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Structural and rural transformation and food systems: a quantitative synthesis for LMICs

by
Aslihan Arslan
Romina Cavatassi
Marup Hossain

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Contents

Abstract

Structural and rural transformations in a country are intricately linked to food system outcomes. Structural transformation captures a country's level of dependence on agriculture, while rural transformation captures the productivity in the agricultural sector. Specifically, agri-food system and employment transitions accompany structural and rural transformation and shape the spatial distribution of populations by influencing where people live, work and eat, all of which closely relate to food system transitions. We create a food systems index (FSI) capturing a rich set of drivers established in the literature. Using country-level data from 85 low- and middle-income countries (LMICs), we analyse and assess the linkages between food systems and structural and rural transformations, as well as spatial population distributions at the country level. We also select a number of policy-relevant variables from World Development Indicators and use machine learning methodology to shed light on patterns related to institutions, female empowerment, infrastructure and health. We find that countries in the lowest FSI group will see their youth populations more than double in the next 30 years, indicating that the food system investments of today will affect one third of global youth in the future. We find that structural transformation is a necessary but not sufficient condition for desirable food system outcomes. Rural transformation by itself without structural transformation is not enough either. For LMICs, broad development interventions such as financial and digital connectivity as well as women's empowerment loom more important regarding progress in the food system.

Keywords: structural transformation, rural transformation, food systems index, machine learning, LMIC.

1. Introduction

Food is indispensable to life. The production, processing and delivery of food to our plates affects the global economy and every person on the planet. Food systems are a key element in delivering the Sustainable Development Goals (SDGs) and making progress over the next decade. Yet, despite an unprecedented level of economic growth and progress in decreasing global poverty in recent decades (World Bank, 2017), food systems, as they currently operate at the global, national and local levels, are failing to deliver the desired outcomes in terms of climate, environment, human health and social welfare (Davis et al., 2021).

The purpose of this paper is to highlight the potential for improving the livelihoods of the rural poor and the most vulnerable groups through the lenses of the food system approach, and structural and rural transformation, as well as to guide the prioritization of related policies. The food system approach is used to analyse interactions between food production and consumption, which are intricately linked to a country's transformation levels.

Following the HLPE (2017) definition, a food system is a complex construct that includes all elements and activities related to the production, processing, distribution, preparation and consumption of food (including storage and waste), the market and institutional networks for their governance, and the socio-economic and environmental drivers and outcomes of these activities.

Different levels of structural and rural transformation and of their combinations shape food systems in every country. Structural transformation captures a country's level of dependence on agriculture (versus other sectors), while rural transformation captures the productivity in the agricultural sector (IFAD, 2016). Specifically, the agri-food system (AFS) and employment transitions accompany the structural and rural transformation processes with different inclusion challenges (for rural populations, youth, women and young rural women).[1] These transitions also shape the spatial distribution of populations by influencing where people live, work and eat, all of which relate closely to food system transitions (IFAD, 2019).

Using country-level data from 85 low- and middle-income countries (LMICs), this paper analyses and assesses the linkages between food systems and structural and rural transformation, as well as spatial population distributions at the country level. To characterize food system outcomes, we use the set of indicators created by Wageningen University and Research (WUR) as part of the analytical framework for the *Rural Development Report* (RDR) for 2021 (IFAD, 2021). These indicators show the performance of individual countries along seven main dimensions that proxy the main elements and drivers of a food system as identified above: population (food demand), productivity (availability of food), markets (accessibility of food), food consumption inclusiveness, enabling environment, nutrition and health, and climate and environment.

Our analysis establishes and highlights the strong linkages between the RDR 2021 and the RDR 2019. The RDR 2019 on *Creating Opportunities for Rural Youth* created three interlinked typologies to assess the global distribution of rural youth and their opportunities and challenges. The country typology assessed global population by grouping countries by the level of structural and rural transformation; the spatial typology placed the world's population on a rural opportunity space (ROS) defined by the agricultural production and commercialization potentials of the spaces in which they live;[2] and the household typology looked at the micro-determinants of rural youth employment and welfare outcomes. The RDR 2019 also discussed at length the AFS and employment transitions, and their implications for nutritional challenges for the overall population and specifically for rural youth. By situating this discussion within the food system approach, we also contribute to the discussion on rural youth.

[1] The agri-food system (AFS) is defined as the set of supply chains stretching from the supply of inputs and services, through production on the farm and all the post-farm activities that result in the retailing of food (including food prepared and consumed away from home) and other agricultural commodities to consumers. The food system encompasses the AFS and extends beyond the retailing of food to consumers to include food preparation, consumption and waste. The literature on transitions that accompany structural and rural transformation is traditionally concerned with AFS. We bring in the food system dimension in this paper, but stick with the AFS terminology when referring to that literature.
[2] Using spatially explicit age- and gender-differentiated population data from the WorldPop project. See RDR Annex B for details.

We combine the country-level data from RDR 2019 (covering 85 LMICs that are used for the first two typologies above) with the food system indicators to: (i) identify whether and how the country typology (the levels of structural and rural transformation) correlates with the individual food system dimensions; (ii) create a food systems index (FSI) by combining all dimensions to investigate trends and correlations in a descriptive analysis; (iii) assess the distribution of world population across the ROS over various combinations of transformations (structural/rural transformation versus food systems); and (iv) present results from a predictive model based on machine learning to assess the factors that play the most important role in explaining variations in the FSI.

Given that the ultimate goal of agricultural development investments is to improve welfare outcomes of the rural poor, we differentiate the analysis of populations that live in countries with different levels of FSI by the dominance of rural, semi-rural, peri-urban and urban areas to the extent possible to help identify policy entry points. We also enrich our dataset with a number of variables sourced from World Development Indicators (WDIs) to shed light on patterns related to institutions, female empowerment, infrastructure and health for the predictive modelling.

Although the sample size is relatively small given that variables are measured at country level, the FSI's cross-correlations with country transformation levels and population distributions can provide insights to guide investments towards desirable patterns of food system transformation. Note that given the inherent endogeneities in the concepts analysed and the small sample size, this analysis cannot establish causality. Nonetheless, rigorous descriptive analysis of patterns in the FSI, structural and rural transformation as well as population distributions can help tailor policies and design projects to ensure inclusive food system transformations.

We introduce the three interlinked typologies in the next section, create the FSI and present the descriptive analysis of combinations of various categorizations in section 3, and present the results of the predictive analysis in section 4. We conclude in section 5 with implications for policy, investments and future research.

2. Three interlinked typologies

2.1 Country transformation typology

The RDR 2019 (IFAD, 2019) created a country transformation typology to identify transformation levels of 85 LMICs. The typology is characterized by two axes that are spanned by indicators of structural and rural transformation (Figure 1). Structural transformation is often measured by the share of non-agricultural activity in gross domestic product (GDP), while rural transformation can be measured by agricultural value added per worker (IFAD, 2016).[3] Countries can have different combinations of structural and rural transformation as they develop. Some may make faster progress in improving productivity in agriculture (i.e. high rural transformation), while their economy remains primarily agricultural (i.e. low structural transformation), as in quadrant III; others may have achieved structural transformation even though their agricultural sector remains a relatively low return sector (quadrant I).

Structural transformation, in general terms, changes the sectoral and functional distribution of income-generating opportunities. More and more people work outside the agricultural sector, and increasingly as wage labourers or in other types of formal employment rather than self-employment. This process is both driven by, and contributes to, rising productivity and incomes throughout the economy (Lewis, 1954; IFAD, 2016). With increased incomes, food consumption patterns switch away from starchy staples and towards more nutrient-dense foods (including processed foods) and animal proteins (i.e. Bennett's Law; Bennett, 1941). In terms of overall spending, consumers spend an increasing share of their income on non-food items, even as the absolute level of spending on food increases (Engel, 1857). Historically, "structural transformation has been the main pathway out of poverty" (Timmer, 2017).

[3] The data are from World Development Indicators of the World Bank. Data from the latest year available at the time of data processing in 2018 (the majority are from 2016) are used for the classifications presented here.

The manifestation of this process in rural areas is called rural transformation. Agricultural activities use increasing amounts of external inputs, achieve dramatic increases in farm productivity and produce more for the market.[4] Countries go through these processes at different times and paces, which have implications for the spatial distribution of their populations as well as the types of food system in which their populations live.

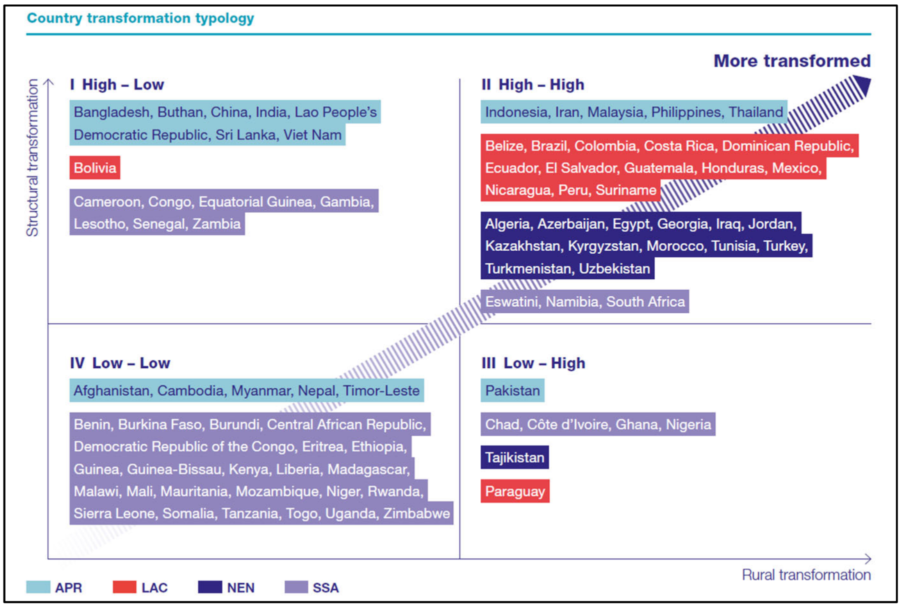


Figure 1: Structural and rural transformation for 85 LMICs

Notes: APR: Asia and the Pacific; LAC: Latin America and the Caribbean; NEN: Near East, North Africa, Europe and Central Asia; SSA: sub-Saharan Africa. Countries are classified as having attained a relatively high degree of rural transformation if their value added per worker exceeds the sample median (US$1,592) and as having attained a relatively high degree of structural transformation if the share of non-agriculture in GDP exceeds the sample mean (80 per cent). The sample consists of 85 LMICs (World Bank, 2018). Source: IFAD (2019).

2.2 Rural opportunity space

The welfare outcomes of populations are also shaped by the opportunities presented to them by the geographic spaces in which they live. Opportunities in rural areas are shaped to a large extent by the natural resource base that determines the potential agricultural productivity, and market access that determines the commercialization potential, both with strong spatial dimensions (Wiggins and Proctor, 2001; Ripoll et al., 2017). These two factors define the ROS in the RDR 2019 (IFAD, 2019) to study the opportunities and challenges faced by the rural population in general and rural youth in particular, subject to the characteristics of the broader national economy. We use this spatial typology in our analysis.

