1
Joint F-test (p-value): Farming Systems	0.000	0.002	0.000	0.000	0.000	0.000

Source: Authors' calculations from LSMS-ISA surveys, various rounds: Ethiopia (2015), Nigeria (2012, 2015, 2018), and Tanzania (2012).

Notes: All specifications include country and survey round indicators. *p<.10 **p<.05 ***p<.01. Gaps in consumption of individual food groups are measured as a percentage of healthy diet requirements. Thus positive coefficient estimates indicate increased deprivation.

Even conditional on this specification, indicator variables for farming systems remain jointly significant for consumption adequacy of each food group. Many of the coefficients on farming systems are very large in magnitude and individually significant. For example, systems with more rainfall – such as highland perennial, maize mixed, root and tuber crops – have much higher fruit consumption. Pastoral systems have much higher dairy consumption than even agro-pastoral, and several systems have much lower dairy consumption than the omitted agro-pastoral group. However, pastoral systems also have much lower vegetable consumption. In short, there seems to be very large variations in consumption of specific food groups across farming systems, and the patterns are largely to be expected, especially at the extremes of very dry livestock-intensive locations (pastoral, agro-pastoral) and very wet agro-ecologies conducive to fruit production or foraging. This also implies that spatial market integration for these perishable foods is likely very poor in rural Africa.

Figure 6. Local polynomial smoothing regression plots of consumption gaps by food group as a function of asset ownership



Source: Authors' calculations from LSMS-ISA surveys, various rounds: Ethiopia (2015), Nigeria (2012, 2015, 2018), and Tanzania (2012).

4.3 Mechanisms

The direct role of asset accumulation in supporting household resilience to shocks is well established. The results above, as well, suggest an indirect contribution of asset accumulation to household resilience via the clear positive effect of assets on diet quality. As asset ownership dominates crop diversification as a driver of dietary quality. Thus, any positive determinants of asset accumulation contribute indirectly to improved diet quality. The question then is what are the drivers of asset ownership?

We address this question by repeating our previous empirical strategy, now with asset ownership as the dependent variable (Table 5).[6] Larger households with a smaller proportion of working age adults, and older heads with at least primary schooling have greater wealth. The result for crop diversification is weakly suggestive of a small negative association with wealth, possibly reflecting on balance the condition of subsistence farmers.

Among our spatial agri-food system characteristics, access to a community market has a small but robust and positive association with wealth. We also find a robust and increasing marginal negative effect of travel time to cities on wealth, potentially reflecting the improved off-farm employment opportunities that come with proximity to cities. The effect of distance to markets (conditional on the existence of a community market) is unclear, with a small positive association for moderately distant households relative to the closest ones, yet a small and negative effect in the fully-specified model. We also find that higher rural population density is associated with less wealth – perhaps a reflection of land constraints - while greater intensity of night lights intensity is associated with more household wealth (clearly a potential artifact of reverse causation). And again, even conditional on observed aspects of the agro-food environment, household controls and crop diversification, indicator variables for farming systems remain jointly significant.

[6] We exclude livestock species diversity from this specification, as livestock ownership in many settings functions directly as a form of wealth holding.

