INTERNATIONAL
FOOD POLICY
RESEARCH
INSTITUTE

IFPRI Discussion Paper 01362

July 2014

Understanding the Context for Agriculture for Nutrition Research

Identifying Country Typologies of Child-Stunting Determinants

Eduardo Maruyama

Laurian J. Unnevehr

Jiarui Wang

Markets, Trade and Institutions Division

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

The International Food Policy Research Institute (IFPRI), established in 1975, provides evidence-based policy solutions to sustainably end hunger and malnutrition and reduce poverty. The Institute conducts research, communicates results, optimizes partnerships, and builds capacity to ensure sustainable food production, promote healthy food systems, improve markets and trade, transform agriculture, build resilience, and strengthen institutions and governance. Gender is considered in all of the Institute's work. IFPRI collaborates with partners around the world, including development implementers, public institutions, the private sector, and farmers' organizations, to ensure that local, national, regional, and global food policies are based on evidence.

AUTHORS

Eduardo Maruyama (e.maruyama@cgiar.org) is a research coordinator in the Markets, Trade and Institutions Division of the International Food Policy Research Institute (IFPRI), Washington, DC.

Laurian J. Unnevehr is a professor emerita in the Agricultural and Consumer Economics Department of the University of Illinois at Urbana-Champaign.

Jiarui Wang is a senior research assistant in the Markets, Trade and Institutions Division of IFPRI, Washington, DC.

Notices

IFPRI Discussion Papers contain preliminary material and research results and are circulated in order to stimulate discussion and critical comment. They have not been subject to a formal external review via IFPRI's Publications Review Committee. Any opinions expressed are those of the author(s) and do not necessarily reflect the policies or opinions of IFPRI.

Copyright 2014 International Food Policy Research Institute. All rights reserved. Sections of this material may be reproduced for personal and not-for-profit use without the express written permission of but with acknowledgment to IFPRI. To reproduce the material contained herein for profit or commercial use requires express written permission. To obtain permission, contact the Communications Division at ifpri-copyright@cgiar.org.

Contents

Abstract	v
Acknowledgements	vi
1. Introduction	1
2. Review of Literature	2
3. Data	4
4. Method	7
5. Results	9
6. Conclusions and Implications	21
Appendix: Data Selection and Estimation Procedures	24
References	37

Tables

5.1 Food security clusters: Sample means and country lists	10
5.2 Health environment quality and care for mothers and children clusters: Sample means and country lists	12
5.3 Poverty clusters: Sample means and country lists	14
5.4 Child-stunting clusters: Sample means and country lists	15
5.5 Second-stage clusters: Sample means and country lists	18
A.1 Data year for child stunting by country	24
A.2 Data sources and data year for variables considered	27
A.3 Stopping rules' statistics for child stunting clusters	32
A.4 Stopping rules' statistics for poverty clusters	33
A.5 Stopping rules' statistics for food security clusters	34
A.6 Stopping rules' statistics for health and care clusters	35
A.7 Stopping rules' statistics for second-stage clusters	36

Figures

5.1 Distribution of food security indicators by cluster	11
5.2 Distribution of health and care indicators by cluster	13
5.3 Stunting and poverty	16
5.4 Distribution of all indicators by second-stage clusters	17
6.1 Child stunting and food security: Mozambique:	22
6.2: Child stunting and food security: Bangladesh	23
A.1 Correlation matrix of food security variables	25
A.2 Correlation matrix of health and care variables	26
A.3 Scatter plots of food security variables and child stunting using different lagged values	28
A.4 Scatter plots of health and care variables and child stunting using different lagged value	30
A.5 Dendrogram of child stunting clusters	32
A.6 Dendrogram of poverty clusters	33
A.7 Dendrogram of food security clusters	34
A.8 Dendrogram of health and care clusters	35
A.9 Dendrogram of second-stage clusters	36

ABSTRACT

We use data from 52 countries on child stunting, poverty, determinants of food security, environmental health, and quality of maternal and child care to carry out a cluster analysis of country typologies. The purpose is to identify where agriculture-led interventions might address binding constraints to progress in improving nutrition outcomes and to identify how existing research on the links between agriculture and nutrition in particular country contexts may or may not be representative. We find that countries with average to poor nutrition outcomes within this sample set fall into groups where one supporting area tends to lag, such as environmental health or food security. Although integrated programs to address all aspects that support nutrition are needed in most of these 52 countries, we identify a group of 11 countries where interventions to improve diet diversity may be most relevant toward progress in alleviating child malnutrition. Agriculture for Nutrition and Health intervention research is underway in 6 of these 11 countries.

Keywords: agriculture, nutrition, typology, developing countries, cluster analysis, child-stunting

ACKNOWLEDGEMENTS

The authors thank Maximo Torero for comments and guidance, and William Collier for research assistance in the early stages of the project.

1. INTRODUCTION

The potential for agriculture to address nutrition has received increased attention in the development community in recent years, including a special issue of *Lancet* released in June 2013 as well as the formation of the Global Panel on Agriculture and Food Systems for Nutrition. Ruel and Alderman (2013) outline how a number of agricultural interventions can improve nutrition, and many of these are the focus of expanding efforts by donors and civil society. This renewed attention is also reflected in the creation of a cross-cutting research program on Agriculture for Nutrition and Health (A4NH) within the CGIAR, which includes long-standing efforts in biofortification as well as new research to understand how value chains can enhance nutrition outcomes.

In spite of this renewed attention, there remains only limited evidence regarding the impacts of agricultural development on nutrition, and in particular on child malnutrition, which remains a stubborn problem in many developing countries, where one in four children suffer from chronic undernourishment (United Nations 2013). Furthermore, it is well established that child malnutrition has multifaceted determinants, including many outside the agriculture sector. Smith and Haddad (2000) have shown that child nutrition outcomes are broadly linked to indicators of environmental health, women's empowerment, and food security. Child malnutrition generally declines with income growth and development, but it exhibits substantial variation around this general relationship (Ruel and Alderman 2013), presumably due to the differing progress among countries in the multiple areas that determine child malnutrition.

To better understand the potential for agricultural interventions, it is useful to first understand how countries vary in terms of the broad determinants of child malnutrition. Because Smith and Haddad (2000) have already examined the causal links, our analysis is focused on creating a typology of countries with particular characteristics associated with child stunting. The purpose of this typology is to illuminate the different contexts where potential interventions take place, in order to set the stage for understanding the lessons from emerging research. This analysis should also help identify where agriculture-led interventions might address binding constraints to progress, or how existing research on the links between agriculture and nutrition in particular contexts may or may not be representative.

We begin with a brief review of the literature, and in particular, the Smith and Haddad (2000) model to motivate our choice of variables. Data relationships are summarized and the methods outlined next. Results and their implications for research choices in A4NH follow.

2. REVIEW OF LITERATURE

Child malnutrition is a persistent problem and progress lags behind the substantial progress in reducing poverty and hunger over the past two decades. Poverty rates have declined dramatically since 1990, from 47 percent of developing country populations down to 27 percent (United Nations 2013). Similar but slower progress has occurred in reducing hunger; the proportion of developing country populations that is chronically malnourished has declined from 23 percent to 15 percent. Yet the prevalence of child stunting (the most accepted indicator of deprivation and long-term health impacts from undernourishment) remains stubbornly high. According to the Food and Agriculture Organization of the United Nations (FAO), “Between 1990 and 2011, the prevalence of stunting in developing countries declined by an estimated 16.6 percentage points, from 44.6 percent to 28 percent” (FAO 2013). Furthermore, child stunting prevalence is as high as 30 to 40 percent in most countries of Africa south of the Sahara and in South Asia.

Child malnutrition outcomes are determined by a number of complex variables, which have been summarized under three categories: food security, care for mothers and children, and health environment quality (Smith and Haddad 2000). Small children require both adequate calories and greater nutrient density in their diets. Traditional weaning and infant feeding practices often do not provide sufficient micronutrients, even when calories are adequate. Provision of adequate diet quality may be hampered by insufficient knowledge, income, or access to appropriate foods. Such household decisions take place within the context of the national food system, which shapes choices through prices, availability, and access. Furthermore, small children are more susceptible to disease, particularly diarrheal disease, especially during weaning, when they may be exposed to contaminated water and food. Environmental health determinants, such as access to safe water, sanitation, and health services, influence the ability of small children to utilize nutrients and to thrive. These are also determined by national-level decisions on health investments and health care access. Finally, the quality of care received influences how these other determinants interact. Quality of care includes maternal nutrition during pregnancy, maternal health care, and the mother’s ability to care for the child in terms of feeding and health-protective activities. These abilities can be severely hampered by competing demands for women’s time and energy, women’s lack of education, and women’s inability to access and control household resources. Women’s empowerment is also determined within a national social and cultural context.