The agricultural production potential axis of the ROS is proxied by the Enhanced Vegetation Index (EVI), and the commercialization potential axis is proxied by population density (IFAD, 2019).[5] Indices based on remote sensing data (such as the EVI) are increasingly used as a proxy agricultural production potential to facilitate global comparisons (Jaafar and Ahmad, 2015; Chivasa et al., 2017). Commercialization potential increases with connections to people, markets, ideas and information. This axis of the ROS is proxied by globally comparable population density, which correlates with agricultural commercialization, off-farm diversification and market density (Bilsborrow, 1987; Wood, 1974). Both ROS axes are divided into three

[4] These are historical and observational characterizations of economies, and do not reflect value judgements or environmental sustainability dimensions of the transition (e.g. preference for external input use as opposed to low-input/organic agriculture).
[5] Data for the commercialization potential were drawn from the age- and gender-differentiated population densities from the WorldPop project. Data for agricultural potential were obtained using the Enhanced Vegetation Index (EVI) of MODIS for land that is classified as cropland or pastureland excluding built-up and forested areas. (See Box 2.2 of the RDR 2019 for more details.)

categories (low, medium and high) for all rural spaces in the sample to assess the rural population distributions across this space. Figure 2 shows the percentages of the total population in our sample of 85 LMICs that live in each cell of the ROS.

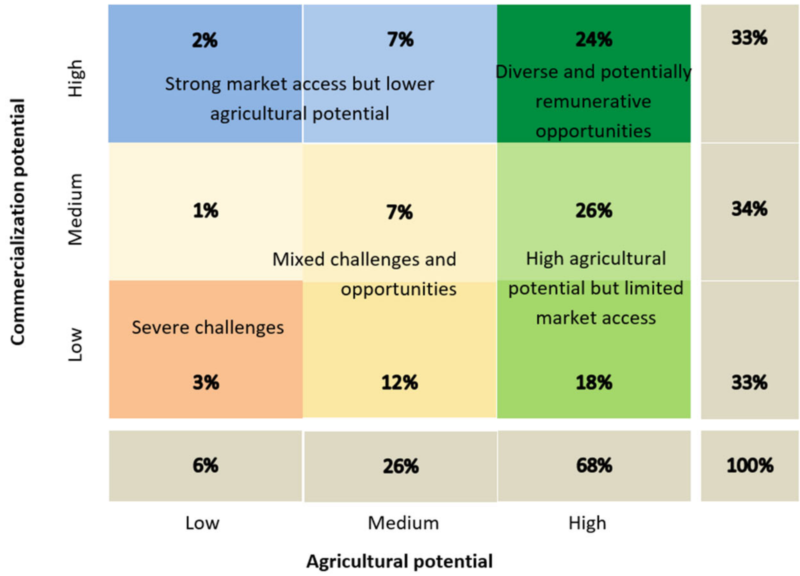


Figure 2: Percentage of total population distribution over the ROS quadrants for 85 LMICs

Source: Authors' calculations.

Around 70 per cent of the non-urban population lives in spaces with the highest agricultural production potential; however, only 25 per cent of this share also has good access to markets defined by the commercialization potential. Arslan et al. (2020) analysed the welfare implications of the two axes of the ROS using data from 13 nationally representative household surveys, finding that the commercialization potential has a much stronger impact on welfare outcomes (income and poverty) compared with agricultural potential. The categories of commercialization potential are defined by population density and were specifically designed for non-urban areas to conceptualize the "rural" opportunity space, and correspond to rural, semi-rural and peri-urban areas. The food system approach of RDR 2021 (IFAD, 2021) has a strong emphasis on factors that shape food consumption (demand and use), which is increasingly driven by demand in urban (and surrounding) areas. We therefore bring in the urban areas and use the population distribution along the full rural-urban gradient to assess food systems indicators in 85 LMICs.

2.3 Food systems typology

A food system that sustainably provides food security and nutrition for all is essential for the well-being of all people and the planet. Food security is defined by the United Nations Committee on World Food Security as "All people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their food preferences and dietary needs for an active and healthy life" (FAO-WFS, 1996). The four pillars of food security – availability, accessibility, utilization and stability – combined with nutrition and sustainability, provide the foundations of a desirable food system. Although it is hard to characterize a complex food system, some key indicators can be identified to monitor and track progress toward a desired food system. This can also support decision makers to steer and focus policy interventions and investment opportunities for improved system outcomes.

We use indicators that illustrate key components of food system dimensions: food demand, availability, accessibility and inclusiveness, food policy and business environment, nutrition and health, and the ecological boundaries of food systems. Table 1 shows the indicators, measurement details and data sources for each dimension of the food system. Indicators are drawn from publicly available sources. All indicators are standardized on a scale of 0 to 100 to facilitate comparative analysis.[6] The dimensions are composed of one or more indicators and the overall value of a dimension is the unweighted average of indicator values. Given that some indicators indicate better performance as the value of the indicator decreases (e.g. import tariffs, stunting, wasting), the scales for such indicators are inverted, such that increasing scores indicate more desirable outcomes for all indicators.

One exception is the demand dimension, which is made up of population and urbanization growth rates. The direction in which "desirability" increases in terms of these indicators is not clear a priori. For example, a high population and urbanization growth rate can put a lot of stress on the food system to meet the increasing demand. In countries with well-functioning food systems in all dimensions, population growth rate can be expected to have plateaued (or even turned negative), suggesting a negative relationship, although urbanization growth can still be high, suggesting a positive one. Based on the premise that high growth rates in both indicators create challenges for the food system to meet rapidly increasing and changing demand, we interpret this dimension in the opposite way; that is, the lower the dimension value, the more "desirable" the food system outcome.

Table 1
Food system typology: Dimensions and indicators

Food system dimension	*Indicator*	*Measurement/unit*	*Source*
Demand (population)	Urbanization growth rate	Growth over 2015-2020 (%)	UN World Urbanization Prospects
	Population growth rate	Growth over 2015-2020 (%)	UN World Population Prospects
Production (availability)	Yield rates (cereals, pulses, roots and tubers, vegetables, milk, meat)	Hectogram/hectare	FAOSTAT 2017
Accessibility (markets)	Consumer price index	Average 2015-2018	World Bank WDI
	Import tariffs	Average 2015-2018	World Bank WDI
Food consumption inclusiveness	Income per capita	Average 2015-2018	World Bank WDI
	Gini-index of income inequality	Average value, various years	World Bank WDI
	Poverty rate	Population below poverty line of US$1.90 (%), various years	World Bank WDI
Policy (enabling environment)	World Bank ease of doing business index	Average 2019-2020	World Bank
Nutrition & health	Child stunting and wasting	Under 5 years stunting/wasting (%), 1999-2016	World Bank/UNICEF/WHO
	Overweight children and adults	Weight for height and BMI, 2016	World Bank/UNICEF/WHO
	Micronutrient deficiencies	Anaemia among women of reproductive age (%), 2016	World Bank/UNICEF/WHO
Climate and environment	Climate adaptation performance	ND-GAIN 2017	University of Notre Dame

Note: WDI = World Development Index; UNICEF = United Nations Children's Fund; WHO = World Health Organization; ND-GAIN = Notre Dame Global Adaptation Initiative; BMI = body mass index. Source: Authors' elaborations.

Although a combined index of all these dimensions may be hard to interpret to tease out policy entry points, it is useful to create a typology of food systems for countries. This would allow a descriptive analysis of food system patterns combined with regional and country transformations, and population distribution categories. To this end, we create an FSI using principal component analysis (PCA) on the food system dimensions listed in Table 1. We use the FSI to first assess general patterns across the three interlinked typologies and

[6] The rating from 0 to 100 on each indicator is determined by the following formula: ((country's individual score on the indicator − the lowest score on the indicator)/(highest score − lowest score on the indicator))*100. The country with the highest score rates 100 and the one with the lowest rates 0. All other countries are in between relative to their distance from both ends.

then zoom in to identify relevant policy levers by various categorizations of countries in our sample based on predictive modelling/machine learning.

3. Combining all three: country transformation, population distribution and FSI

The level of structural and rural transformation reached by a country is closely related to a large set of indicators that reshape its food system. Specifically, the AFS changes as labour moves out of agriculture and into non-farm sectors; increasing urbanization reshapes demand patterns; and value chains lengthen and become more complex, increasingly connecting rural and urban spaces.

The stages of AFS transformation are classified by the High-level Panel of Experts on Food Security and Nutrition (HLPE, 2017) as traditional, mixed and modern. The Panel looked at the interactions between food markets and the food environment. Reardon et al. (2019) classifies them as traditional, transitional and modern, focusing on the transformation of food value chains. Using the intersections between structural and rural transformation and the main characteristics of the dominant food system in these intersections, we categorize countries as agricultural, inverse, diversifying and transformed, providing a description of their main economic, agricultural and food system characteristics, as used in RDR 2021 (IFAD, 2021; see Figure 3). Each of these stages has unique production, distribution and consumption patterns, which we capture with multiple combinations of indicators in our analysis below.

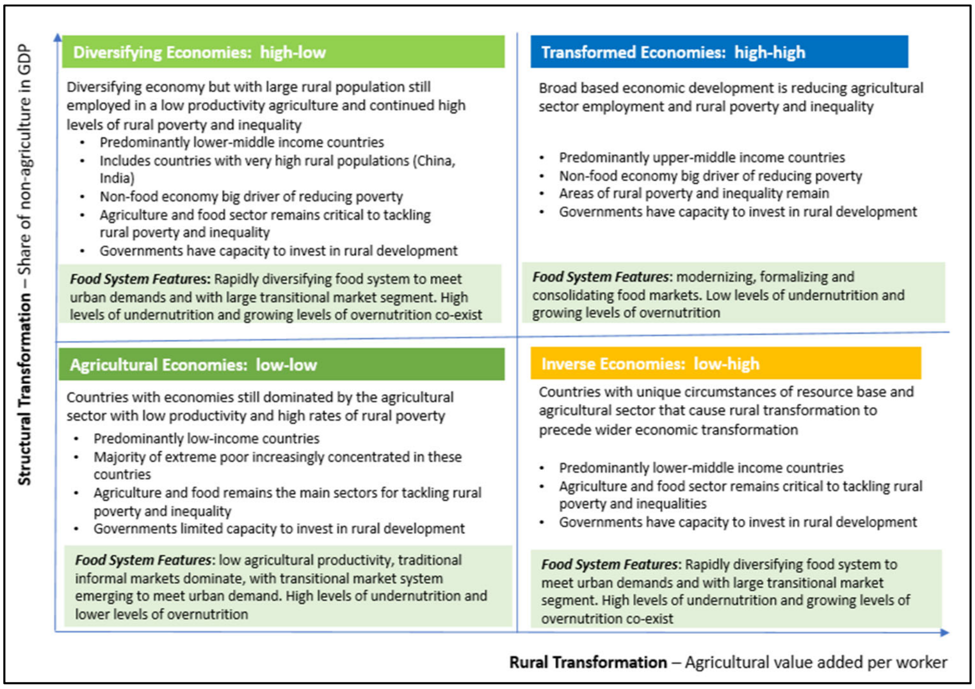


Figure 3: Food system features and the country transformation typology

Source: IFAD (2021).