Table 5. Determinants of Asset Ownership

	(1) Assets	(2) Assets	(3) Assets	(4) Assets	(5) Assets
Household Controls:					
Household Size	0.0610***	0.0621***	0.0741***	0.0750***	0.0828***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Dependency Ratio	-1.208***	-1.202***	-1.255***	-1.249***	-1.234***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Head Age	0.00852***	0.00873***	0.00575***	0.00593***	0.00481***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.002)
Primary Educ (head)	0.450***	0.449***	0.392***	0.390***	0.299***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Secondary Educ (head)	-0.327***	-0.334***	-0.280***	-0.284***	-0.208***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)
Farm Diversification Strategy:					
Number of Crops Grown		-0.0189**		-0.0166**	-0.0136*
		(0.013)		(0.026)	(0.075)
Agro-Food Environment:					
Community Market Exists			0.222***	0.223***	0.147***
			(0.000)	(0.000)	(0.000)
Travel Time to City tertile 2 vs 1			-0.315***	-0.324***	-0.218***
			(0.000)	(0.000)	(0.000)
Travel Time to City tertile 3 vs 1			-0.438***	-0.450***	-0.327***
			(0.000)	(0.000)	(0.000)
Distance to Mkt tertile 2 vs 1			0.144***	0.152***	0.0376
			(0.006)	(0.004)	(0.476)
Distance to Mkt tertile 3 vs 1			-0.0998*	-0.0891*	-0.227***
			(0.059)	(0.093)	(0.000)
Pop Density (rural) tertile 2 vs 1			-0.283***	-0.276***	-0.374***
			(0.000)	(0.000)	(0.000)
Pop Density (rural) tertile 3 vs 1			-0.0151	-0.00595	-0.148**
			(0.801)	(0.921)	(0.028)
Night Lights (mean) tertile 2 vs 1			0.000201	-0.00685	0.0401
			(0.997)	(0.885)	(0.394)
Night Lights (mean) tertile 3 vs 1			0.546***	0.533***	0.474***
			(0.000)	(0.000)	(0.000)
Additional Geographic Farming System Effects:					
Agro-Pastoral (excluded)					
Artisinal Fishing					0.347***

	(1) Assets	(2) Assets	(3) Assets	(4) Assets	(5) Assets
					(0.000)
Cereal-Root Crop Mixed					0.512***
					(0.000)
Highland Mixed					0.327***
					(0.000)
Highland Perennial					0.240***
					(0.001)
Humid Lowland Tree Crop					1.297***
					(0.000)
Irrigated					0.0247
					(0.833)
Maize Mixed					0.0354
					(0.569)
Pastoral					0.0284
					(0.880)
Root & Tuber Crop					0.638***
					(0.000)
Observations	7799	7799	7799	7799	7799
Adjusted R-squared	0.383	0.383	0.421	0.422	0.440
F	255.3	243.0	158.8	150.6	110.5
Joint F-test (p-value): Farming Systems					0.000

Source: Authors' calculations from LSMS-ISA surveys, various rounds: Ethiopia (2015), Nigeria (2012, 2015, 2018), and Tanzania (2012).
Notes: All specifications include country and survey round indicators. *p<.10 **p<.05 ***p<.01. Gaps in consumption of individual food groups are measured as a percentage of healthy diet requirements. Thus positive coefficient estimates indicate increased deprivation.

5. Conclusions

This paper presents exploratory analyses of the determinants of diet quality in four African countries using a new and improved measure of household diet deprivation. We assess these determinants from the perspectives of wealth accumulation, production diversification, and key characteristics of the agri-food environment and of African farming systems more generally. What do conclude?

First, we find solid support for the role of wealth in supporting diet quality, consistent with other studies of either household income elasticities or child dietary patterns and their associations with household wealth (Choudhury et al., 2019; Colen et al., 2018; Headey et al., 2023). Clearly, poverty is a root cause of poor diets in Africa, as recent healthy diet affordability studies document (Headey et al., 2023).

Second, we find some support for livestock diversification but not crop diversification. The weak association between crop diversification and diet diversification is consistent with recent reviews of this literature (Jones, 2017; Sibhatu and Qaim, 2018), although those reviews under-emphasize the potential for livestock diversification to influence farm household diets, particularly dairy consumption. A substantial number of studies now show that cow ownership is Africa is a strong predictor of dairy consumption, while study from Ethiopia also shows that there may be community-level spillovers of dairy production on consumption (Headey et al., 2019). Efforts to diversify incomes and diets among farm households should therefore consider livestock interventions. Indeed, a well-known study of asset-building poverty reduction interventions in six countries found that livestock grants were generally highly effective at raising incomes (Banerjee et al., 2015).

Third, access to markets or cities seems to have relatively modest associations with diet quality. One study form Africa that looked at remoteness, urbanization and child dietary diversity reached the same conclusion (Headey et al., 2018), and also found evidence that rural-urban diet quality differences were primarily driven by differences in wealth and other socioeconomic status indicators. Thus, it may be that improving markets or food environments in rural areas, without improving household incomes or wealth, will only lead to modest improvements in dietary diversity.