Given the complexity of these child nutrition determinants, it is not surprising that this outcome lags during the development process. Yet, in spite of these complexities, Smith and Haddad (2000) were able to find national-level associations between reductions in child undernutrition and broad indicators of the determinants of care, health, and food security in examining progress from 1970 to 1995. They found that improvements in women’s education during that period was the most important contributor (43 percent) to progress in reducing child malnutrition, with improvements in national food availability accounting for only 26 percent. Women’s status and improved health environment accounted for 12 percent and 19 percent, respectively. They have recently revised the model to better reflect current understanding of these determinants and updated relationships (Haddad 2013), including the importance of diet diversity in supporting enhanced nutrient density in diets. In preliminary results from the more recent analysis, food determinants accounted for about a third of variance in child-stunting progress among countries (20 percent explained by dietary energy adequacy and 12 percent explained by diet diversity). Women’s status and improvements in environmental health each account for about another third. Thus, the more recent results reinforce the important role of all three basic determinants in child nutrition outcomes. Furthermore, food and agriculture remain important determinants of child malnutrition, in spite of global improvements in food security over the past four decades.

This paper seeks to understand where and how progress is being made in addressing the underlying determinants of child malnutrition to better inform emerging research on how agriculture can address nutrition. In particular, there is a strong development community interest in making agricultural

interventions and investments more effective in addressing nutrition, and we turn now to a brief review of the recent literature addressing this question.

A number of review articles have examined the evidence regarding the complex links between agriculture and nutrition (for example, FAO 2013; Webb 2013). These reviews have generally concluded that increased incomes, increased calorie availability, and reduced prices of staples are generally associated with improved nutrition over the long term (for example, Ruel and Alderman 2013), but also that more specific micro-level pathways should receive more attention. For example, Herforth and Harris (2013) posit that agriculture can influence nutrition by (1) increasing production (and consumption) of nutrient-dense [non-staple] foods, (2) increasing women's empowerment, and (3) incorporating nutrition behavior change communication into agricultural extension. In general, there is consensus that the health and agriculture sectors should align their efforts to achieve better results for nutrition (Gillespie et al. 2013).

The A4NH program seeks to build on past CGIAR research efforts to further enhance nutrition and health outcomes from agriculture. This program includes seven different research themes, each of which approaches a different aspect of agriculture for nutrition. However, a central purpose of these efforts is to improve diet quality by enhancing micronutrient intake and diet diversification (A4NH 2013). One particular theme area supported by research in IFPRI's Markets, Trade and Institutions Division is focused on developing value chains for nutrient-rich foods by addressing barriers to enhanced diet quality in both supply and demand. To better understand where such interventions might be most effective, it is useful to first understand where the broader determinants of child malnutrition would favor a focus on food value chains.

Our analysis of country progress along the three dimensions of care, health, and food security can inform emerging research by identifying where progress in one or another dimension lags and where food system constraints are binding relative to other determinants, as well as by providing guidance on the validity of research results for different country contexts.

3. DATA

When using national-level aggregate variables, data restrictions make it difficult to properly identify causal links and obtain reliable estimates of the effects between child nutrition outcomes and their determinants using standard regression analysis. Country-level attrition caused by data availability, quality, and consistency often bias regression coefficients because the quality of data reporting tends to be highly correlated with many development indicators of the country. Data aggregated at the national level also do not reflect within-country heterogeneity, making it hard to exploit the distributional relationship between determinants and outcomes through regression analysis.

Our analysis is focused on creating a typology of countries with particular characteristics associated with child stunting in order to illuminate the different contexts where potential interventions take place. Because ours is a data-driven exercise that classifies countries according to their variation in aggregated measures of child malnutrition and its determinants, we prefer to rely on the literature discussed in the previous section to inform and justify our choice of variables and estimation structure. By using aggregated data, we look to identify stylized facts about the links between nutrition determinants and outcomes that hold at the national level in a large sample of countries in South Asia, East Asia, and Africa south of the Sahara, exploiting their relevant differences to split them apart and their similarities to group them together. Because we are seeking to explore the data and generate hypotheses rather than test them, we use cluster analysis to analyze our data.

Variable Selection

Our sample includes 52 countries in Africa and Asia. The A4NH target countries, which primarily consist of low-income countries in Africa south of the Sahara and in South Asia, constitute our initial sample. We added middle- and high-income countries in Africa, South Asia, and East Asia for further variation across the spectrum of each indicator and to observe how the A4NH countries group in relation to these more developed countries.

We use the prevalence of child stunting as the indicator of nutrition outcomes, given that it is the most accepted indicator of deprivation and long-term health impacts from undernourishment (Ruel and Alderman 2013). We then looked at indicators for Smith and Haddad's three categories of child malnutrition determinants: food security, care for mothers and children, and health environment quality (Smith and Haddad 2000).

The main challenge when constructing the country dataset for this study was finding consistent and reliable information for the full set of variables over the same time period. Because data on child stunting collected by the World Health Organization Global Health Observatory typically comes from the Demographic and Health Surveys, which are not conducted on an annual basis, we had to pick the latest year available for each country; this ranged from 2001 to 2011 in our sample. Because our grouping strategy implicitly assumes the causal links between determinants and nutrition outcomes found in previous studies, the time period selected for each determinant of child malnutrition should be prior to the one used for child stunting. Moreover, taking into account that in many cases the relationship between a given determinant and the outcome of interest is not concurrent, but instead can lag one or several years (depending on how fast the transmission mechanism is), we explore which lag of each determinant is most highly correlated to child stunting. The appendix describes in more detail how the lags were selected.

Variable Description

The process described above resulted in the elimination of several variables from the analysis due to the lack of data for the required time period, low correlation with child stunting, or high correlation with other variables included in the analysis. The ones that remain are briefly described below. (The appendix also shows more detail on the year used for each variable by country.)

Child Stunting (Child Nutrition Outcome)

Child stunting is measured as the percentage of stunting (height-for-age less than -2 standard deviations of the World Health Organization Child Growth Standards median) among children aged 0 to 5 years. We chose child stunting as a summary statistic because, as mentioned before, it is the one that best reflects chronic undernourishment that leads to long-term health impacts.

Average Dietary Energy Supply (DES) Adequacy (Food Security Indicator)

This indicator expresses the DES as a percentage of the Average Dietary Energy Requirement (ADER) in each country. It shows whether the national food supply is sufficient to support adequate caloric intake. Countries with lower adequacy indicators will have more pervasive food insecurity at the household level.

Cereal Import Dependency Ratio (Food Security Indicator)

This indicator expresses the ratio of cereal imports to total cereal supply (cereal production + cereal import - cereal export) of a country. It measures the cereal self-sufficiency of a country and the reliance on cereal imports, both of which reflect policy decisions regarding imports and food prices. Low cereal import dependency can reflect restrictive trade policies and high vulnerability to variations in domestic supply, while high cereal import dependency can reflect low capacity for local supply and high vulnerability to international prices, especially in rural areas.

Prevalence of Undernourishment (Food Security Indicator)

The prevalence of undernourishment expresses the probability that a randomly selected individual from the population consumes an amount of calories that is insufficient to cover her/his energy requirement for an active and healthy life. The indicator is computed by comparing a probability distribution of habitual daily Dietary Energy Consumption with a threshold level called the Minimum Dietary Energy Requirement. It reflects the proportion of the population at risk of caloric inadequacy and therefore is directly linked to nutrition outcomes.

Share of DES Derived from Sources Other Than Cereals, Roots, and Tubers (Food Security Indicator)

This indicator is calculated as the ratio of energy supply (in kcal/caput/day) from sources other than cereals, roots and tubers divided by total DES (in kcal/caput/day) based on the Statistics Division of the FAO (FAOSTAT) Food Balance Sheets. It measures the quality of diets; diets that depend less on cereals, roots, and tubers and more on fruits, vegetables, livestock products, and vegetable oils will have greater nutrient density and be more likely to meet nutritional needs of vulnerable populations (Arimond and Ruel 2004).