Table 2 provides descriptive statistics of key variables in our dataset. The average share of non-agricultural sectors in the GDP is 80 per cent, and the average value added per agricultural worker is US$3,300 (in constant 2010 values), both with a wide variation. On average, 43 per cent of the sample country populations live in the rural hinterland, 16 per cent in semi-rural areas and 18 per cent in peri-urban areas, while 23 per cent are in urban areas. The FSI is created by combining all the dimensions using PCA and rescaled to have a range of between 0 and 100, and its average is 51 in our sample.[7] Some dimensions have missing data for some countries; therefore, the aggregate FSI can be created for only 81 countries. Among the seven dimensions of the FSI, nutrition has the smallest standard deviation. Note that this dimension is a combination of undernutrition (including micronutrient deficiencies) and overnutrition indicators, and notwithstanding the occurrence of the double burden of malnutrition in some countries, the simple averages of these indicators seem to balance each other out on average.[8]

Table 2
Descriptive statistics of key variables

	Mean	*SD*	*Min value*	*Max value*	*N*
ST: Share of non-agriculture in GDP	81.01	12.40	41.00	98.00	81
RT: Value added per worker in agriculture	3326.21	3955.56	202.44	19261.20	81
Percentage living in rural areas	42.48	19.72	1.18	83.12	81
Percentage living in semi-rural areas	16.05	11.04	1.56	46.97	81
Percentage living in peri-urban areas	18.49	11.29	0.23	69.73	81
Percentage living in urban areas	22.99	13.41	0.02	78.93	81
FSI (principal component index)	50.93	24.61	0.00	100.00	81
Population/food demand	44.65	18.77	13.13	95.73	81
Food production (availability)	38.73	19.12	11.25	100.00	81
Markets (accessibility)	72.27	16.73	8.75	99.95	81
Food consumption inclusiveness	40.94	17.06	4.66	72.71	81
Policy/enabling environment	75.01	10.76	52.95	100.00	81
Nutrition and health	47.11	5.58	32.54	60.12	81
Climate adaptation performance	79.97	9.54	59.05	100.00	81

Note: The *indicators* that make up the FSI dimensions have been rescaled to range between 0 and 100 in our sample. Some of these dimensions are averages of two or more indicators; therefore, the average values for each *dimension* do not always add up to 100. ST = structural transformation; RT = rural transformation. Source: Authors' calculations.

Linkages between the food system dimensions and structural and rural transformation are not always linear, given the complexities of the food system and the transformation pathways. Nonetheless, some expectations can be built based on the historical co-evolution of these concepts.

At the beginning of the structural transformation process, most countries have high population and urbanization growth rates. These correspond to the early stages of demographic transition, which first sees death rates and then birth rates decline as countries transform (Stecklov and Menashe-Oren, 2019). The relationship between structural transformation and the demand dimension is expected to be non-linear, increasing at a decreasing rate that, at some point, may turn negative as most developed countries are now struggling with shrinking populations.

The **production** dimension is measured by productivity (hectograms per hectare) of main food groups, therefore is expected to be unambiguously positively correlated with structural and rural transformation. The **access** dimension, measured by the consumer price index and import tariffs, is more ambiguous, as countries can transform structurally but still keep high tariffs or have high inflation. Similarly, for consumption inclusiveness, while average incomes and the poverty situation can be expected to improve with rural/structural transformation, inequality can initially (but must not) worsen (Kuznets, 1955; UNRISD, 2010). The exact relationship with inequality depends on many factors, such as the speed and type of transformation, and eventually is a case-specific empirical question (Baymul and Sen, 2020, and references therein). The **policy** dimension is measured by the World Bank's ease of doing business index and captures the enabling environment that can facilitate or hinder a desirable food system outcome. Its expected relationship with a country's transformation level is ambiguous, as it is highly political.

[7] The principal component analysis (PCA) is a technique for reducing the dimensionality of large datasets, increasing interpretability but at the same time minimizing information loss, preserving as much variability as possible. It does so by creating new variables that are linear functions of those in the original dataset, that successively maximize variance and are uncorrelated with each other. These new variables are called the principal components of the dataset. (Jolliffe and Cadima, 2016).

[8] The overall negative correlation among undernutrition and overnutrition indicators ranges between 52 per cent and 75 per cent.

The **nutrition and health** dimension is measured by the prevalence of micronutrient deficiency, stunting and wasting for children, as well as overweight for females, males, boys and girls. As countries develop, they also go through a nutrition transition, which leads to important changes in dietary intake and energy expenditure. Although this process is expected to be associated with a decreasing incidence of malnutrition, it is increasingly linked to growing overweight and obesity (Popkin et al., 2012; Popkin and Reardon, 2018). Using the same definitions of structural and rural transformation, Kadiyala et al. (2019) found that they are associated with improvements in malnutrition and underweight. At the same time, most LMICs face a double burden of malnutrition and overweight/obesity (Haddad et al., 2016). The expected relationship between the nutrition/health indicators used here and structural/rural transformation therefore may be better established by separating the undernutrition (including micronutrient deficiency) and overnutrition indicators. We keep these separate in the rest of this paper and expect the former to decrease and the latter to increase with transformation on average (noting that the exact relationship at the country level will depend on the level and speed of development in each case).

Finally, the **climate and environment** dimension of the food system is measured by the University of Notre Dame's Global Adaptation Index (ND-GAIN) (Chen et al., 2015). It combines a rich set of vulnerability indicators for six sectors (food, water, health, ecosystem service, human habitat and infrastructure) with readiness measures in three categories (economic, governance and social). As structural and rural transformation progress, the vulnerability of the food system will change along with the AFS transitions. Although the most vulnerable populations may be those dependent on agriculture in rural areas at first, as urbanization increases and food supply chains get longer (i.e. spatial evolution of AFS), vulnerability can be expected to expand along the value chain (Reardon and Zilberman, 2018) towards more densely populated urban areas, unless effective adaptation investments are made along the value chain. Therefore, there is no a priori expectation about the direction of change in this dimension as transformation unfolds.

Before we empirically document the linkages between the FSI and structural/rural transformation categories in our sample, we document the regional distribution of our sample by transformation group in Table 3.[9] There are strong regional patterns in terms of structural and rural transformation levels, as expected. While most highly transformed countries (both structural and rural) are in Latin America and Caribbean (LAC) and Near East, North Africa, Europe and Central Asia (NEN) regions, countries with low transformation levels are concentrated in sub-Saharan Africa (SSA). Asia and the Pacific (APR) region dominates the high structural but low rural transformation group. These patterns are linked to food system outcomes, as below.

Table 3
Number of countries by transformation levels and regions

	APR	*LAC*	*NEN*	*SSA*	*Total*
Transformed	5	13	12	3	**33**
Diversifying	7	1	0	6	**14**
Inverse	1	1	1	4	**7**
Agricultural	5	0	0	22	**27**
Total	**18**	**15**	**13**	**35**	**81**

Note: Countries are classified as having attained a relatively high degree of rural transformation (RT) if their value added per worker exceeds the sample median (US$1,592) and as having attained a relatively high degree of structural transformation (ST) if the share of non-agricultural value added exceeds the sample mean (80 per cent). The sample consists of 81 LMICs as defined by the World Bank (2018). APR = Asia and the Pacific; LAC = Latin America and the Caribbean; NEN = Near East, North Africa, Europe and Central Asia; SSA = sub-Saharan Africa.

We divide the sample into three groups using the terciles of the aggregate FSI distribution. Table 4 shows the number and percentages of the low, medium and high FSI countries per region. Parallel to the regional transformation patterns above, the highest FSI group is dominated by LAC and NEN, and the lowest FSI group is dominated by SSA (containing 26 out of 27 countries in this group).[10] All other countries in SSA, except for South Africa, are in the medium FSI group, including most countries in APR.

[9] The regional classifications are IFAD regions, though sub-Saharan Africa combines the East and Southern Africa (ESA) and West and Central Africa (WCA) regions.

[10] The only country in the low FSI group that is not in sub-Saharan Africa is Afghanistan, which is not surprising given the conflict and fragility situation there.

Table 4
Regional distribution of FSI categories

PCA categories		*APR*	*LAC*	*NEN*	*SSA*	*Total*
Low FSI (N)		1	0	0	26	**27**
	%	3.7	0	0	96.3	**100**
Medium FSI (N)		12	5	2	8	**27**
	%	44.44	18.52	7.41	29.63	**100**
High FSI (N)		5	10	11	1	**27**
	%	18.52	37.04	40.74	3.7	**100**
Total		**18**	**15**	**13**	**35**	**81**
%		22.22	18.52	16.05	43.21	100

Source: Authors' calculations.

Combining FSI groups with population distributions over the rural-urban gradient, we find that out of the total population of 5.6 billion in the countries in our sample, the majority (2.7 billion) live in countries with the highest FSI (the left panel in Figure 4). This is followed by the medium FSI group, which hosts 2.1 billion people. The total number of people in the least desirable FSI group is around 770 million.

The spatial distribution of the population within countries across rural, semi-rural, peri-urban and urban spaces follows an interesting pattern (the right panel in Figure 4). Countries with the lowest FSI are also those with the highest share of rural populations (around 45 per cent). The second highest population share in these countries lives in urban areas, with very low shares in semi-rural and peri-urban spaces. Medium FSI countries have the opposite pattern, where the population is agglomerated in the semi-rural and peri-urban spaces. At the highest end of the FSI, spatial distribution becomes more or less even over the rural-urban gradient. These spatial patterns overlaid with the FSI categories reflect the evolution of the AFS transitions that increasingly connect rural hinterlands to semi-rural and peri-urban spaces by spatially lengthening value chains (Reardon et al., 2019). This is also called the "spatial structural transformation of the food system" and has implications for policies (FAO, 2017).

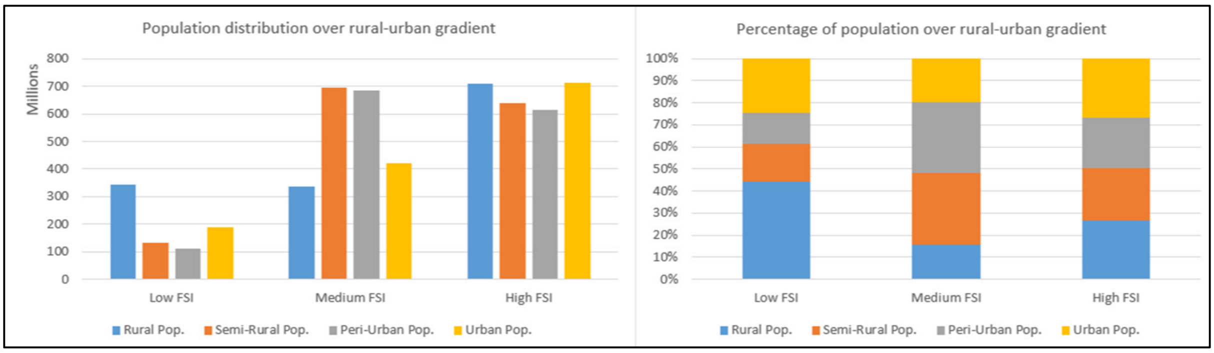


Figure 4: Population distribution and shares over the rural-urban gradient by three FSI groups

Source: Authors' calculations.

The population data in Figure 4 are from United Nations population projections for 2015 (UNDESA, 2017). They represent the current exposure of the world population to different categories (levels of desirability) of the FSI over space. To understand how this picture is projected to change in the next 30 years and what it may mean for the youth population, we plot the population projections for 2030 and 2050 over FSI categories in Figure 5.