Fourth, at the farming system level it still seems that agro-ecological conditions matter, at least at the extremes of lower rainfall systems where livestock is important for both livelihoods and diets, and higher rainfall systems that allow greater fruit consumption. Connecting this fact to the weak associations between diet quality and market access indicators leads to the conclusion that food markets in rural Africa are often poorly integrated with each other, leading to spatial disparities in the availability and affordability of different foods, especially perishable foods. Conversely, if markets were integrated and food group preferences were similar over space (perhaps a strong assumption), then farming systems would not be strongly predictive of diet patterns and deprivation. This is only a conjecture, but it is a conjecture consistent with the stylized facts presented above. Further research should document food market integration more rigorously and extensively at the commodity level.

This work has some important limitations. Although we use a much improve dietary deprivation measure, household consumption data have limitations from a dietary perspective, such as inadequate information on food consumed away from home, recall biases and quite high measurement error. Some LSMS-ISA surveys have food lists that are relatively short compared to true population of different foods consumed in Africa's diverse food environments. These surveys, and the community level GIS data we attach to them, also offer limited indicators of the quality and characteristics of rural food environments. For example, the LSMS-ISA contains distance to the nearest food market or presence in a community, but that by itself is far from a complete picture of food access since affordability, availability (across seasons) and food safety and quality may also influence consumption patterns. More granular work on rural food environments is still needed in Africa. Finally, this is an ecological analysis of factors associated with household dietary quality, and we do not claim that these associations are causal.

In summary, dietary quality is very poor in sub-Saharan Africa. Strategies to address this problem should focus on poverty reduction and asset building, including through livestock programs that can also improve animal-sourced food intake, especially if integrated with nutritional education. From a dietary perspective, however, "market access" and rural food environments more broadly, remain poorly understood. We do not yet have adequate indicators of the quality of rural food environments, how those environments influence food choices, and what scope there is for food environment interventions to improve diets. These issues are therefore an important area for novel research.

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Appendix 1 – EAT-Lancet Reference Diet

The six major food groups in ReDD are starchy staples, vegetables, fruits, dairy foods, protein foods (including plant-based and animal-source foods—hence allowing substitution between these subgroups and considering the possibility of healthy flexitarian, pescatarian, and vegetarian diets), and added fats/oils. The healthy reference diet provides reference intakes, expressed in kilocalories (kcal) per day for an average adult, by major food group or, for some food groups, by food category (which can be summed up to the group-level reference intake).[7] These caloric intakes for the six required major food group are directly used as the reference intakes in the ReDD index version that is applied in this study. When summed together, the EAT-*Lancet* reference diet provides a requisite 2,500 kcal per day, in this instance for a moderately active, average (female and male) adult—a caloric value that, in this population-based study, is also used to define one unit of adult equivalence.

The data used to estimate households' calorie consumption amounts by major food groups are available from the food expenditure and consumption modules of the LSMS-ISA surveys. These modules report food consumption quantities for each consumed food item that are then converted into calorie consumption amounts using international and national food composition tables (Lukmanji and Hertzmark, 2008; USDA, 2016) and summed by the major food groups. Together with the food-group-specific reference intakes, these calorie consumption amounts enter the computation of the ReDD index.

[7] While these caloric intakes should not be interpreted as absolute thresholds, or even minimum requirements, that must be achieved, they provide a useful benchmark for an aspirational diet that yields enough daily calories from a diverse food basket that promotes individual health.

Table A1.1 EAT-Lancet reference diet intakes in grams per day and kcal per day of the

Food groups	Intake & range (g/day)	Reference intake (kcal/day)
1. Starchy staples		850
a) Grain cereals	232g (≤ 60% energy)	811
b) Root crops	50g (0–100g)	39
2. Vegetables	300g (200–600g)	78
3. Fruits	200g (100–300g)	126
4. Dairy foods	250g (0–500g)	153
5. Protein sources		726
a) Animal protein		151
Beef and lamb	7g (0–14g)	15
Pork	7g (0–14g)	15
Poultry	29g (0–58g)	62
Eggs	13g (0–25g)	19
Fish	28g (0–100g)	40
b) Legumes & nuts		575
Pulses	50g (0–100g)	172
Soy foods	25g (0–50g)	112
Groundnuts	25g (0–75g)	142
Tree nuts	25g	149
6. Added fats		447
Palm oil	6.8 (0–6.8g)	57
Unsaturated oils	40 (20–80g)	354
Lard or tallow	5 (0–5g)	36
7. Discretionary foods	31 (0–31g)	120
Total		2,500