Access to Improved Sanitation Facilities (Health Environment Quality Indicator)

This indicator refers to the percentage of the population using improved sanitation facilities, which include flush/pour-flush toilets (to piped sewer system, septic tank, pit latrine), ventilated improved pit (VIP) latrines, pit latrines with slab, and composting toilets. Water and sanitation are crucial to hygienic conditions and to reducing the risk of waterborne diseases that can affect a child's capacity to absorb nutrients from food.

Female Life Expectancy at Birth (Care for Mothers and Children Indicator)

This indicates the number of years a female newborn infant would live if prevailing patterns of mortality at the time of her birth were to stay the same throughout her life. Countries with higher female life expectancies have better conditions supporting female health, including nutrition, access to health

services, and environmental health. Better female health supports improved outcomes at all stages of pregnancy, childbirth, and child development.

Female-Male Life Expectancy Ratio (Care for Mothers and Children Indicator)

This indicator calculates the ratio of female life expectancy at birth to male life expectancy at birth. When health conditions are optimal, female life expectancy tends to be greater than male life expectancy. In many countries of our sample, this ratio is less than one, indicating especially poor health conditions for women, including lack of adequate access to food and health services. This ratio is a measure of female empowerment through relative health status. Where it is low, it indicates that women are less able to provide adequate care for themselves and their children, thus leading to poor outcomes for child nutrition.

Maternal Mortality (Care for Mothers and Children Indicator)

The maternal mortality ratio (MMR) is the annual number of female deaths from any cause related to or aggravated by pregnancy or its management (excluding accidental or incidental causes) during pregnancy and childbirth or within 42 days of termination of pregnancy, irrespective of the duration and site of the pregnancy, per 100,000 live births, for a specified year. High rates of maternal mortality are associated with poor nutrition and lack of access to health services for women of reproductive age, which influences child nutrition, as discussed above.

Poverty Head Count Ratio at \$1.25 per Day (Poverty Indicator)

This indicator is the percentage of the population living on less than \$1.25 a day at 2005 international prices. Poverty generally correlates with poor nutrition outcomes, but there is substantial variation at low income levels (Ruel and Alderman 2013). This indicator is included in the analysis in order to detect countries where there exist specific inconsistencies between the country's degree of development and nutrition outcomes.

4. METHOD

We want to classify the 52 countries in our sample into a number of groups that is large enough to reflect the heterogeneity in nutrition outcomes and determinants across countries, but small enough to be tractable and to set the stage for understanding the lessons from emerging research in a systematic way. In a nutshell, we want countries to be as *similar* as possible within groups and as *different* as possible between groups in terms of the variables we have selected for the study. The difficulty lies in both dealing with the dimensionality of the analysis and choosing an appropriate measure of distance between observations in a multidimensional space. In other words, we need an approach that lets us compare observations (countries) when we observe several of their characteristics (as opposed to a single one) with a well-defined measure of similarity/dissimilarity. A two-stage cluster analysis is used to address these issues.

Cluster analysis divides a sample into homogenous groups based on a chosen set of variables or characteristics. We use the variables described above for the 52 countries in our sample to form clusters that maximize heterogeneity between groups and minimize it within groups. Although it would be possible to include all the variables in our analysis in a single cluster model, favoring a two-stage approach that allows us to reduce the number of parameters by exploiting the structure of the data can lead to more precise parameter estimates and more informative and useful cluster analysis solutions (Everitt et al. 2011). This approach is possible when the variables in the data are structured to follow a factor model—that is, the observed or manifest variables are indicators of a relatively small number of latent variables or factors, and it is the relationships between the manifest and latent variables that accounts for the correlation between the manifest variables. In cases like this, it is possible to exploit the structural information to define summary measures from the full variable set in the first stage to reduce the number of variables that need to enter the final clustering. In our case, each (manifest) variable of our dataset described above is an indicator of a smaller number of dimensions or latent variables (food security, health environment quality, care for mothers and children, poverty and child malnutrition), and we assume that it is through these latent variables that the manifest variables are correlated with the child nutrition outcome variable. If the subset of variables describing each dimension were fairly homogenous in terms of their scale and how they are measured, we could choose a simple summary statistic, such as the mean or median across those variables. However, because this is not the case in our data, we perform a cluster analysis in both the first and the second stage so we can mix and summarize the information coming from different types of variables.¹

First-Stage Cluster Analysis

The first stage of the typology involves conducting a cluster analysis on each of the four dimensions independently²: (1) food security, (2) health environment quality and care for mothers and children, (3) poverty, and (4) child malnutrition (stunting). Because we seek to find natural groupings in our data that are hierarchically related, we adopt an agglomerative hierarchical cluster-analysis approach³ and choose Ward's method (Ward 1963) as the linkage method. Ward's method is a space-conserving method that minimizes the internal sums of squares. In the first step of Ward's method, each observation is in a cluster of one, thus the total internal sum of squares (TSS) is zero. The next stage joins the nearest observations such that the TSS is the smallest distance between two observations. After that, observations are added together, or to previous groups, in a way that minimizes the increase in the TSS. At each step along the

¹ See Everitt et al. (2011) for several examples of papers using different applications of the two-stage procedure.

² To simplify the analysis, and because of conceptual similarities, we merge together the care for mothers and children and health environment quality dimensions. Doing this does not affect the final clustering results.

³ Agglomerative hierarchical clustering methods begin treating each observation as a separate group and then combining the two closest ones. This process is repeated until all observations belong to the same group, creating a hierarchy of clusters.

way, the TSS is calculated as the sum of squared distances to the group centroid. The recurrence formula of this method is

$$d_{k(ij)} = \alpha_i d_{ki} + \alpha_j d_{kj} + \beta d_{ij} + \gamma |d_{ki} - d_{kj}| \quad (1)$$

where d_{ij} is the distance between cluster i and cluster j ; $d_{k(ij)}$ is the distance between cluster k and the new cluster formed by joining clusters i and j . Using this method, α , β , and γ take the following values:

$$\alpha_i = \frac{n_i + n_k}{n_i + n_j + n_k} ; \quad \alpha_j = \frac{n_j + n_k}{n_i + n_j + n_k} ; \quad \beta = \frac{-n_k}{n_i + n_j + n_k} ; \quad \gamma = 0 \quad (2)$$

These distances (d) can be defined differently depending on the data. We use the squared Euclidean distance as the similarity measure, which is a common measure of “closeness” when working with continuous variables, such as those used to characterize our four dimensions.

Finally, we need to define the number of clusters we want to have for each dimension. Although there are some popular stopping rules to determine the optimal number of clusters (such as Caliński and Harabasz’s [1974] pseudo-F statistic; Duda and Hart’s [1973] Je(2)/Je(1); and Duda and Hart’s [1973] pseudo-T²), they can produce extremely different results and there is no clear consensus on which is the most appropriate. Moreover, the stopping rules become less informative as the number of elements in groups becomes small (that is, having many groups, each with few observations). Given these potential problems with the stopping rules, we use the results from the three cited above to inform our choice of the final number of clusters for each dimension.

Second-Stage Cluster Analysis

The clusters resulting from the first stage group countries according to (1) food security, (2) health environment quality/care for mothers and children, (3) poverty, and (4) child stunting, looking at each of these dimensions separately. In the second stage our objective is to combine these four separate groupings into a single one reflecting as much as possible the cluster structure found in the first stage for each dimension. In order to attain this, we characterize each country in our dataset according to the cluster it belongs to for each dimension in the first stage, so that every country in our dataset is associated with a four-element vector containing the cluster identifier for each of the four dimensions analyzed. We can then perform the second-stage cluster analysis treating the four elements in that vector as the variables of interest similarly to what we did in the first stage. The only difference is that because the second-stage variables (the cluster identifiers from the first stage) are no longer continuous variables, we use the Pearson correlation coefficient instead of the Euclidean distance as the similarity measure, which is better suited for dichotomous variables.⁴

⁴ We create a set of dummy variables for each cluster in each of the dimensions of the first stage, and perform the cluster analysis in the second stage over that set of dummies. For example, if each of the four dimensions in the first stage had five clusters, we would have ended up with 5⁴ dummies over which we perform the second-stage cluster analysis.

5. RESULTS

We first review briefly the results of the first-stage clusters, where countries tend to group in a fairly consistent way. These results demonstrate that countries tend to fall into reasonable groups when related indicators are considered separately. Next, we turn to the second-stage results, which reflect the complexity of the underlying determinants and the multifaceted way that these determinants interact.