Although the low FSI group has the smallest population as of 2015, its total population is projected to more than double by 2050, while projected population increases everywhere else are much lower (30 and 11 per cent for the medium and high FSI groups, respectively). This is indicative of the delayed demographic transition of countries in this group, with persistently high birth rates (Stecklov and Menashe-Oren, 2019), and underlines the need for urgent action to transform the food system to sustainably meet the projected increase in food demand. Related to a delayed demographic transition, countries in this group will also see the youth population more than double by 2050, while medium FSI countries will see only a 3 per cent increase and high FSI countries will see a 15 per cent decrease in their youth populations. This means that while countries in the lowest FSI group today host one in six of all youth in our sample, they will host one in three in 2050. Today's policies and programmes to improve the food system in different countries have very different implications for the lives of the world's youth, including their health, diet and employment opportunities in the future.

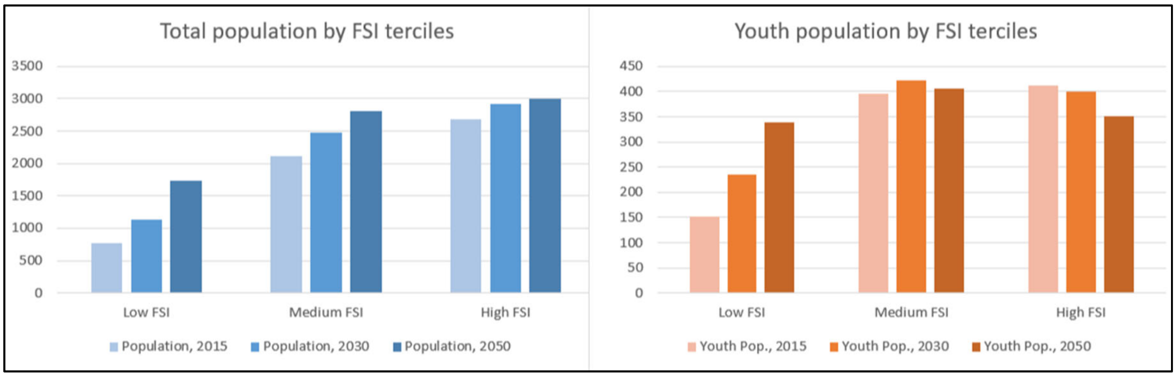


Figure 5: Total population and youth population by FSI terciles, 2015-2050

Notes: Population figures are in millions. FSI groups are created using the terciles of the aggregate FSI.
Source: Authors' calculations based on UNDESA (2017). The dataset covers 81 LMICs (based on the World Bank definitions and data for 2018).

RDR 2019 (IFAD, 2019) demonstrates similar patterns between populations, youth shares and country transformation levels, showing that countries with the lowest transformation levels (and those in SSA) stand out in terms of projected increases in total and youth populations.

3.1 Deriving insights from combined analysis of FSI and transformation stage

Figure 6 combines all three typologies and plots all countries on the structural-rural transformation axes along with their FSI categories. Some food system dimensions have missing data for some countries; therefore, we restrict the analyses to 81 countries. The aggregate FSI is strongly correlated with structural transformation levels, while there is a notable variation in FSI over rural transformation levels.

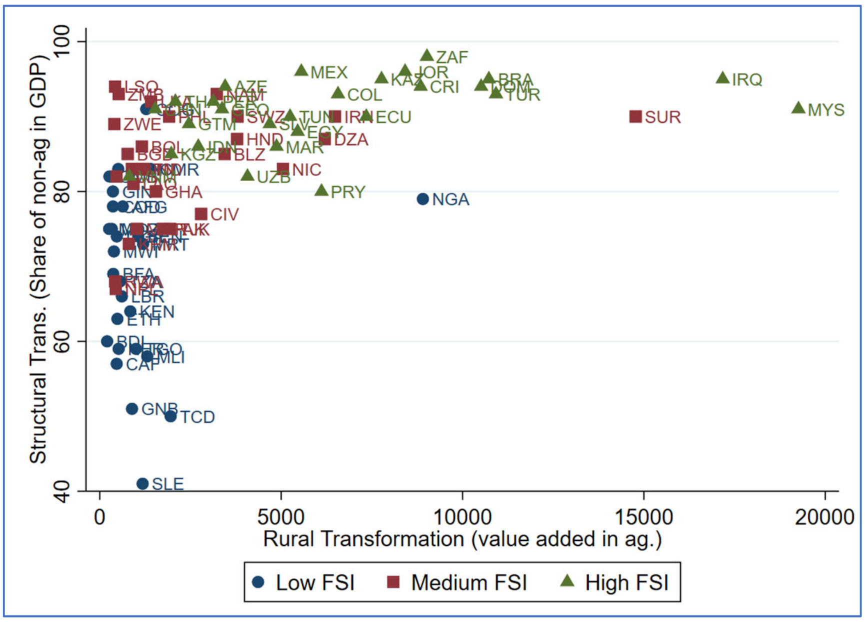


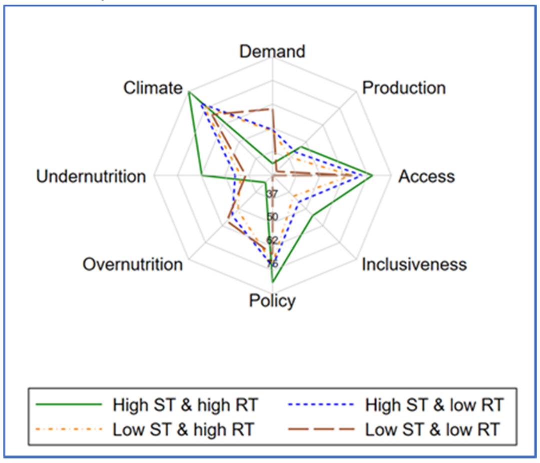
Figure 6: Structural and rural transformations, showing strong correlation with the FSI

Source: Authors' own elaborations.

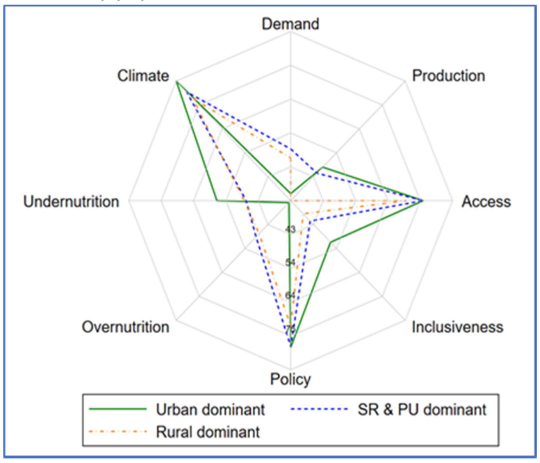
All countries reporting a high FSI are also highly transformed structurally, that is more than 80 per cent of their GDP comes from non-agricultural sectors.[11] At the same time, around 45 per cent of highly structurally transformed countries (i.e. 21 out of 47) have a medium or low FSI – indicating that structural transformation is a necessary but not a sufficient condition to foster a desirable food system as captured by our multifaceted index. Finally, out of the 27 countries in the low FSI group, 21 report a low rural transformation (i.e. value added per worker in agriculture is below the sample median of US$1,592) and low structural transformation levels. Rural transformation in and of itself (without structural transformation) is not enough either; Nigeria and Chad both have high rural but low structural transformation levels, and are in the lowest FSI group. At the other extreme is China and Viet Nam, which have achieved high FSI levels with high structural but low rural transformation.

The FSI can be used to identify broad patterns among the multiple country categorizations discussed above. As in any composite index, the FSI needs to be unpacked to gain a more detailed understanding of the potential policy levers. We assess the individual food system dimensions used to create the aggregate FSI by combining them with structural/rural transformation categories, population distribution structures and regions in radar graphs in Figure 7.

Panel a. By structural and rural transformation



Panel b. By population structure



Panel c. By region

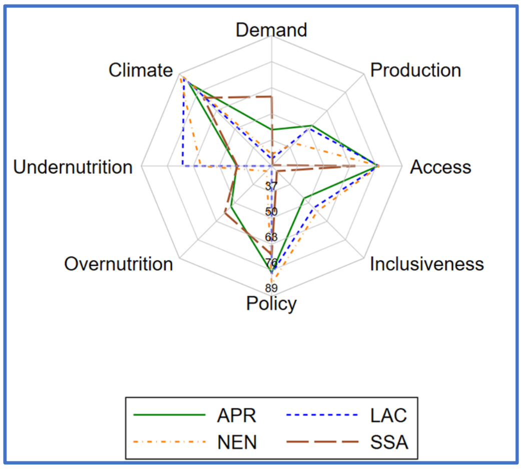


Figure 7: Radar graphs of food system dimensions and country characteristics

Note: ST = structural transformation; RT = rural transformation. SR = semi-rural; PU = peri-urban. Source: Authors' calculations.

[11] The only exception to this is Paraguay, although its share is exactly 80 per cent, which is the threshold for high structural transformation excluding the boundary. Therefore, Paraguay is not considered as a meaningful outlier from which one can extract some lessons through a case study.

Given the important differences between overnutrition and undernutrition indicators of the nutrition and health dimension, we keep these components separate in the rest of this paper.

Figure 7a shows that highly transformed countries perform the best in all dimensions except overnutrition.[12] They have a very high incidence of overweight and a low incidence of stunting, wasting and micronutrient deficiencies, reflecting the changes in the quality of food and lifestyles that accompany urbanization and AFS transitions along with structural and rural transformation (Kadiyala et al., 2019; Reardon et al., 2019).

Given the implications of these transitions for spatial characteristics of value chains, population distribution and hence food system outcomes, we categorize countries into three spatial population structures. We use data on the percentages of population that live in different segments of the rural-urban gradient and create three categories: rural dominant, urban dominant, and semi-rural and peri-urban dominant. Countries are assigned to one of the three categories based on where the largest share of their population lives.

Interestingly, countries in which the semi-rural and peri-urban populations are dominant perform just as well as urban-dominant populations, on average, in terms of access and the policy environment (Figure 7b). Urban-dominant countries perform the best in production, climate and undernutrition dimensions, and worst in overnutrition. This finding indicates that the overweight prevalence in urban-dominant countries in our sample is significant, despite all being LMICs, where overweight problems seem to be starting at earlier levels of economic development (Popkin et al., 2012). The average values for rural-dominant countries lag behind in most of the food system dimensions, but particularly so in terms of production and inclusiveness. Productivity increases in agriculture are essential for structural transformation, which sets in motion a movement of labour from rural to urban sectors (Lewis ,1954). Therefore, it is not surprising that these countries fare worst in the production dimension. Rural-dominant countries and semi-rural and peri-urban-dominant ones perform very similarly in terms of average nutrition dimensions: better than the urban-dominant group in overnutrition, and worse than the urban-dominant group in undernutrition. Semi-rural and peri-urban-dominant countries, however, would be expected to have better nutrition outcomes (than the rural-dominant group), thanks to the more developed value chains and rural-urban connectivity. This finding indicates that countries in this group, 11 out of 19 of which have a high structural transformation, need to invest more heavily to make their value chains more nutrition sensitive.