Source: Willet, et al. (2019)

Appendix 2 – Supplementary Tables

Table A.2.1: Farm System Characteristics, by System

Agro-Pastoral	N	Mean	SD	Min	Max
Have a market in community	2415	.34	.47	0	1
Population density/sqkm (rural)	3219	91.19	87.22	2.19	510.14
Median travel time (minutes) to	3219	91.83	89.12	5.27	538.48
HH Distance in (KMs) to Nearest	3219	77.17	52.21	1.6	283
Number of crops grown by HH	3108	3.18	2.21	0	18
Length of growing period in days	3219	167.34	34.71	79.99	268.74
Artisinal fishing					
Have a market in community	756	.28	.45	0	1
Population density/sqkm (rural)	1262	378.52	561	0	4042.2
Median travel time (minutes) to	1262	104.27	101.46	0	369.91
HH Distance in (KMs) to Nearest	1262	91.3	50.88	2.2	176.9
Number of crops grown by HH	1052	1.45	1.8	0	15
Length of growing period in days	1262	239.69	23.14	186.77	301.85
Cereal-root crop mixed					
Have a market in community	921	.3	.46	0	1
Population density/sqkm (rural)	930	76.1	48.38	5.9	281.52
Median travel time (minutes) to	930	50.17	38.76	9.8	249.73
HH Distance in (KMs) to Nearest	930	97.51	42.16	16	214.36
Number of crops grown by HH	835	3.79	2.07	0	14
Length of growing period in days	930	193.82	20.31	153.01	228.31
Highland mixed					
Have a market in community	643	.65	.48	0	1
Population density/sqkm (rural)	643	144.54	98.43	9.24	520.2
Median travel time (minutes) to	643	114.46	99.59	12.47	569
HH Distance in (KMs) to Nearest	643	59.69	31.62	5	190
Number of crops grown by HH	633	5.58	3.27	0	18
Length of growing period in days	643	194.27	53.82	101.81	282.21
Highland perennial					
Have a market in community	788	.41	.49	0	1
Population density/sqkm (rural)	1112	103.57	105.77	7.86	615.71
Median travel time (minutes) to	1112	108.46	88.44	2.62	587.13
HH Distance in (KMs) to Nearest	1112	63.59	44.56	4	200
Number of crops grown by HH	1098	3.75	3.7	0	20
Length of growing period in days	1112	236.22	37.45	167.72	303.66
Humid lowland tree crop					
Have a market in community	447	.36	.48	0	1
Population density/sqkm (rural)	456	451.98	320.78	29.98	1286.43
Median travel time (minutes) to	456	17.27	18.45	.62	180.63
HH Distance in (KMs) to Nearest	456	57.54	26.21	7.4	167
Number of crops grown by HH	365	4.41	2.81	0	15

Length of growing period in days	456	263.08	13.99	239.43	288.84
Irrigated					
Have a market in community	269	.28	.45	0	1
Population density/sqkm (rural)	271	248.07	208.41	0	1493.1
Median travel time (minutes) to	271	31.63	14.48	0	64.38
HH Distance in (KMs) to Nearest	271	53.09	28.49	15.6	126.21
Number of crops grown by HH	243	4.52	2.23	1	12
Length of growing period in days	271	117.92	16.69	87.7	142.3
Maize mixed					
Have a market in community	1293	.43	.5	0	1
Population density/sqkm (rural)	1949	51.55	55.24	1.51	338.44
Median travel time (minutes) to	1949	160.23	114.69	.07	644.82
HH Distance in (KMs) to Nearest	1949	86.13	56.94	1	226.8
Number of crops grown by HH	1911	2.76	2.39	0	17
Pastoral					
Have a market in community	94	.29	.45	0	1
Population density/sqkm (rural)	94	11.13	9.98	3.07	37.67
Median travel time (minutes) to	94	179.9	88.35	17.37	300.64
HH Distance in (KMs) to Nearest	94	76.86	92.14	1.92	279
Number of crops grown by HH	84	.51	1.28	0	8
Length of growing period in days	94	68.22	32.71	40.86	138.02
Root & tuber crop					
Have a market in community	654	.64	.48	0	1
Population density/sqkm (rural)	935	113.58	127.73	9.17	822.75
Median travel time (minutes) to	935	55.03	41.49	1.87	171.8
HH Distance in (KMs) to Nearest	935	90.22	38.47	19.9	195.29
Number of crops grown by HH	863	2.63	2.44	0	12
Length of growing period in days	935	237.27	8.43	219.92	273.11