First-Stage Clusters

Food Security

The variables we have selected for this dimension measure key aspects of food security: (1) availability and diversity of the food supply (average DES adequacy and share of DES derived from sources other than cereals, roots, and tubers), (2) access to the food supply (prevalence of undernourishment), and (3) vulnerability and stability of the food supply (cereal import dependency ratio). According to the stopping rules and our own exploration stopping at different numbers of clusters, we chose five as the optimal number of groups for the food security clustering (see the appendix for more detail on the stopping criteria).

Table 5.1 and Figure 5.1 show how the countries are classified into each food security cluster and the sample means for the variables considered. Roughly speaking, countries in cluster 3 are the most food secure in the sample, averaging a lower prevalence of undernourishment in the population, a higher DES adequacy, and a higher share of DES from non-starchy foods. On the other extreme, we can place countries in clusters 2 and 5 as the least food secure, with a relatively high prevalence of undernourishment and a low DES adequacy. Countries in cluster 4 can be considered, on average, to be the next better off in terms of food security after cluster 3 countries, with better averages for prevalence of undernourishment and DES adequacy than the full sample means, but a lower share of DES from non-starchy foods. Cluster 1 can be viewed as the “average” cluster, having the closest average to the full sample for all variables except cereal import dependency ratio.

It is interesting to note that diet diversity does not cluster in a uniform way with energy adequacy or prevalence of undernourishment. In general, diet diversity increases with rising incomes and development (as seen in cluster 3), but at the low income levels for countries in this group, it varies widely. Both clusters 4 and 5 tend to have low diet diversity, but cluster 4 has higher energy adequacy and lower prevalence of undernourishment compared to cluster 5. This shows how diet quality may be influenced by factors other than energy adequacy.

It is also interesting to note that we cannot easily associate high or low values of the cereal imports dependency ratio with good or bad food security clusters. The most food secure clusters (3 and 4), for instance, are on opposite sides of the spectrum, with 78 percent of the domestic cereal supply in cluster 3 countries depending on imports, as opposed to only 11 percent in cluster 4 countries. The same contrast is observed on the least food secure clusters (2 and 5), with a 96 percent cereal imports dependency ratio for cluster 2 countries and only 16 percent for cluster 5 countries. These differences reflect not only how these countries are satisfying their domestic cereal demand but also what risks they are exposed to. High cereal dependency ratios mean the country is highly vulnerable to shocks in the international cereal market, but low ratios reflect high vulnerability to domestic supply shocks and to policies associated with closed international trade policies.

Table 5.1 Food security clusters: Sample means and country lists

Indicator	Full Sample	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
Prevalence of undernourishment (% of population)	26.2	27.9	37.9	7.2	19.3	37.9
Cereal import dependency ratio (% of domestic cereal supply)	31.4	53.1	95.5	77.9	11.1	16.1
Average dietary energy supply adequacy (% of AEDR)	104.1	102.7	91.0	122.7	110.0	94.1
Share of dietary energy supply derived from sources other than cereals, roots and tubers (% of DES)	38.2	37.6	44.3	51.3	36.0	37.9
Countries		Angola ²⁰⁰⁷ Cote d'Ivoire ²⁰⁰⁷ Gambia ²⁰⁰⁶ Guinea-Bissau ²⁰⁰⁸ Lesotho ²⁰¹⁰ Liberia ²⁰⁰⁷ Mongolia ²⁰⁰⁵ Mozambique ²⁰⁰⁸ Namibia ²⁰⁰⁷ Senegal ²⁰¹¹ Sierra Leone ²⁰⁰⁸ Sri Lanka ²⁰⁰⁹ Swaziland ²⁰⁰⁸	Botswana ²⁰⁰⁸ Congo ²⁰⁰⁵ Djibouti ²⁰⁰⁶	Gabon ²⁰⁰¹ Malaysia ²⁰⁰⁶ Mauritania ²⁰⁰⁸	Bangladesh ²⁰⁰⁷ Benin ²⁰⁰⁶ Burkina Faso ²⁰⁰⁹ Cambodia ²⁰¹¹ China ²⁰¹⁰ Ghana ²⁰⁰⁸ Guinea ²⁰⁰⁸ India ²⁰⁰⁶ Indonesia ²⁰⁰⁷ Malawi ²⁰¹⁰ Mali ²⁰⁰⁶ Nepal ²⁰¹¹ Niger ²⁰⁰⁶ Nigeria ²⁰⁰⁸ Pakistan ²⁰¹¹ Philippines ²⁰⁰⁸ South Africa ²⁰⁰⁸ Thailand ²⁰⁰⁶ Togo ²⁰⁰⁸ Uganda ²⁰⁰⁶ Vietnam ²⁰⁰⁸	Cameroon ²⁰⁰⁶ Central African Republic ²⁰⁰⁶ Chad ²⁰⁰⁴ Ethiopia ²⁰¹¹ Kenya ²⁰⁰⁹ Lao PDR ²⁰⁰⁶ Madagascar ²⁰⁰⁹ Rwanda ²⁰¹¹ Sudan ²⁰⁰⁶ Tanzania ²⁰¹⁰ Zambia ²⁰⁰⁷ Zimbabwe ²⁰¹¹

Source: Authors' calculations using data from FAO (various years).

Figure 5.1 Distribution of food security indicators by cluster

Source: Authors' calculations using data from FAO (various years).

Note: The right and left edges of the box represent the 25th and the 75th percentile of the indicator, respectively. The line inside the box represents the median.

Health Environment Quality/Care for Mothers and Children Clusters

For this dimension, we have selected access to improved sanitation to characterize the quality of the health environment, and female life expectancy, female-male life expectancy ratio, and maternal mortality as outcomes for the state of care for mothers and children in each country. Following the stopping rules and our own sensitivity analysis we chose five clusters as the optimal number of groups (see the appendix for more detail). Table 5.2 lists the sample means and countries by the environment and care clusters. Figure 5.2 shows the distribution of countries for each indicator in the health and care clusters.

Table 5.2 Health environment quality and care for mothers and children clusters: Sample means and country lists

Indicator	Full Sample	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
Access to improved sanitation (% of population)	39.0	30.8	20.0	38.7	38.0	76.5
Female life expectancy (years)	57.4	50.7	50.1	55.2	64.0	74.0
Female-male life expectancy ratio	1.0424	1.0253	1.0363	1.0317	1.0514	1.0914
Maternal mortality ratio (per 100,000 live birth)	459.9	608.3	938.8	395.6	260.0	62.4
Countries		Angola ₂₀₀₇ Cameroon ₂₀₀₆ Congo ₂₀₀₅ Cote d'Ivoire ₂₀₀₇ Lao PDR ₂₀₀₆ Lesotho ₂₀₁₀ Mali ₂₀₀₆ Mauritania ₂₀₀₈ Mozambique ₂₀₀₈ Niger ₂₀₀₆ Zambia ₂₀₀₇ Zimbabwe ₂₀₁₁	Central African Republic ₂₀₀₆ Chad ₂₀₀₄ Guinea-Bissau ₂₀₀₈ Guinea ₂₀₀₈ Liberia ₂₀₀₇ Nigeria ₂₀₀₈ Sierra Leone ₂₀₀₈ Sudan ₂₀₀₆	Bangladesh ₂₀₀₇ Benin ₂₀₀₆ Botswana ₂₀₀₈ Burkina Faso ₂₀₀₉ Ethiopia ₂₀₁₁ Gambia ₂₀₀₆ Ghana ₂₀₀₈ Kenya ₂₀₀₉ Malawi ₂₀₁₀ Rwanda ₂₀₁₁ Senegal ₂₀₁₁ South Africa ₂₀₀₈ Swaziland ₂₀₀₈ Tanzania ₂₀₁₀ Togo ₂₀₀₈ Uganda ₂₀₀₆	Cambodia ₂₀₁₁ Djibouti ₂₀₀₆ Gabon ₂₀₀₁ India ₂₀₀₆ Indonesia ₂₀₀₇ Madagascar ₂₀₀₉ Namibia ₂₀₀₇ Nepal ₂₀₁₁ Pakistan ₂₀₁₁	China ₂₀₁₀ Malaysia ₂₀₀₆ Mongolia ₂₀₀₅ Philippines ₂₀₀₈ Sri Lanka ₂₀₀₉ Thailand ₂₀₀₆ Vietnam ₂₀₀₈

Source: Authors' calculations using data from the World Bank, WHO, and FAO (various years).