Regionally, APR, LAC and NEN lead in terms of access, policy and climate adaptation dimensions. At the same time, NEN dominates the inclusiveness dimension, potentially because Central and Eastern European countries make up most of this region in our dataset (Figure 7c). Overnutrition indicators are worst in LAC and NEN, while undernutrition is worst in SSA and APR. SSA lags behind in all dimensions except one: overnutrition. The average difference is the starkest in terms of production and inclusiveness dimensions, underlining the continuing challenges of low productivity and poverty in the region. Considering that the demand dimension captures the stress to the food system posed by high population and urbanization growth rates, SSA's challenges in meeting the increasing demand are expected to increase given the population dynamics discussed earlier.

In the next section, we use multivariate analysis as well as machine learning methodologies to establish more granular associations between transformation and food system indicators (both for individual dimensions and aggregate index). We also introduce a large set of covariates hypothesized to affect food system outcomes to zoom in on a set of policy levers that correlate strongly with desirable outcomes. We then use these covariates to more clearly identify the policy levers that may be relevant for the outlier countries discussed above to draw some lessons.

[12] Note that the food demand dimension is measured by the growth rates of urbanization and population, and not levels. Highly urbanized countries tend to have low urbanization growth, which makes lower values preferable from a food systems perspective. Lower growth rates in population and urbanization would put less stress on the food system.

4. Drivers of FSI and its dimensions

4.1 Association with structural and rural transformation

We first examine the associations of individual food system dimensions as well as the aggregate FSI with structural and rural transformation. To do this, we use ordinary least square regression (OLS) as follows,

$$FS_c = \alpha_0 + \alpha_1 S_c + \alpha_2 R_c + \zeta_c$$

where FS indicates different food system dimensions or the aggregate index (in different specifications), S stands for structural transformation indicator (i.e. share of non-agricultural sectors in GDP), R stands for rural transformation (i.e. value added per worker in agriculture), and ζ is the idiosyncratic error term. Finally, c indicates unit of observations (i.e. LMIC countries in our sample). Notwithstanding the inherent endogeneities in this specification, our main aim is to establish whether the average correlations discussed above are statistically significant.

Figure 8 shows the coefficients of S and R and their confidence intervals from the OLS regressions. Both structural and rural transformations are significantly associated with most of the food system dimensions and the aggregate FSI. The positive association of the FSI with structural transformation appears to be stronger compared to that with rural transformation.

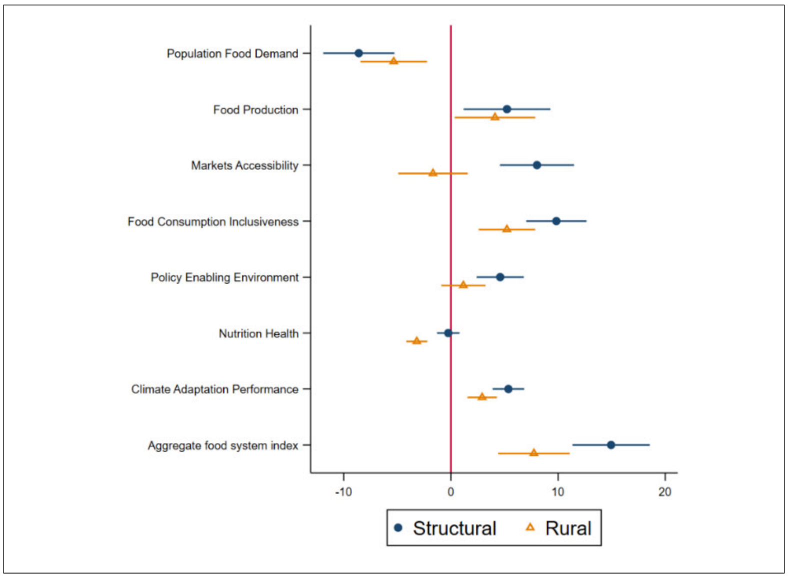


Figure 8: Associations of food system dimensions and FSI with structural and rural transformation

Note: Indicators on the vertical axis are dependent variables, all from separate OLS regression specifications. Circles and cones show point estimates for structural and rural transformations, respectively, and the lines indicate 90 per cent confidence intervals. Source: Authors' calculations.

Although the relationships of structural and rural transformations to the food system are complex, our findings above confirm strong interlinkages (Timmer, 2017; FAO, 2017). The associations with individual dimensions are not clearly established in the literature, as discussed above in terms of setting up expectations. To the extent that it was possible to build expectations regarding directions of relationships between food system dimensions and structural and rural transformation, our results confirm them, although some are statistically insignificant. The negative association with population food demand is as expected because population and urbanization growth rates are expected to decrease with transformation. All other food system dimensions except for overall nutrition (overnutrition and undernutrition combined) are positively and significantly associated with structural transformation. Recall that most of the expected directions of the relationship between structural transformation and these dimensions were ambiguous ex ante. Our findings indicate that the 81 LMICs in our data are likely to record improvements in most food system outcomes as they transform structurally. The smallest improvements are recorded in climate adaptation and the policy/enabling environment, underlining the need for more investment in these dimensions.

Regarding associations with rural transformation, food production, consumption inclusiveness and climate adaptation dimensions have positive coefficients. Market access and policy-enabling environment dimensions, however, are not significantly associated with rural transformation. Finally, rural transformation is negatively associated with the overall nutrition and health dimension.

The counter-intuitive findings for nutrition and health are, yet again, the artefact of the nutrition dimension being a combination of undernutrition and overnutrition indicators to capture the double burden of malnutrition in the overall classification (Haddad et al., 2016). Given that these nutrition challenges are expected to have different and sometimes opposite associations with structural/rural transformation and require different policy interventions, we explore this issue further (as in the previous section). We show the association of these disaggregated nutrition indicators with structural and rural transformation in Figure 9. The benefit of separating these indicators is evident in the figure, as all coefficients become significant in opposite directions. Similarly to the picture seen with the simple averages in the radar graphs above, the disaggregated results show that structural and rural transformation correlate significantly with an improved undernutrition situation in a country. At the same time, the correlation with overnutrition indicators is significantly negative (Kadiyala et al., 2019; Reardon et al., 2019).

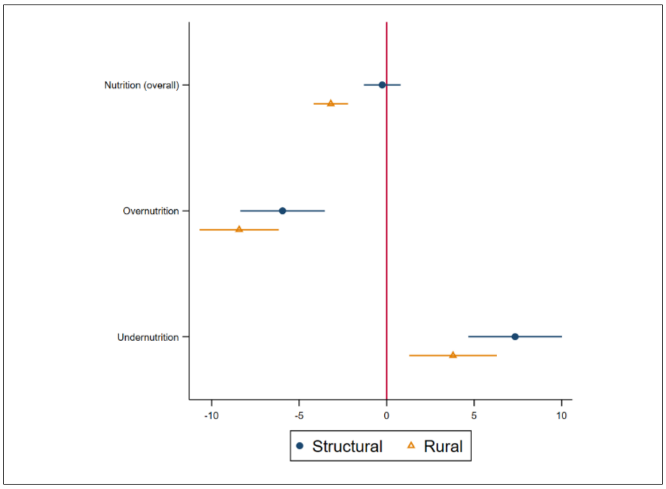


Figure 9: Associations of overall overnutrition and undernutrition with structural and rural transformation

Note: Indicators on the vertical axis are dependent variables, all from separate OLS regression specifications. Circles and cones show point estimates for structural and rural transformations, respectively, and the lines indicate 90 per cent confidence intervals. Source: Authors' calculations.

4.2 Association with other indicators

Structural and rural transformation are high-level indicators of a country's development pathway. Although they can be policy priorities of a country (i.e. industrialization and agricultural development policies at the highest level), multitudes of policy levers at lower levels are intricately connected with the accompanying transformations traversed by countries. These include demographic, employment, nutrition and food system transformations, which are set against a backdrop of social, climatic and policy changes. In this subsection, we assess some of these policy levers by selecting a large set of indicators organized in broad themes that reshape the global food system, following the literature.

To date, a unified food system index has been elusive for methodological or political reasons; however, there is a rich literature that puts a structure on the complex drivers of the food system (HLPE, 2017; Fanzo et al., 2020; Denning and Fanzo, 2016). The food system dimensions we use here are based on the framework established by HLPE (2017). Others have developed similar frameworks. For instance, Fanzo et al. (2020) developed a food systems dashboard and identified several external drivers: climate change, globalization and trade, income growth and distribution, urbanization, population growth and migration, politics and leadership, and sociocultural context. Similarly, Denning and Fanzo (2016) listed 10 factors reshaping the global food system: natural resources, climate change, urbanization, globalization, consumer, culture and tradition, government policies, conflict and fragile states, technology innovation and sustainability. Several key publications highlight the need to transform food (and agricultural) systems to achieve nutritional and climate change objectives (Shukla et al., 2019; Smith et al., 2014; Willett et al., 2019; Searchinger et al., 2018). Using different models, approaches and points of view, these sources argue consistently for major changes in agricultural land use, production systems and dietary choices, with an emphasis on increasing resource use efficiency, reducing agricultural extensification and reducing consumption of meat-based products while increasing intake of nutritionally dense foods.

We also use existing literature to identify some variables that are important determinants of the food system. Rittner et al. (2019) and Cracau et al. (2017) report the importance of access to capital and financial services and networks for food system sustainability. Reardon et al. (2019) discuss the role of technology adoption for food system transformations. Women's empowerment has become an important dimension in recent AFS literature. Studies show that women's empowerment can boost food security, nutritional conditions and market orientation (Akter et al. 2017; Galiè et al., 2019; Gupta et al., 2017; Gupta et al., 2019). Similarly, the role of human capital and knowledge management in the global food system are discussed in detail by Sporleder and Moss (2002). Finally, Spears (2012) shows that open defecation in developing countries is strongly associated with child height. This literature is discussed in a review piece within a structural transformation framework by Pingali and Sunder (2017).

To identify our final covariates list, we follow two additional criteria. Firstly, data availability: we limit the covariate list to the indicators available in the WDI. Secondly, we exclude variables that are already included in building food system dimensions. Using these two criteria, we list 55 covariates under 10 broad thematic categories. These include indicators on: (i) access to infrastructure (e.g. access to sanitation or electricity); (ii) access to technology (e.g. computer and internet use); (iii) environment and climate (e.g. rural and urban elevation level); (iv) access to finance facilities (e.g. bank branch or cashpoint/ATM availability); (v) human capital (e.g. education); (vi) migration (e.g. remittances, migrant shares); (vii) population distribution (e.g. population in rural and urban areas); (viii) technology adoption (e.g. machinery use); (ix) war and conflicts (e.g. displaced population); and (x) women's empowerment (e.g. right to property, age at marriage). Table A1 in the appendix contains the full list of covariates and their details.

4.2.1 Estimation method

The main hurdle in our estimation is that we have a small sample but a large covariate set. Under such conditions, OLS-based regressions suffer from a problem with degrees of freedom and can generate imprecise estimates because of overfitting of regression models. To overcome the overfitting problem, some regularized regression methods are available. In this study, we use the Least Absolute Shrinkage and Selection Operator (LASSO) method, which is commonly used in the literature in this regard. Storm et al. (2020) provide an excellent review of the application of the LASSO method in the applied economics literature. In recent literature, Lentz et al. (2019) and Knippenberg et al. (2019) used the LASSO model for food security prediction. In brief, the LASSO method is an extension of the OLS method; it adds a penalty term to the OLS objective function to reduce the number of parameters to those that are most important. By dropping less important covariates, the LASSO method reduces overfitting of a model.