Source: Authors' calculations from LSMS-ISA surveys, various rounds: Ethiopia (2015), Nigeria (2012, 2015, 2018), and Tanzania (2012).

Table A.2.2: Household Characteristics, by System

Agro-Pastoral	N	Mean	SD	Min	Max
ReDD-C index in base year	3219	.559	.163	0	.839
HDDS	3219	7.691	1.771	2	12
Household size	3219	9.358	6.12	2	55
Dependency Ratio	3219	.713	.222	.2	1.667
Age of head	3217	44.805	12.738	18	108
Head completed primary school	2952	.394	.489	0	1
Head completed secondary school	2952	.305	.46	0	1
Number of Assets	3219	3.201	1.689	0	10
Artisinal fishing					
ReDD-C index in base year	1262	.604	.134	.083	.845
HDDS	1262	8.689	1.677	3	12
Household size	1262	7.553	3.353	2	24
Dependency Ratio	1262	.62	.139	.2	1
Age of head	1261	44.294	13.387	21	102
Head completed primary school	1255	.547	.498	0	1
Head completed secondary school	1255	.266	.442	0	1
Number of Assets	1262	3.638	1.77	0	10
Cereal-root crop mixed					
ReDD-C index in base year	930	.44	.159	.031	.814
HDDS	930	7.699	1.841	2	12
Household size	930	9.308	3.422	3	21
Dependency Ratio	930	.684	.149	.167	1.429
Age of head	914	42.958	10.312	19	89
Head completed primary school	787	.598	.491	0	1
Head completed secondary school	787	.358	.48	0	1
Number of Assets	930	4.086	2.09	0	9
Highland mixed					
ReDD-C index in base year	643	.656	.115	.228	.836
HDDS	643	6.666	1.635	3	12
Household size	643	6.978	2.223	2	17
Dependency Ratio	643	1.297	.194	.5	1.75
Age of head	641	40.858	11.355	21	87
Head completed primary school	643	.118	.323	0	1
Head completed secondary school	643	.054	.227	0	1
Number of Assets	643	1.628	1.153	0	7
Highland perennial					
ReDD-C index in base year	1112	.586	.136	.124	.831
HDDS	1112	8.121	1.924	3	12
Household size	1112	6.579	2.554	2	19
Dependency Ratio	1112	.809	.34	.2	1.778
Age of head	1110	40.112	13.282	19	93
Head completed primary school	1112	.184	.388	0	1
Head completed secondary school	1112	.12	.325	0	1
Number of Assets	1112	2.626	1.584	0	8