Figure 5.1 Distribution of health and care indicators by cluster

Source: Authors' calculations using data from the World Bank, WHO, and FAO (various years).

Note: The right and left edges of the box represent the 25th and the 75th percentile of the indicator, respectively. The line inside the box represents the median.

Countries in cluster 5 stand out as the better-off group in this dimension, with better values for all indicators, although Mongolia falls behind in both access to improved sanitation and female life expectancy. It is also worth noting that while China's female life expectancy is close to the cluster 5 average for female life expectancy, the ratio of female to male life expectancy is much lower compared to other countries in the group. Cluster 4 can be considered the second to best group in all indicators except for access to improved sanitation, in which it overlaps with cluster 3, the "average" group in this dimension. Clusters 1 and 2 are the worst-off groups in this dimension, with similar outcomes for most indicators, but with cluster 1 showing considerably higher maternal mortality numbers.

Poverty and Child-Stunting Clusters

Economic development and child nutrition outcomes, as represented by the poverty rate and the percentage of children under 5 years old who are stunted, respectively, are considered separately as first-stage dimensions. Because countries are clustered on a single variable for these dimensions, the results are very straightforward. The clustering divides the ranking of countries along each variable in groups according to the measure of distance, without the possibility of overlapping between clusters. We only show the groupings for poverty and child-stunting clusters in Tables 5.3 and 5.4 and omit any figures.

Table 5.3 Poverty clusters: Sample means and country lists

Indicator	Full Sample	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
Poverty rate at \$1.25 a day (% of population)	38.3	46.8	64.4	82.5	6.4	25.1
Countries		Angola ₂₀₀₇ Bangladesh ₂₀₀₇ Benin ₂₀₀₆ Burkina Faso ₂₀₀₉ Congo ₂₀₀₅ Guinea-Bissau ₂₀₀₈ Guinea ₂₀₀₈ India ₂₀₀₆ Kenya ₂₀₀₉ Lesotho ₂₀₁₀ Mali ₂₀₀₆ Sierra Leone ₂₀₀₈ Swaziland ₂₀₀₈ Togo ₂₀₀₈ Uganda ₂₀₀₆ Zimbabwe ₂₀₁₁	Central African Republic ₂₀₀₆ Chad ₂₀₀₄ Malawi ₂₀₁₀ Mozambique ₂₀₀₈ Niger ₂₀₀₆ Nigeria ₂₀₀₈ Rwanda ₂₀₁₁ Tanzania ₂₀₁₀ Zambia ₂₀₀₇	Liberia ₂₀₀₇ Madagascar ₂₀₀₉	Cameroon ₂₀₀₆ China ₂₀₁₀ Gabon ₂₀₀₁ Malaysia ₂₀₀₆ South Africa ₂₀₀₈ Sri Lanka ₂₀₀₉ Thailand ₂₀₀₆	Botswana ₂₀₀₈ Cambodia ₂₀₁₁ Cote d'Ivoire ₂₀₀₇ Djibouti ₂₀₀₆ Ethiopia ₂₀₁₁ Gambia ₂₀₀₆ Ghana ₂₀₀₈ Indonesia ₂₀₀₇ Lao PDR ₂₀₀₆ Mauritania ₂₀₀₈ Mongolia ₂₀₀₅ Namibia ₂₀₀₇ Nepal ₂₀₁₁ Pakistan ₂₀₁₁ Philippines ₂₀₀₈ Senegal ₂₀₁₁ Sudan ₂₀₀₆ Vietnam ₂₀₀₈

Source: Authors' calculations using data from the World Bank (various years).

Table 5.4 Child-stunting clusters: Sample means and country lists

Indicator	Full sample	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
% of under-5 children stunted	35.8	27.2	33.0	15.4	45.9	39.4
Countries		Angola ₂₀₀₇ Gabon ₂₀₀₁ Gambia ₂₀₀₆ Ghana ₂₀₀₈ Guinea-Bissau ₂₀₀₈ Mauritania ₂₀₀₈ Mongolia ₂₀₀₅ Namibia ₂₀₀₇ Senegal ₂₀₁₁ South Africa ₂₀₀₈ Togo ₂₀₀₈	Botswana ₂₀₀₈ Burkina Faso ₂₀₀₉ Cameroon ₂₀₀₆ Congo ₂₀₀₅ Djibouti ₂₀₀₆ Kenya ₂₀₀₉ Philippines ₂₀₀₈ Vietnam ₂₀₀₈ Zimbabwe ₂₀₁₁	China ₂₀₁₀ Malaysia ₂₀₀₆ Sri Lanka ₂₀₀₉ Thailand ₂₀₀₆	Bangladesh ₂₀₀₇ Benin ₂₀₀₆ Central African Republic ₂₀₀₆ Chad ₂₀₀₄ Ethiopia ₂₀₁₁ India ₂₀₀₆ Lao PDR ₂₀₀₆ Madagascar ₂₀₀₉ Malawi ₂₀₁₀ Mozambique ₂₀₀₈ Niger ₂₀₀₆ Pakistan ₂₀₁₁ Rwanda ₂₀₁₁ Tanzania ₂₀₁₀ Zambia ₂₀₀₇	Cambodia ₂₀₁₁ Cote d'Ivoire ₂₀₀₇ Guinea ₂₀₀₈ Indonesia ₂₀₀₇ Lesotho ₂₀₁₀ Liberia ₂₀₀₇ Mali ₂₀₀₆ Nepal ₂₀₁₁ Nigeria ₂₀₀₈ Sierra Leone ₂₀₀₈ Sudan ₂₀₀₆ Swaziland ₂₀₀₈ Uganda ₂₀₀₆

Source: Authors' calculations using FAO Food Security Indicators (various years).

Although there exist many measures of a country's population economic development and well-being, we selected the \$1.25 poverty rate because it is a simple criteria estimated consistently for all the countries in our sample. It is important to point out that this is a measure of extreme poverty based on an international standard.⁵

Although the positive association between poverty and stunting (Figure 5.3) is easy to predict, it is interesting to note some deviations from this relationship. China, for example, is the only country in our sample to fall below the 10 percent line in terms of child stunting, but it still ranks behind five other countries in poverty. Liberia, the country in our sample with the highest poverty rate (83.8 percent), shows a lower stunting rate (39.4 percent) than countries placed in the second least poor cluster, such as Cambodia, Ethiopia, Indonesia, Lao PDR, Nepal, and Pakistan. These deviations from the basic poverty-nutrition relationship evidence the complexity of the interactions among the factors influencing child nutrition outcomes.

Second-Stage Clusters

We combine the results of the first-stage clusters above into second-stage clusters to obtain our final classification of countries. Reviewing the results and supported by the stopping rules (see the appendix), we decided on a final set of six clusters. Figure 5.4 and Table 5.5 show how the countries are grouped into the final clusters.

⁵ For example, in terms of \$1.25 poverty rates, Cameroon (9.6 percent in 2007) and Gabon (4.8 percent in 2005) are both in the least poor cluster together with China, Malaysia, South Africa, Sri Lanka, and Thailand (which range from 0 to 13.8 percent). In fact, both China and South Africa have higher poverty rates measured at the \$1.25 poverty line than do Cameroon and Gabon. Poverty rates at the national poverty line (a measure of relative poverty) in Cameroon (39.9 percent) and Gabon (32.7 percent) would be far above the other countries in the cluster (which range from 3.6 to 23.4 percent). The reason why we select the \$1.25 poverty rate over the national poverty line rate is that the former follows a methodology that is consistent across countries, is comparable across space and time, and is more commonly available. However, it is important to keep in mind that the ranking obtained from this variable reflect a particular measure of poverty.

Figure 5.2 Stunting and poverty

Figure 5.3 Distribution of all indicators by second-stage clusters

Source: Authors' calculations using data from the World Bank, WHO, and FAO (various years).