The adjusted objective function of the OLS model after adding the penalty term, called lambda (λ), is as follows:

$$L_{(\beta,\lambda)} = \sum_{c=1}^{N}\left(FS_c - X_c\beta\right)^2 + \lambda\sum_{j=1}^{p}|\beta_j|,$$

where $\lambda\sum_{j=1}^{p}|\beta_j| < t$ for some $t > 0$, *FS* indicates different food system dimensions and the FSI (in different specifications), and X is the vector of covariates. The penalty term selects and shrinks coefficients of the covariates with high predictive power and ignores covariates that have little to no power in predicting the dependent variable. To select the penalty term (λ) that reduces prediction errors most, we use a five-fold cross-validation approach.[13]

4.2.2 Results

Pooled results

We run 10 LASSO specifications: seven for food system dimensions, two for additional nutritional indicators (overnutrition and undernutrition) and one for the aggregate FSI. We first show which variables are selected by the LASSO as predictors for each of these specifications. As we have 10 specifications, a variable can be selected a maximum of 10 times. Figure 10 shows the list of variables selected at least twice.

The indicators of financial inclusion are selected with the highest frequency. For instance, availability of bank branches and ATMs are selected five and four times, respectively, out of 10 specifications. Social development status (open defecation rate) is also selected in 4 out of 10 specifications. Indicators of demographic transition (age dependency ratio), women's empowerment (age at marriage, property ownership rights, tertiary school enrolment), access to information technology (internet and fixed telephone users) and remittances (percentage share in GDP) are selected in 3 out of 10 specifications. Agricultural machinery use, schooling and education indicators, infant mortality rate, internally displaced population, and other indicators of women's empowerment and digital connectivity are among the indicators selected twice.

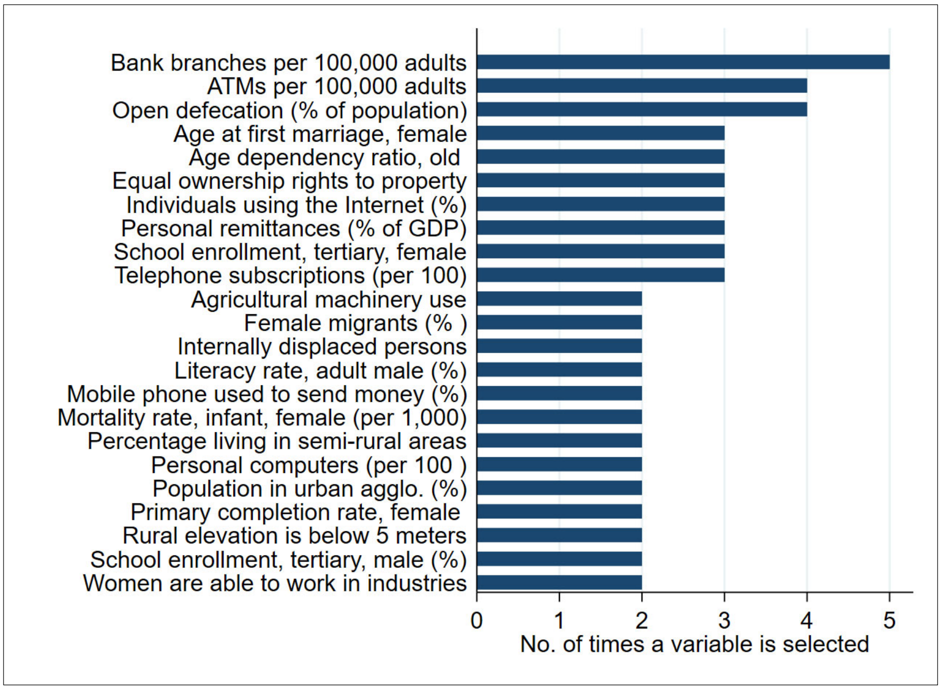


Figure 10: List of selected variables in the LASSO specifications

Note: Figure shows the list of variables selected at least twice in the LASSO specifications with their selection frequency. The maximum number can be 10. The LASSO is based on linear specification. Optimal value of lambda is estimated using a five-fold cross-validation method. Source: Authors' calculations.

[13] A five-fold cross-validation method randomly splits the sample into five equal size sub-samples. Then, out of the five sub-samples, four sub-samples are used to train the model (training data) and the remaining sub-sample is used for testing the model (test data). The cross-validation process is then repeated five times (once for each fold), such that each of the five sub-samples are used exactly once as the test data. Finally, the five sets of results (one from each fold) are averaged to produce the results.

Table 5 provides a closer understanding of the full list of variables (including those selected only once) that are influential and their direction of influence for each dimension and the FSI. We show coefficients of the selected variables for individual dimensions in columns 1 to 9 and the aggregate FSI in column 10.[14] For the aggregate FSI, we find that indicators on financial inclusion (availability of bank branches and ATMs), technology adoption in farming (machinery use), use of information and communication technology (internet users), human capital (school enrolment, dependency ratio), access to infrastructure (electricity), women's empowerment (age at first marriage) and rural electrification are the most influential variables selected by LASSO. They are all positively associated with the aggregate FSI.

For the food demand dimension, we find that tertiary school enrolment for males and age at first marriage for females are the most influential variables, both improving the demand dimension (recall the negative direction of improvement). Other selected variables correlated with improvements in this dimension are availability of bank branches, population living in semi-rural areas and internally displaced population. Total fertility rate and mobile money indicators are negatively associated with this dimension, as they capture increasing population and urbanization growth rates.

For food production and policy dimensions, the LASSO specifications select only a few variables: access to ATMs and age dependency ratio for production, and primary school completion rate for policy. Although these variables are good proxies for access to credit, and presence of institutional support and labour force and social structure, the results also suggest that our covariate set does not predict these two dimensions well. For example, one could expect agricultural machinery use to predict production. Results suggest that more fundamental issues such as agricultural research and development, access to inputs and technical assistance, access to institutions, and climate conditions may matter more, which are not covered in our set. The enabling environment (proxied by the ease of doing business index) tends to be highly political and heterogeneous, hence is difficult to predict, as we expected. Although results seem to indicate a larger scope of actions from the enabling environment, the variables covered and captured are insufficient to shed additional light.

For market access and inclusiveness, access to banks or ATMs and female tertiary education indicators are positive influencers. Food consumption inclusiveness is significantly higher in older societies. This suggests that countries with high youth populations, which predominantly have low FSI and will see their youth numbers double in the next 30 years, need to pay special attention to this dimension. One surprising result is that equal ownership rights to property (a women's empowerment indicator) is negatively related to access dimension, although the magnitude of the coefficient is close to zero.

The importance of separating overnutrition and undernutrition becomes evident again in this section. The overnutrition dimension (i.e. overweight) becomes that with the highest number of influential variables. Interestingly, although the unconditional averages in the radar graphs indicated that this dimension was worse in countries with an urban-dominant population, we find that, conditional on a large set of covariates, urban population share improves the overweight situation. This finding indicates that a multitude of policy levers, specifically related to education and women's empowerment, improve the overweight situation even in increasingly urban-dominated countries. It also suggests the importance of education and cultural matters regarding nutrition outcomes, particularly considering healthy and sustainable diets.

Interestingly, climate adaptation is the dimension with the second-highest number of selected influential variables. Most of these variables are concentrated around education, women's empowerment, and digital and financial inclusion, pointing to basic rural development interventions as an essential component of efforts to improve the sustainability of the food system.

[14] Note that the desirability directions of dimensions remain the same as before, that is an increase indicates an improvement in desirability of food system outcome for all dimensions except for the demand dimension, where an increase indicates higher stress to the food system.

Table 5

Directional determinants and magnitudes of food system dimensions and the overall FSI

Variable	*Demand*	*Production*	*Access*	*Inclusiveness*	*Policy*	*Nutrition*	*Overnutrition*	*Undernutrition*	*Climate*	*FSI*
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Bank branches per 100,000 adults	-1.906			0.723		-2.026	-2.396			1.555
Open defecation (% of population)				-2.663		-0.138	0.733	-2.500		
ATMs per 100,000 adults		1.955	1.610						0.816	4.953
Individuals using the internet (%)								2.089	1.438	0.113
School enrolment, tertiary, female			1.263	2.122						1.089
Equal ownership rights to property			-0.030				1.267		0.346	
Telephone subscriptions (per 100)							-7.696	1.558	0.488	
Age dependency ratio, old				2.368					0.256	7.156
Personal remittances (% of GDP)						0.484	-1.372	0.138		
Age at first marriage, female	-4.586								2.034	2.971
Agricultural machinery use						0.016				0.408
Personal computers (per 100)			0.934			0.952				
Population in urban agglomerations (%)				0.195			-0.111			
Percentage living in semi-rural areas	-0.124						0.162			
School enrolment, tertiary, male (%)	-6.137								1.595	
Internally displaced persons	-0.551						2.625			
Primary completion rate, female						1.816	1.521			
Female migrants (%)						1.313	2.611			
Rural elevation is below 5 metres						0.135	1.840			
Literacy rate, adult male (%)							0.783		0.194	
Women can work in industries							-2.048	0.091		
Mortality rate, infant, female (per 1,000)			-0.080			-0.110				
Mobile phone used to send money (%)	1.212					2.105				
Age dependency ratio, young		-8.454								
Percentage living in urban areas							0.695			
Elevation is below 5 metres (urban)						0.899				
Access to electricity, rural (%)										1.241
Female headed households								5.190		
Fertility rate, total (births per woman)	1.070									
Equal rights to inherit assets from parents							-0.029			
Age at first marriage, male				0.353						
Basic handwashing facilities (% of pop)			3.159							
School enrolment, gender parity index							0.027			
Primary completion rate, male					2.017					
Women Business and the Law Index score								1.444		
Share of youth in total country population							-1.668			

Note: Standardized coefficients of the post-selected variables from the LASSO liner model. Optimal value of lambda is estimated using a five-fold cross-validation method

Results by level of structural/rural transformation

Some of the variables above can have different impacts on food system dimensions depending on the structural and rural transformation levels in a country. For example, at lower levels of structural/rural transformation, agricultural machinery use may be associated with more desirable food system outcomes, although this variable probably loses its influence as countries become highly transformed. If this is the case, pooling all countries in the analysis would compound the selection and directional analysis of variables. Identifying food and nutrition policies suitable for each country's structural transformation stage remains a challenge (Pingali and Sunder, 2017). We therefore perform additional LASSO analyses by separating our sample by structural transformation level (49 high versus 36 low ST countries) and then by rural transformation level (44 high versus 41 low RT countries).