Humid lowland tree crop					
ReDD-C index in base year	456	.463	.14	.097	.767
HDDS	456	9.428	1.614	2	12
Household size	456	7.748	2.811	3	21
Dependency Ratio	456	.652	.131	.2	1
Age of head	456	48.186	12.97	24	88
Head completed primary school	452	.721	.449	0	1
Head completed secondary school	452	.334	.472	0	1
Number of Assets	456	5.757	1.909	0	10
Irrigated					
ReDD-C index in base year	271	.413	.181	0	.821
HDDS	271	7.535	1.865	1	12
Household size	271	9.199	2.866	3	20
Dependency Ratio	271	.681	.098	.333	.9
Age of head	270	44.2	10.67	24	82
Head completed primary school	234	.483	.501	0	1
Head completed secondary school	234	.239	.428	0	1
Number of Assets	271	3.893	1.934	0	9
Maize mixed					
ReDD-C index in base year	1949	.63	.115	.121	.843
HDDS	1949	7.829	1.863	2	12
Household size	1949	7.135	3.799	2	35
Dependency Ratio	1949	.774	.323	.25	1.7
Age of head	1947	43.171	14.435	18	93
Head completed primary school	1949	.272	.445	0	1
Head completed secondary school	1949	.217	.412	0	1
Number of Assets	1949	2.521	1.568	0	7
Pastoral					
ReDD-C index in base year	94	.517	.122	.157	.762
HDDS	94	8.053	1.061	6	10
Household size	94	7.904	2.437	2	12
Dependency Ratio	94	1.237	.261	.571	1.75
Age of head	92	43	12.861	20	80
Head completed primary school	93	.161	.37	0	1
Head completed secondary school	93	.108	.311	0	1
Number of Assets	94	2.064	1.632	0	7
Root & tuber crop					
ReDD-C index in base year	935	.55	.16	0	.833
HDDS	935	8.458	1.838	3	12
Household size	935	7.736	3.41	2	20
Dependency Ratio	935	.65	.127	.2	1
Age of head	932	42.049	13.238	19	100
Head completed primary school	930	.428	.495	0	1
Head completed secondary school	930	.241	.428	0	1
Number of Assets	935	4.047	2.129	0	10

Source: Authors' calculations from LSMS-ISA surveys, various rounds: Ethiopia (2015), Nigeria (2012, 2015, 2018), and Tanzania (2012).

Appendix 3 -- Missing-Indicator Method II (Jones, 1996)

To maximize the available regression sample in the face of numerous missing observations, we employ the method designated Missing-Indicator Method II in Jones (1996).

Assume the true regression model is

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_{2i} X_{2i} + \varepsilon_i$$

where Y and X_1 are always measured but observations of X_{2i} may be missing.

Replacing the missing observations of X_2 with an arbitrary constant and defining dummy variable Q_{2i} to equal 1 when X_{2i} is observed and zero when it is missing, this approach to the missing-indicator method is to estimate the model

$$Y_i = \theta_0 Q_{2i} + \theta_1 X_{1i} Q_{2i} + \theta_2 X_{2i} Q_{2i} + \theta_3 (1 - Q_{2i}) + \theta_4 X_{1i} (1 - Q_{2i}) + e_i$$

Jones (1996) demonstrates that if ε is independent of (X_1, X_2, Q_2) then conditional on those variables, $(\hat{\theta}_0, \hat{\theta}_1, \hat{\theta}_2)$ are unbiased estimators of $(\hat{\beta}_0, \hat{\beta}_1, \hat{\beta}_2)$.

In our application, the binding constraint in our specifications was number of crops grown by households, which we thus treat as X_2.

Appendix 4: Country specific results

Table A-1 presents country-specific results for the aggregate ReDD index in Ethiopia, Nigeria, and Tanzania. While there is some degree of cross-country variation, the results are broadly consistent with the pooled results of Table 3. With regard to household controls, it is clear that larger households with higher dependency ratios suffer greater dietary deprivation. Secondary education is strongly associated with reduced levels of dietary deprivation in Ethiopia and Nigeria, while the benefits of primary education are more pertinent in Tanzania. There is a strong and increasing marginal association between asset holdings (i.e., the wealth strategy) and reducing dietary deprivation, with a particularly strong increasing marginal effect in Ethiopia. Diversified crop production significantly reduced dietary deprivation in Nigeria and Tanzania, with less clear results in Ethiopia. Livestock diversification appears to be more potent in protecting diet quality than crop diversification.

The agro-food environment variables focus on households' market access and the conditions of production, drawing on key characteristics of farming systems. There is evidence that access to a community market is protective of diet quality in Nigeria and Tanzania. In Tanzania there is little sign of any robust association between diet deprivation and the time and distance measures. Coefficients on population density and intensity of night lights vary across countries, having the opposite signs in Ethiopia and Tanzania and no robust association evident in Nigeria. Night lights intensity is associated with more dietary deprivation in Nigeria, though the association is quite weak.