Table 5.5 Second-stage clusters: Sample means and country lists

Indicator	Full Sample	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6
% of under-5 children stunted	35.8	36.1	37.7	33.3	32.5	46.3	15.4
Poverty rate at \$1.25 a day (% of population)	38.3	47.9	44.9	39.6	23.0	59.7	4.2
Prevalence of undernourishment (% of population)	26.2	28.0	20.1	33.4	22.5	38.1	16.0
Cereal import dependency ratio (% of domestic cereal supply)	31.4	58.0	13.0	50.6	41.2	13.1	33.0
Average dietary energy supply adequacy (% of AEDR)	104.1	104.1	109.9	94.7	105.6	95.5	113.5
Share of dietary energy supply derived from sources other than cereals, roots and tubers (% of DES)	38.2	34.7	35.3	41.3	41.9	33.2	49.0
Access to improved sanitation (% of population)	39.0	29.0	29.7	35.6	45.8	28.6	85.7
Maternal mortality ratio (per 100,000 live births)	459.9	741.4	477.3	613.3	309.3	592.7	42.3
Female life expectancy (years)	57.4	47.5	54.8	50.2	63.4	53.0	75.6
Female-male life expectancy ratio	1.0424	1.0266	1.0272	1.0182	1.0617	1.0339	1.0762
Countries		Angola ²⁰⁰⁷ Cote d'Ivoire ²⁰⁰⁷ Guinea-Bissau ²⁰⁰⁸ Lesotho ²⁰¹⁰ Liberia ²⁰⁰⁷ Sierra Leone ²⁰⁰⁸ Swaziland ²⁰⁰⁸	Bangladesh ²⁰⁰⁷ Benin ²⁰⁰⁶ Burkina Faso ²⁰⁰⁹ Guinea ²⁰⁰⁸ India ²⁰⁰⁶ Kenya ²⁰⁰⁹ Mali ²⁰⁰⁶ Nigeria ²⁰⁰⁸ South Africa ²⁰⁰⁸ Togo ²⁰⁰⁸ Uganda ²⁰⁰⁶	Cameroon ²⁰⁰⁶ Congo ²⁰⁰⁵ Zimbabwe ²⁰¹¹	Botswana ²⁰⁰⁸ Cambodia ²⁰¹¹ Djibouti ²⁰⁰⁶ Gabon ²⁰⁰¹ Gambia ²⁰⁰⁶ Ghana ²⁰⁰⁸ Indonesia ²⁰⁰⁷ Mauritania ²⁰⁰⁸ Mongolia ²⁰⁰⁵ Namibia ²⁰⁰⁷ Nepal ²⁰¹¹ Pakistan ²⁰¹¹ Philippines ²⁰⁰⁸ Senegal ²⁰¹¹ Sudan ²⁰⁰⁶ Vietnam ²⁰⁰⁸	Central African Republic ²⁰⁰⁶ Chad ²⁰⁰⁴ Ethiopia ²⁰¹¹ Lao PDR ²⁰⁰⁶ Madagascar ²⁰⁰⁹ Malawi ²⁰¹⁰ Mozambique ²⁰⁰⁸ Niger ²⁰⁰⁶ Rwanda ²⁰¹¹ Tanzania ²⁰¹⁰ Zambia ²⁰⁰⁷	China ²⁰¹⁰ Malaysia ²⁰⁰⁶ Sri Lanka ²⁰⁰⁹ Thailand ²⁰⁰⁶

Source: Authors' calculations based on data from the World Bank, WHO, and FAO (various years).

Cluster 1 (Angola₂₀₀₇, Cote D'Ivoire₂₀₀₇, Guinea-Bissau₂₀₀₈, Lesotho₂₀₁₀, Liberia₂₀₀₇, Sierra Leone₂₀₀₈, Swaziland₂₀₀₈)

Countries in this cluster present average child nutrition outcomes, along with higher than average poverty and poor health environment quality. Although three out of seven countries in this group have child-stunting rates that are below the sample median, only one country places below the median poverty rate. These countries all have poor environmental health indicators, especially for maternal mortality and female life expectancy. In the food sector, energy adequacy and diet diversity are below average. This suggests that integrated interventions addressing diet adequacy/quality and health, specifically focused on women and children, would be good entry points for research in this group of countries.

Cluster 2 (Bangladesh₂₀₀₇, Benin₂₀₀₆, Burkina Faso₂₀₀₉, Guinea₂₀₀₈, India₂₀₀₆, Kenya₂₀₀₉, Mali₂₀₀₆, Nigeria₂₀₀₈, South Africa₂₀₀₈, Togo₂₀₀₈, Uganda₂₀₀₆)

Countries in this group present poor child nutrition outcomes and high poverty rates. Seven out of 11 countries in this cluster show higher child-stunting rates than the sample median, and eight show higher poverty rates. (South Africa and Togo are exceptions within the group in having lower stunting, but placed in this cluster due to poor performance in health environment indicators.) In the food security variables, these countries have adequate energy on average, but a wide range of diet diversity outcomes. These countries have very low cereal import ratios. Health environment outcomes tend to be poor, especially access to sanitation, but female-specific indicators are not as poor as in cluster 1 above. For countries in this cluster, research attention to food policy, and to understanding how import policies may be influencing food security at the household level, would be suggested. As in cluster 1 above, integrated programs that address diet quality and environmental health are important to evaluate, but gender gaps in health access seem to be less important in this group.

Cluster 3 (Cameroon₂₀₀₆, Congo₂₀₀₅, Zimbabwe₂₀₁₁)

This group includes only three countries, all of which have very poor outcomes in food security and relatively low health environment quality indicators. Two out of three are above the median poverty rate, and they are very close to the sample median child-stunting rate. What particularly distinguishes this group is their very low energy adequacy and high prevalence of undernourishment. Agriculture and food interventions might be especially important in these countries, where basic caloric adequacy is not being provided to a large segment of the population.

Cluster 4 (Botswana₂₀₀₈, Cambodia₂₀₁₁, Djibouti₂₀₀₆, Gabon₂₀₀₁, Gambia₂₀₀₆, Ghana₂₀₀₈, Indonesia₂₀₀₇, Mauritania₂₀₀₈, Mongolia₂₀₀₅, Namibia₂₀₀₇, Nepal₂₀₁₁, Pakistan₂₀₁₁, Philippines₂₀₀₈, Senegal₂₀₁₁, Sudan₂₀₀₆, Vietnam₂₀₀₈)

Countries in this cluster are characterized, in general, by their above average performance in all four dimensions of our analysis. Twelve out of 16 countries in this group have lower child-stunting rates than the sample median, and all of them are in the bottom half of our sample poverty rate distribution. For both food security and health environment quality dimensions they have similarly relatively good outcomes, although there is wide variation within this cluster for some indicators. A subset of these countries has higher child malnutrition rates (Pakistan, Indonesia, Cambodia, Nepal) but falls within this cluster due to more positive indicators in some other areas. Why these countries have such poor nutrition performance in spite of progress in many underlying determinants warrants closer attention.

Cluster 5 (Central African Republic₂₀₀₆, Chad₂₀₀₄, Ethiopia₂₀₁₁, Lao PDR₂₀₀₆, Madagascar₂₀₀₉, Malawi₂₀₁₀, Mozambique₂₀₀₈, Niger₂₀₀₆, Rwanda₂₀₁₁, Tanzania₂₀₁₀, Zambia₂₀₀₇)

This cluster contains countries whose poor values for all indicators are reflected in extremely high child-stunting rates. Countries in this group have the highest child-stunting rates and second to highest poverty rates. They also have the worst indicators for food security and average to poor indicators of health environment quality. These countries clearly need broad-based development efforts of all kinds, including those that would directly address child stunting. The poor indicators for food security suggest that agricultural development will be an important component of such efforts.

Cluster 6 (China₂₀₁₀, Malaysia₂₀₀₆, Sri Lanka₂₀₀₉, Thailand₂₀₀₆)

This group contains the better-off countries in all dimensions, with all countries falling in the best clusters for child stunting, poverty, and health environment quality. Only in food security do we observe a slight deviation from this pattern, with Sri Lanka falling in the average cluster for this dimension. These are countries that can provide lessons regarding past success in addressing all of the dimensions that determine child stunting. Indeed, poverty reduction and nutrition efforts in China and Sri Lanka have been extensively studied.

6. CONCLUSIONS AND IMPLICATIONS

The above cluster analysis of countries for child-stunting outcomes along the dimensions of poverty, care, health, and food security is undertaken to inform emerging research into how agriculture can support better nutrition. The purpose is to identify (1) where progress in one or another dimension lags, (2) where food system constraints are lagging relative to other determinants or vice versa, and (3) where research results may be limited to specific country contexts.