Figure 11 shows the list of variables selected and their frequency of selection for each transformation group.[15] For the low structural transformation group, women's empowerment (age at first marriage), internet

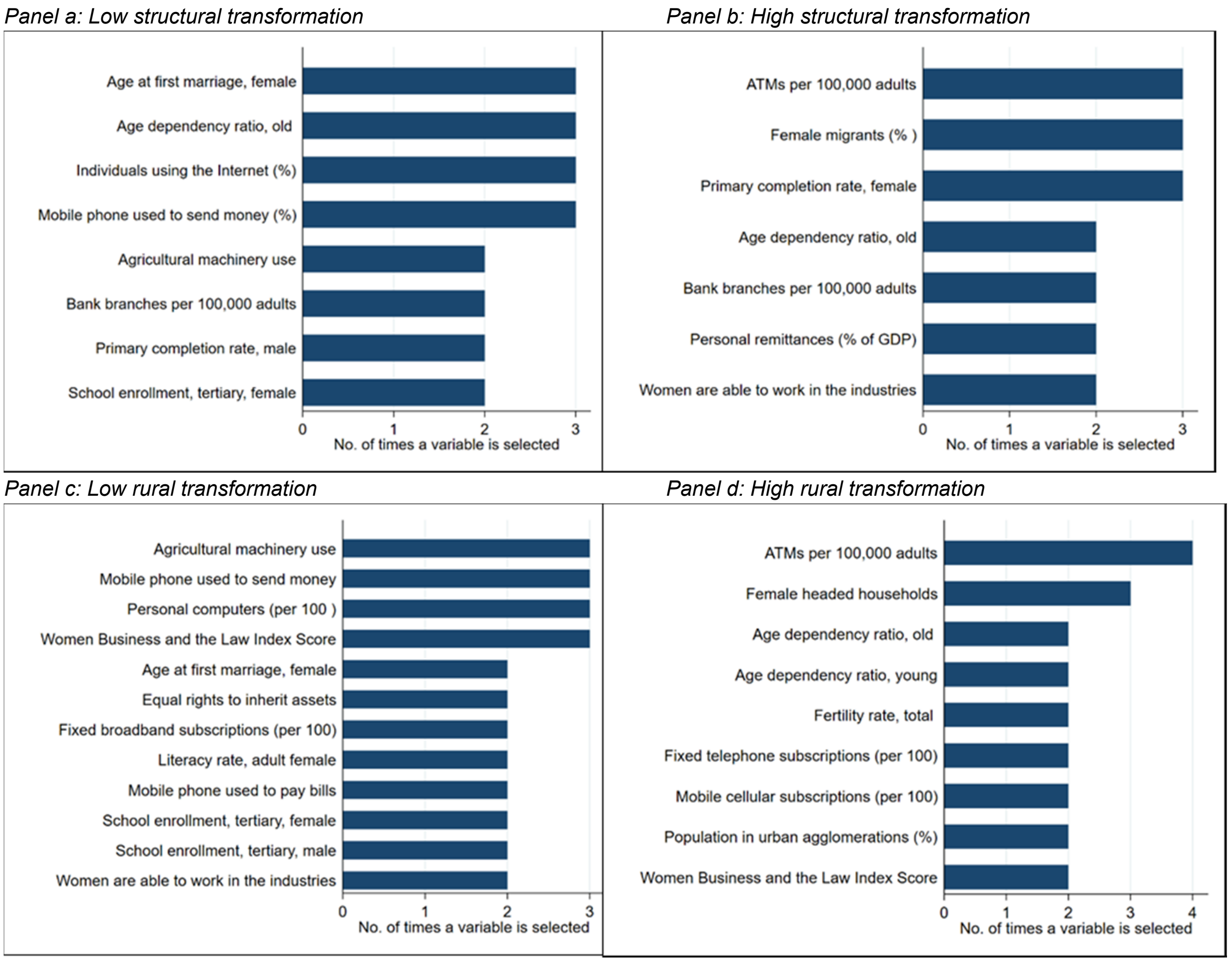


Figure 11: Selected variables by structural and rural transformation levels

Note: Figure shows the list of variables selected in the LASSO specifications with their frequency. The maximum number can be 10. We listed variables selected at least twice. The LASSO is based on linear specification. Optimal value of lambda is estimated using a five-fold cross-validation method. Source: Authors' calculations.

[15] Appendix Tables A2-A5 show coefficients of all selected variables. Directions of the coefficients are largely aligned to the full sample case. The major difference with the full sample case is that there are fewer variables selected when we split the sample into different groups, which is expected as food systems under different levels of transformations will be determined by a different set of indicators. This is also related to the number of observations and variation becoming very low in split samples. Therefore, results from this subsection should be used to gain insights into which food system predictors are important for different transformation groups rather than directions/magnitudes of coefficients for each dimension.

and mobile money use, and age dependency ratio are the most frequently selected variables. For the high structural transformation group, availability of ATMs (financial inclusion indicator), female migrants and primary school completion rates are the most selected indicators. Access to financial services (through bank branches) is selected for both groups.

Agricultural machinery use is selected only for low structural transformation and low rural transformation country samples, as expected. On the other hand, higher level women's empowerment indicators, such as ability to work in industry, and existing laws and regulations for women's economic inclusion, are only selected for high structural and rural transformation groups. These findings underline the dynamic nature of policies needed to improve food system outcomes as countries transform. At the lower end, they are closely related to broader rural development interventions, with female empowerment and enabling environment becoming more crucial for sustainable and inclusive food systems as broad rural development objectives are met.

Close-up of selected outlier countries

If we recall that South Africa is the only country in SSA that has reached a high level of structural and rural transformation, as well as the highest FSI. China and Viet Nam are the only two countries that achieved the highest FSI in spite of having a low level of rural transformation (though high structural), and Chad and Nigeria are the only two countries that have high rural transformation (and low structural) but low FSI. It is important to note that both countries are among the most fragile states, ranking 7th and 14th respectively in the Fragile State Index (FFP, 2020) as a result of internal conflicts, political instability and particularly difficult climatic and environmental conditions, all elements that pose a heavy burden on the food system. We zoom in on the 23 variables selected by the pooled LASSO model (see Figure 10) as key predictive indicators for these countries in Table 6.

China and Viet Nam have reached a high FSI despite their low rural transformation status (combined with high structural transformation). They perform highest in most education-related indicators for both males and females. Interestingly, these two countries have the highest agricultural machinery use. Although they have a high FSI, financial inclusion and women's enhanced participation in industry remain challenging. In the case of Viet Nam, progress in terms of FSI seems to be under threat from climate change, as one third of the rural population lives in low-lying areas and merits special attention on this food system dimension.

South Africa, on the other hand, is in the high-performing group on all fronts, and the only such country in SSA. Note that it has achieved high rural transformation despite having a relatively low agricultural machinery use, confirming that improving value added in agriculture requires much more than machinery use at higher levels of transformation. South Africa stands out on some women's empowerment indicators (age at first marriage and participation in industrial labour force) despite not being on top of basic education indicators. It has the lowest ranking in terms of overweight individuals, and one in three South Africans live in urban agglomerations of at least 1 million people, underlining again the urbanization and nutrition transition linkages that strengthen as countries transform economically (Mbogori et al., 2020).

Chad and Nigeria have high levels of rural transformation, although both rank lower in the structural and FSI categories. They lag behind in most of the selected indicators, primarily women's empowerment, and financial and digital connectivity. Relevant investments are needed to address connectivity problems and create economic opportunities and progress towards structural transformation. Investments in female education and empowerment, although culturally challenging, also create positive overspills in terms of demographic transition (e.g. later marriage and lower infant mortality rates). Recall that both of these countries are characterized as fragile, which can be both cause and effect of low ranking on these indicators, and requires special attention to create an inclusive transformation on all fronts.

Table 6
World Development Indicators selected by LASSO in outlier countries

	China	*Viet Nam*	*South Africa*	*Nigeria*	*Chad*
Structural/rural transformation level	High ST and low RT	High ST and low RT	High ST and high RT	Low ST and high RT	Low ST and high RT
FSI category	High	High	High	Low	Low
FSI	87.9	66.0	77.1	29.1	11.8
Bank branches per 100,000 adults	8.8	3.6	10.3	4.6	1.0
ATMs per 100,000 adults	82.8	24.2	68.5	16.5	1.5
Open defecation (% of population)	0.3	3.0	1.7	20.0	67.1
Age at first marriage, female	25.4	22.7	27.2	21.5	18.6
School enrolment, tertiary, female (%)	55.5	31.7	26.4	8.2	1.0
Equal ownership rights to property	1	1	1	1	0
Age dependency ratio, old	14.9	10.3	8.0	5.1	4.9
Personal remittances (% of GDP)	0.2	6.6	0.3	5.5	0.0
Fixed phone subscriptions (%)	13.8	4.7	6.4	0.1	0.1
Individuals using the internet (%)	53.8	62.4	55.1	16.6	5.7
Percentage living in semi-rural areas	33.2	25.1	13.0	12.3	11.1
Mobile phone use to send money (%)	10.7	1.6	10.1	5.2	12.3
School enrolment, tertiary, male (%)	45.8	25.5	18.4	11.5	4.5
Internally displaced persons (1000)	4,926	237	7	243	13
Personal computers (%)	5.5	9.6	7.4	0.7	0.1
Infant mortality rate, female (per 1,000)	7.1	14.2	25.5	69.5	65.0
Pop. in urban agglomeration >1 million (%)	27.6	16.6	35.1	16.5	8.5
Agricultural machinery use	83.7	262.5	49.7	6.6	
Rural pop. living below 5 metres (%)	2.4	29.6	0.1	0.7	
Primary completion rate, female (%)	95.2	109.2	88.1	68.9	33.0
Female migrants (%)	38.6	42.1	44.4	45.1	53.9
Literacy rate, adult male (%)	98.5	96.5	87.7	71.3	31.3
Women are able to work in industries	0	0	1	0	0

Note: ST = structural transformation; RT = rural transformation. Source: Authors' calculations.

5. Conclusions and recommendations

The complexity of food system transformation and its linkages with structural and rural transformation have been discussed – mostly conceptually – at length in the literature. This paper contributes to this literature by linking these concepts quantitatively using data from 81 LMICs and creating an aggregate FSI, which together allow a rich descriptive analysis (using machine learning) of the components, drivers and outcomes of the food system. It includes spatial and youth angles to better characterize today's and tomorrow's food system challenges along these dimensions.

Several salient conclusions and recommendations can be drawn from this analysis. Firstly, although structural transformation is often associated with the transformation of the food system, we document that it is a necessary but not sufficient condition for desirable food system outcomes. Rural transformation (the manifestation of transformation in rural areas) by itself without structural transformation is not enough either. For LMICs, broad development interventions, such as financial and digital connectivity as well as women's empowerment, are more important regarding progress in the food system.

Secondly, food system policies need to be tailored to the spatial and age structure of populations. The spatial population distributions also reflect the AFS transition stages (traditional, transitional, modern) of countries. Countries with the lowest FSI have rural-dominant populations and a hallow middle ground (semi-rural and peri-urban areas), and the population distribution over space evens out with improvements in the FSI. Importantly, countries in the lowest FSI group will see their youth populations more than double in the next 30 years, while those in the highest FSI group will see a decrease in youth numbers. Investments made in the lowest FSI countries of today will affect one third of the future generation of youth.

Thirdly, characterizing the nutrition and health dimension of food systems requires special attention on the double burden of malnutrition. The large set of variables we analysed frequently have opposite relationships with the undernutrition (i.e. stunting, wasting and micronutrient deficiencies) and overnutrition (overweight children and adults) dimensions, underlining the importance of finding the right balance and targeting in interventions. Empirically, any attempts to create an aggregate FSI should keep these components separate to disentangle these challenges.