Finally, farming system coefficients continue to be jointly significant in each country, with particular systems, such as pastoral systems in Ethiopia having especially strong individual effects. Yet, also in Ethiopia, households living in the cereal-root crop system suffer significantly greater dietary deprivation. In Nigeria, pastoral systems benefit, while highland mixed experiences significantly greater deprivation. In Tanzania, highland perennial and maize mixed have less deprivation than the omitted agro-pastoral group.

Table 4.1. Determinants of Dietary Deprivation (ReDD), by Country (rural sample)

	(1)	(2)	(3)
	Ethiopia	**Nigeria**	**Tanzania**
	Household Controls:		
Household Size	0.243	1.128***	0.303***
	(0.106)	(0.000)	(0.000)
Dependency Ratio	11.46***	-3.166	8.607***
	(0.000)	(0.226)	(0.000)
Head Age	0.0426	0.0419	0.0916***
	(0.120)	(0.113)	(0.000)
Primary Educ (head)	0.194	0.0430	-1.681**
	(0.877)	(0.948)	(0.049)
Secondary Educ (head)	-5.571***	-1.173*	1.341
	(0.002)	(0.097)	(0.144)
	Wealth Strategy:		
Asset count: med vs. low	-1.346*	-1.723**	-2.165***
	(0.097)	(0.020)	(0.000)
Asset count: high vs. low	-9.610*	-2.903***	-3.779***
	(0.063)	(0.000)	(0.000)
	Farm Diversification Strategy:		
Number of crops grown:med vs low	2.182**	-1.956***	-0.107
	(0.015)	(0.007)	(0.825)
Number of crops grown: high vs low	0.982	-1.415*	-3.112***
	(0.236)	(0.065)	(0.001)
Number of Livestock species: med vs low	-0.224	-2.651***	-0.224
	(0.782)	(0.936)	(0.000)
Number of Livestock species: high vs low	-1.361*	-1.054	-5.840***
	(0.066)	(0.152)	(0.000)
Agro-Food Environment:			
Has market in community	-0.822	-3.439***	-0.780*
	(0.166)	(0.000)	(0.081)
Time to City: med vs. low	2.734**	0.972	0.224
	(0.020)	(0.159)	(0.814)
Time to City: high vs. low	4.895***	2.057*	1.178
	(0.000)	(0.082)	(0.233)
Distance to market: med vs low	-1.988***	1.858**	0.307
	(0.009)	(0.019)	(0.641)
Distance to market: high vs low	-1.068	0.952	-0.446
	(0.191)	(0.293)	(0.491)
Population density: med vs low	3.674***	1.464*	-2.012***

	(1)	(2)	(3)
	Ethiopia	**Nigeria**	**Tanzania**
	(0.000)	(0.060)	(0.000)
Population density: high vs low	3.123***	2.275**	-8.163***
	(0.001)	(0.030)	(0.000)
Night lights: med vs low	-0.970	2.247***	0.783
	(0.167)	(0.003)	(0.159)
Night lights: high vs low	1.585	1.971**	0.600
	(0.177)	(0.047)	(0.424)
Additional Geographic/Farming System Effects:			
Artisanal Fishing	0	3.618*	0.968
	(.)	(0.086)	(0.236)
Cereal-Root Crop Mixed	6.226**	1.929**	0
	(0.015)	(0.014)	(.)
Highland Mixed	2.780***	7.449*	0
	(0.004)	(0.068)	(.)
Highland Perennial	-4.628***	0	-4.682***
	(0.000)	(.)	(0.000)
Humid Lowland Tree Crop	0	4.534***	0
	(.)	(0.000)	(.)
Irrigated	0	-2.196**	0
	(.)	(0.035)	(.)
Maize Mixed	0.433	0	-2.384***
	(0.657)	(.)	(0.000)
Pastoral	-8.339***	-7.005	0
	(0.000)	(0.452)	(.)
Root & tuber crop	0	2.498**	1.603*
	(.)	(0.014)	(0.057)
Observations	1691	2531	2956
Adjusted R-squared	0.140	0.258	0.140
F	11.99	32.34	11.99
Farming systems significant?	0.000	0.000	0.000

All specifications include country & survey round indicators. P-values in parentheses *=10*; **=5%; ***=1% level.

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