In general, our second-stage results show the interlinked nature of determinants of child stunting, and thus distinctions among some of these six groups are not clear-cut. In interpreting the results, it is also important to keep in mind that the mean level of child stunting for this group of countries is quite high. In five out of six groups, progress is needed across *all* dimensions of poverty reduction, health, food security, and nutrition. Only cluster 6 has relatively little need to address nutrition or poverty.

Cluster 4 countries still need to make progress, but most seem to be on the path to improved outcomes, with relatively good indicators in most areas. Currently there are two major A4NH projects in cluster 4 countries. The Senegal project to improve nutrition for dairy producers is located in a part of the country with poverty and production characteristics closer to those of Mali. This is an example of how regional characteristics may differ from national averages, and the limits of the generalizations in this paper. The other major A4NH project is the evaluation of homegrown school feeding programs in Ghana. The complexity of such programs may be better placed where food and educational systems are more advanced, but diet diversity lags, and perhaps Ghana provides that opportunity.

Cluster 5 countries clearly need development efforts of all kinds, and the research questions there might focus on how child stunting can be addressed along with other broad-based development efforts. That is, in the cluster 5 countries it may be worthwhile to consider whether nutrition-specific interventions can succeed without broader attention to poverty reduction and agricultural development.

An example of an A4NH-led nutrition intervention and research in a cluster 5 country is the introduction of orange-fleshed sweet potato (OFSP) in Mozambique. This naturally biofortified food staple addresses an important dietary deficiency in a country where the prevalence of undernourishment is above the sample mean, and diet diversity is below (Figure 6.1). Although this intervention has been demonstrated to increase vitamin A biomarkers in small children, it is clearly dependent on the supporting efforts to ensure the productivity of OFSP vines (de Brauw et al. 2013). This project also provides the opportunity to assess the medium-term health impacts of improving vitamin A intake as a standalone intervention in a country where other environmental health indicators lag.⁶

⁶ Among this group of countries, Ethiopia stands out as a focus for donor efforts in food security and nutrition, but there is no A4NH research there currently. Tanzania is a focus for A4NH food safety research, which may eventually include nutrition in value chains.

Figure 6.1 Child stunting and food security: Mozambique

Source: Authors' calculations using the FAO Food Security Indicators (various years).

The distinctions between clusters 1 and 2 are subtler. In these two cluster groups, average stunting rates are close to the mean for the whole sample. What distinguishes each cluster is how progress lags in one dimension or another that would support better nutrition outcomes. In terms of food-based interventions, improving both energy adequacy and diet diversity is needed in cluster 1. However, health environment interventions and improvements, especially those focused on women's health, are also relatively important in cluster 1, where food-based interventions might not succeed without specific attention to these other determinants. There is no A4NH research underway in the cluster 1 countries.

In contrast to cluster 1, a focus on diet diversity and quality will be relatively important in cluster 2, where energy adequacy has been achieved in most countries. With adequate energy and low cereal imports, staple foods productivity may be of less importance in many of these countries, but diet quality needs improvement. Bangladesh, for example, is below the average for diet diversity in our study sample and has a child stunting rate that is 20 percent higher (Figure 6.2).

Figure 6.2 Bangladesh: Child stunting and food security

Source: Authors' calculations using the FAO Food Security Indicators (various years).

Because diet diversity is the nutritional goal of A4NH value-chain interventions, it is worthwhile noting that countries in cluster 2 likely present the best contexts among the six cluster groups for testing whether such interventions can improve diet quality and ultimately nutrition outcomes. Indeed, cluster 2 contains several countries—Bangladesh, Burkina Faso, Kenya, India, Mali, and Uganda—that are currently the focus of A4NH value-chain or integrated program research. These projects include efforts to improve fish and vegetable value chains in Bangladesh, to address nutrition in multiple value chains in India (Leveraging Agriculture for Nutrition in South Asia project), to introduce the orange-fleshed sweet potatoes in Uganda, to test integrated programs in Burkina Faso, and to reduce aflatoxins in Mali and Kenya. It is somewhat reassuring that the cluster analysis identification lines up well with current and planned country-level research. And, this cluster analysis suggests that the results will be valid for contexts where energy adequacy has been met at the national level and environmental health indicators are not lagging behind other countries at similar levels of development.

APPENDIX: DATA SELECTION AND ESTIMATION PROCEDURES

Data Selection

We looked at indicators for child stunting, poverty, health environment quality/care for mothers and children, and food security. We used the latest year of available data for child stunting from the WHO Global Health Observatory, which varies for each country. The data included in our analysis range from 2001 to 2011, depending on the country (see Table A.1).

Table A.1 Data year for child stunting by country

Country	Data year	Country	Data year
Angola	2007	Madagascar	2009
Bangladesh	2007	Malawi	2010
Benin	2006	Malaysia	2006
Botswana	2008	Mali	2006
Burkina Faso	2009	Mauritania	2008
Cambodia	2011	Mongolia	2005
Cameroon	2006	Mozambique	2008
Central African Republic	2006	Namibia	2007
Chad	2004	Nepal	2011
China	2010	Niger	2006
Congo	2005	Nigeria	2008
Cote d'Ivoire	2007	Pakistan	2011
Djibouti	2006	Philippines	2008
Ethiopia	2011	Rwanda	2011
Gabon	2001	Senegal	2011
Gambia	2006	Sierra Leone	2008
Ghana	2008	South Africa	2008
Guinea	2008	Sri Lanka	2009
Guinea-Bissau	2008	Sudan	2006
India	2006	Swaziland	2008
Indonesia	2007	Tanzania	2010
Kenya	2009	Thailand	2006
Lao PDR	2006	Togo	2008
Lesotho	2010	Uganda	2006
Liberia	2007	Vietnam	2008

Source: Authors' worksheets.

For the poverty clustering, we considered indicators, including poverty head count ratio at \$1.25 a day, poverty head count ratio at the national poverty line, and rural and urban poverty rates at the national poverty line. We chose the poverty head count ratio at \$1.25 a day as the measure of poverty because more countries have the data available compared to the other indicators.⁷

For the food security clustering, we considered ten variables from the FAO Food Security Indicators during the initial step. Our final selection of variables included energy adequacy; prevalence of undernourishment; cereal import dependency ratio; and share of DES derived from sources other than cereals, roots, and tubers. Together, these variables capture four aspects of food security: availability, access, vulnerability, and diet diversity/quality. Among these variables, the prevalence of

⁷ Data on poverty headcount ratio at \$1.25 a day is not available for Zimbabwe. We used the poverty headcount ratio at the national poverty line instead to measure the prevalence of extreme poverty.

undernourishment is positively correlated with child stunting, while energy adequacy, cereal import dependency ratio, and non-starchy food ratio are negatively correlated with child stunting. We excluded variables with missing values when matched with the child-stunting data or variables that duplicated information (as revealed by a high correlation with other variables). Excluded variables in this group are domestic food price volatility index, per capita food production variability, per capita food supply variability, and share of food expenditure of the poor. We also excluded depth of food deficit and prevalence of food inadequacy because they are highly correlated with prevalence of undernourishment, which is included in our analysis (see Figure A.1).

Figure A.1 Correlation matrix of food security variables

Source: Authors' estimation using data from FAO (various years).

For the health environment quality/care for mothers and children clustering, we considered variables such as access to improved sanitation facilities, access to improved water sources, maternal mortality, female life expectancy, male life expectancy, and female-male life expectancy ratio. We excluded access to improved water sources because it is positively correlated with access to improved sanitation facilities but has a lower correlation with child stunting compared to access to improved sanitation facilities. We also excluded male life expectancy because it is highly correlated with female life expectancy, as shown in Figure A.2. Among our final selections of variables, maternal mortality has a positive correlation with child stunting, while access to improved sanitation, female life expectancy, and female-male life expectancy ratio exhibit negative correlations with child stunting.

Figure A.2 Correlation matrix of health and care variables

Source: Authors' estimation using data from the World Bank, WHO, and FAO (various years).

Because child stunting data were collected in various years for countries in our sample, we used the year in which the latest child stunting data were collected as the base year for each country. We then analyzed the relationship of child stunting with the concurrent and lagged values of each variable. For variables where data are published on an annual basis, we chose the variable value that has the highest correlation with child stunting among the concurrent and five lagged values from the base year, conditional on that data are available for all countries in that year. For variables where data are not published annually, including maternal mortality and poverty rate at \$1.25 a day, we used the value published in the year that was closest to the child-stunting base year. Details on the choice of variable lags can be found in Table A.2.