Fourthly, there is no one path to achieving desirable food system outcomes and there are many outliers. What seems to stand out in these outliers and the results of the machine learning analysis is women's empowerment indicators (e.g. age at first marriage, higher education, equal legal and economic rights) as well as financial and digital connectivity. These are clearly foundations of economic and social progress and, regardless of the levels of structural and rural transformation, play an important role in the progress of the food system.

Finally, the enabling environment is critical for progress in all food system dimensions, although our indicators do not seem to capture sufficient variation in this aspect. Data on policies and institutions, investments in research and development in food and agriculture, extension services or other access to information (both production- and consumption-related) as well as conflict and fragility should be better incorporated in future food system analyses.

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Appendix

Table A1: List of variables used in the LASSO model

Type	*Variable*
Population	Percentage living in semi-rural areas
	Share of youth in total country population
	Literacy rate, adult female (% of females aged 15 and above)
	Percentage living in urban areas
	Percentage living in peri-urban areas
Technology adoption	Agricultural irrigated land (% of total agricultural land)
	Fertilizer consumption (% of fertilizer production)
	Agricultural machinery, tractors per 100 sq. km of arable land
War and conflicts	Battle-related deaths (number of people)
	Internally displaced persons, new displacement associated with conflict
	Internally displaced persons, total displaced by conflict and violence (number)
	Presence of peacekeepers (number of troops, police and military observers)
	Internally displaced persons, new displacement associated with disasters (number)
	Intentional homicides (per 100,000 people)
	Refugee population by country or territory of origin
	Refugee population by country or territory of asylum
Access to infrastructure	People with basic handwashing facilities including soap and water (% of population)
	Improved sanitation facilities, rural (% of rural population with access)
	Improved water source, rural (% of rural population with access)
	Motor vehicles (per 1,000 people)
	Access to electricity, rural (% of rural population)
	Passenger cars (per 1,000 people)
	Vehicles (per km of road)
	People practising open defaecation (% of population)
Financial access	Mobile account, female (% age 15+)
	Bank accounts per 1,000 adults
	Account at a financial institution (% age 15+)
	Mobile account (% age 15+)
	Mobile account, male (% age 15+)
	Account at a financial institution, female (% age 15+)
	Account at a financial institution, male (% age 15+)
	ATMs per 100,000 adults
	Mobile phone used to pay bills (% age 15+)
	Mobile phone used to send money (% age 15+)
	Bank branches per 100,000 adults
Access to technology	Personal computers (per 100 people)
	Mobile cellular subscriptions (per 100 people)
	Households with television (%)
	Fixed line and mobile cellular subscriptions (per 100 people)
	International internet bandwidth (bits per person)

	Fixed telephone subscriptions (per 100 people)
	Fixed broadband subscriptions (per 100 people)
	Individuals using the internet (% of population)
Women's empowerment	A woman can open a bank account in the same way as a man (1=yes; 0=no)
	Female and male surviving spouses have equal rights to inherit assets (1=yes; 0=no)
	Women Business and the Law Index Score (scale 1-100)
	A woman can travel outside her home in the same way as a man (1=yes; 0=no)
	Sons and daughters have equal rights to inherit assets from their parents
	A woman can choose where to live in the same way as a man (1=yes; 0=no)
	A woman can be head of household in the same way as a man (1=yes; 0=no)
	Men and married women have equal ownership rights to immovable property
	Women are able to work in the same industries as men (1=yes; 0=no)
	Female headed households (% of households with a female head)
Human capital	School enrolment, primary and secondary (gross), gender parity index
	Sex ratio at birth (male births per female births)
	Age at first marriage, male
	School enrolment, tertiary, female (% gross)
	Life expectancy at birth, female (years)
	School enrolment, tertiary, male (% gross)
	Primary completion rate, female (% of relevant age group)
	Life expectancy at birth, total (years)
	Age dependency ratio, old (% of working-age population)
	Mortality rate, infant, female (per 1,000 live births)
	Age dependency ratio, young (% of working-age population)
	Mortality rate, infant (per 1,000 live births)
	Literacy rate, adult male (% of males age 15+)
	Primary completion rate, male (% of relevant age group)
	Age at first marriage, female
	Age dependency ratio (% of working age population)
	Mortality rate, infant, male (per 1,000 live births)
	Fertility rate, total (births per woman)
	Life expectancy at birth, male (years)
Migration	Net migration
	Female migrants (% of international migrant stock)
	International migrant stock (% of population)
	Personal remittances, received (% of GDP)
Environment	Rural population living at elevation below 5 meters (%)
	Urban population living in at elevation below 5 meters (%)
	Disaster risk reduction progress score (1-5 scale; 5=best)
	Population in urban agglomerations of more than 1 million (% of total pop)
	Droughts, floods, extreme temperatures (% of population, average 1990-2009)

Table A2: Selected variables and coefficients (low structural transformation sample)

Variable	*Demand*	*Produc-tion*	*Access*	*Inclusive-ness*	*Policy*	*Nutrition (overall)*	*Nutrition (overweight)*	*Nutrition (deficiency)*	*Climate*	*FSI*
Age at first marriage, female	-2.260								0.279	2.432
Age dependency ratio, old	-0.975	1.992								0.482
Mobile phone used to send money (%)					1.590	2.172		5.252		
Individuals using the internet (%)							-0.329	0.490		0.797
Agricultural machinery use	-0.575									2.387
School enrolment, tertiary, female	-1.408									0.102
Bank branches per 100,000 adults					0.336					1.944
Primary completion rate, male					0.322			0.051		
Age dependency ratio, young		-1.926								
Access to electricity, rural (%)					0.278					
Age at first marriage, male		-3.176								
Primary completion rate, female								0.625		
Basic handwashing facilities (% of population)		0.523								
Gender parity index	1.086									
Women Business and the Law Index Score						0.005				
Telephone subscriptions (per 100)										0.645
Mobile phone used to pay bills (%)					1.773					
A woman can be head of household					0.227					
Percentage living in peri-urban areas					1.565					
Female headed households						0.738				
Women are able to work in the industries										-0.243

Note: Standardized coefficients of the post-selected variables from the LASSO liner model are shown in the table. Optimal value of lambda is estimated using a five-fold cross-validation method.

Table A3: Selected variables and coefficients (high structural transformation sample)

Variable	*Demand*	*Produc-tion*	*Access*	*Inclusive-ness*	*Policy*	*Nutrition (overall)*	*Nutrition (overweight)*	*Nutrition (deficiency)*	*Climate*	*FSI*
ATMs per 100,000 adults					2.102				2.923	9.949
Primary completion rate, female			3.568		5.816					4.175
Female migrants (%)		-1.343		-1.832			1.121			
Women are able to work in the industries			3.418				-3.567			
Age dependency ratio, old				0.898						5.273
Personal remittances (% of GDP)		-4.423					-3.199			
Bank branches per 100,000 adults						-2.435	-1.364			
Telephone subscriptions (per 100)							-7.227			
Age dependency ratio, young				-2.238						
Open defaecation (% of pop)		-1.625								
Elevation is below 5 meters (urban)							2.307			
Share of youth in total country population				-1.561						
School enrolment, tertiary, female (%)				4.040						
Elevation is below 5 meters (rural)						2.151				
Age dependency ratio		-7.704								
Internally displaced persons							3.929			
Mobile cellular subscriptions (per 100)		8.764								
Individuals using the internet (% of population)									3.164	
Agricultural machinery use							1.953			
Basic handwashing facilities (% of population)			3.346							
Percentage living in peri-urban areas		4.317								
Female headed households			LASSO				-1.736			

Note: Standardized coefficients of the post-selected variables from the Lasso liner model are shown in the table. Optimal value of lambda is estimated using a five-fold cross-validation method.

Table A4: Selected variables and coefficients (low rural transformation sample)

Variable	*Demand*	*Produc-tion*	*Access*	*Inclusive-ness*	*Policy*	*Nutrition (overall)*	*Nutrition (overweight)*	*Nutrition (deficiency)*	*Climate*	*FSI*
Agricultural machinery use							0.246		0.576	0.513
Mobile phone used to send money	0.028					2.422	0.280			
Women Business and the Law Index Score		-0.555				0.175	0.096			
Personal computers (per 100)			1.250	0.358						0.195
Women are able to work in the industries		-2.012								-0.400
School enrolment, tertiary, female									1.147	5.216
School enrolment, tertiary, male	-6.748								0.208	
Literacy rate, adult female		0.855					0.085			
Equal rights to inherit assets		0.931	0.019							
Age at first marriage, female						1.093			1.399	
Fixed broadband subscriptions (per 100)		4.875				1.818				
Mobile phone used to pay bills		-2.709				0.005				
Female headed households						0.172				
Bank branches per 100,000 adults						-0.483				
Personal remittances (% of GDP)		0.018								
Age dependency ratio, old										1.406
Individuals using the Internet (%)									1.034	
Share of youth in total country population							-1.009			
Life expectancy at birth, female		4.946								
A woman can choose where to live							1.099			
Female migrants (%)		-0.126								
Fertility rate, total		-3.800								
Mobile cellular subscriptions (per 100)							-0.554			
Elevation is below 5 meters (urban)										0.034
Equal ownership rights to property							0.793			
Telephone subscriptions (per 100)			0.383							

Mortality rate, infant, female	-0.275			
Basic handwashing facilities (% of pop)		3.404		
Age at first marriage, male	-6.368			
ATMs per 100,000 adults				4.131
Internally displaced persons			1.795	

Note: Standardized coefficients of the post-selected variables from the LASSO liner model are shown in the table. Optimal value of lambda is estimated using a five-fold cross-validation method.

Table A5: Selected variables and coefficients (high rural transformation sample)

Variable	*Demand*	*Produc-tion*	*Access*	*Inclusive-ness*	*Policy*	*Nutrition (overall)*	*Nutrition (overweight)*	*Nutrition (deficiency)*	*Climate*	*FSI*
ATMs per 100,000 adults		2.031			0.232				0.965	2.751
Female headed households							-0.046	1.825	1.247	
Fixed telephone subscriptions (per 100)							-8.965	2.233		
Age dependency ratio, old				1.160						0.916
Mobile cellular subscriptions (per 100)					2.607				0.277	
Age dependency ratio, young					-1.559					-8.730
Fertility rate, total	5.349		-2.241							
Women Business and the Law Index Score							-0.542	4.177		
Population in urban agglomerations (%)					0.067				1.193	
Elevation is below 5 meters (rural)							1.075			
Percentage living in urban areas							4.346			
Access to electricity, rural (%)				0.964						
Agricultural machinery use	-0.483									
Personal computers (per 100)	-0.071									
Bank branches per 100,000 adults					0.457					
Internally displaced persons							0.917			
Equal ownership rights to property					0.114					
Share of youth in total country population					-0.530					
Age at first marriage, male							1.153			
Women are able to work in the industries			3.034							
Personal remittances (% of GDP)					-0.786					
Female migrants (%)							2.856			
Primary completion rate, female									1.254	
Fixed broadband subscriptions (per 100)					0.546					
Age dependency ratio									-1.231	
Mortality rate, infant, female								-3.221		

Note: Standardized coefficients of the post-selected variables from the LASSO liner model are shown in the table. Optimal value of lambda is estimated using a five-fold cross-validation method

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