Table A.2 Data sources and data year for variables considered

Variable	Cluster group	Included in analysis	Data year	Source
% of under-5 children stunted	Stunting	Yes	Latest available year	WHO
Poverty rate at \$1.25 a day (% of population)	Poverty	Yes	Closest year to the base year	World Bank; UN Department of Economic and Social Affairs; UNICEF
Poverty rate at national poverty line (% of population)	Poverty	No	N/A	World Bank
Poverty rate at rural poverty line (% of population)	Poverty	No	N/A	World Bank
Poverty rate at urban poverty line (% of population)	Poverty	No	N/A	World Bank
Average dietary energy supply adequacy (% of AEDR)	Food security	Yes	5-year lag	FAO
Cereal import dependency ratio (% of domestic cereal supply)	Food security	Yes	5-year lag	FAO
Prevalence of undernourishment (% of population)	Food security	Yes	4-year lag	FAO
Share of dietary energy supply derived from sources other than cereals, roots and tubers (% of DES)	Food security	Yes	1-year lag	Calculations based on data from FAO
Depth of food deficit	Food security	No	N/A	FAO
Prevalence of food inadequacy	Food security	No	N/A	FAO
Domestic food price volatility index	Food security	No	N/A	FAO
Per capita food production variability	Food security	No	N/A	FAO
Per capita food supply variability	Food security	No	N/A	FAO
Share of food expenditure of the poor	Food security	No	N/A	FAO
Female life expectancy at birth (years)	Health environment quality	Yes	5-year lag	World Bank
Female-male life expectancy ratio	Health environment quality	Yes	5-year lag	Calculations based on data from the World Bank
Access to improved sanitation facilities (% of population)	Health environment quality	Yes	Concurrent year	World Bank
Maternal mortality ratio (per 100,000 live births)	Health environment quality	Yes	Closest concurrent or lagged year to the base year	WHO
Access to improved water sources (% of population)	Health environment quality	No	N/A	WHO
Male life expectancy at birth (years)	Health environment quality	No	N/A	World Bank

Source: Authors' worksheets.

Figure A.3 Scatter plots of food security variables and child stunting using different lagged values

Figure A.3 Continued

Source: Authors' estimation using data from the FAO Food Security Indicator (2013).

Figure A.4 Scatter plots of health and care variables and child stunting using different lagged value

Figure A.4 Continued

Source: Authors' estimation using data from the World Bank and FAO (various years).

Source: Authors' estimation using data from WHO (various years).

Estimation Procedures

In the first stage, we conducted cluster analysis along the four dimensions of our conceptual framework: child stunting, poverty, health environment quality/care for mothers and children, and food security. We used Caliński/Harabasz and Duda/Hart stopping rules to help us decide the optimal number of clusters. The number of clusters for each dimension is limited to five, as we think that going beyond five clusters would increase the difficulty of interpreting the results. For each dimension, we presented a dendrogram and a set of three statistics generated by the stopping rules: the Caliński/Harabasz pseudo F statistic, the Duda/Hart $Je(2)/Je(1)$ statistic, and the Duda/Hart pseudo T-squared statistic. More distinct clusterings are indicated by either larger values of pseudo F and $Je(2)/Je(1)$ or smaller pseudo T-squared statistics. The red lines in the dendrograms indicate the clustering of the countries we chose.

Child Stunting

Table A.3 presents the statistics generated by the Caliński/Harabasz and Duda/Hart stopping rules. The stopping rules suggest that three or five clusters would be optimal. We think five is a better choice in this case because three clusters would generate an overly large group (26 countries) with medium and high prevalence rates of child stunting. Figure A.5 presents the dendrogram.

Table A.3 Stopping rules' statistics for child stunting clusters

Child stunting clusters			
Number of clusters	Caliński/Harabasz		Duda/Hart
	pseudo F	$Je(2)/Je(1)$	pseudo T-squared
2	107.65	0.2997	51.4
3	124.82	0.3509	48.09
4	143.83	0.3216	37.96
5	172.74	0.3305	26.33

Source: Authors' estimation.

Figure A.5 Dendrogram of child stunting clusters

Source: Authors' estimation.

Poverty

The stopping rules suggest possible groupings of three, four, or five clusters. Our choice leans toward four or five clusters because they generate more distinct clusters compared to smaller numbers of clusters. Although five clusters would generate a group of only two countries, we found that moving from four to five clusters would split Liberia and Madagascar, which have an average poverty rate of 82.5 percent, from the rest of the group, which has a lower poverty rate of 64.4 percent. Table A.4 presents the statistics and Figure A.6 presents the dendrogram.

Table A.4 Stopping rules' statistics for poverty clusters

Poverty clusters			
Number of clusters	Caliński/Harabasz	Duda/Hart	
	pseudo F	Je(2)/Je(1)	pseudo T-squared
2	129.19	0.2642	69.63
3	134.51	0.2911	56.02
4	192.74	0.1402	55.2
5	210.57	0.1804	72.71

Source: Authors' estimation.

Figure A.6 Dendrogram of poverty clusters

Source: Authors' estimation.

Food Security

The stopping rules suggest optimal groupings of two or five clusters. The choice of two clusters based on the Calińsk/Harabasz pseudo-F statistic would generate groups of countries with rather heterogeneous attributes of food security, so we chose five clusters based on the Duda/Hart Je(2)/Je(1) and pseudo T-squared criteria. Table A.5 presents the statistics and Figure A.7 presents the dendrogram.

Table A.5 Stopping rules' statistics for food security clusters

Food Security Clusters			
Number of clusters	Calińsk/Harabasz		Duda/Hart
	pseudo F	Je(2)/Je(1)	pseudo T-squared
2	59.53	0.6325	9.88
3	42.54	0.6014	20.54
4	40.69	0.0973	37.12
5	41.11	0.6416	6.14

Source: Authors' estimation.

Figure A.7 Dendrogram of food security clusters

Source: Authors' estimation.

Health Environment Quality/Care for Mothers and Children

The stopping rules indicate optimal groupings of four or five clusters. Looking at the means and standard deviations of the clusters, we found that four clusters would combine two groups of countries with varied rates of maternal mortality and female life expectancy. We think five clusters is a better choice to distinguish the countries while maintaining similarities among countries within each cluster. Table A.6 presents the statistics and Figure A.8 presents the dendrogram.

Table A.6 Stopping rules' statistics for health and care clusters

Health and Environmental Quality Clusters			
Number of clusters	Caliński/Harabasz	Duda/Hart	
	pseudo F	Je(2)/Je(1)	pseudo T-squared
2	96.88	0.2508	53.77
3	94.72	0.2758	78.77
4	163	0.3569	41.45
5	177.7	0.1391	37.12

Source: Authors' estimation.

Figure A.8 Dendrogram of health and care clusters

Source: Authors' estimation.

Second-Stage Cluster Analysis

The statistics generated from the Caliński/Harabasz and Duda/Hart stopping rules are reported in Table A.7. The stopping rules indicate that two or four clusters would be optimal, and six is also a possibility with its pseudo F and pseudo T-squared statistics rank as the second best choice. In this case, we think six clusters is a valid choice that would provide distinct categorizations of the countries while maintaining similarities of the countries within each cluster.

Table A.7 Stopping rules' statistics for second-stage clusters

Second-Stage Clusters			
Number of clusters	Caliński/Harabasz	Duda/Hart	
	pseudo F	Je(2)/Je(1)	pseudo T-squared
2	4.74	0.8563	7.72
3	6.73	0.8393	6.7
4	7.58	0.8467	3.44
5	6.95	0.7288	5.95
6	7.28	0.7323	5.12

Source: Authors' estimation.

One issue is whether to split the countries reported as cluster 4 above, because there is a break into two groups just below the red line in Figure A.9. When we examined those two groups, they did not seem to be sufficiently distinct to warrant creating a separate group. That is, the wide variance seen in cluster 4 among countries for some indicators was not improved by splitting the group.

Figure A.9 Dendrogram of second-stage clusters

Source: Authors' estimation.

REFERENCES

- A4NH (CGIAR Research Program on Agriculture for Nutrition and Health). 2013. "Value Chains". Accessed December 1, 2013. www.a4nh.cgiar.org/impact-pathways/value-chains.
- Arimond, M., and M. Ruel. 2004. "Dietary Diversity Is Associated with Child Nutritional Status: Evidence from 11 Demographic and Health Surveys." *Journal of Nutrition* 134: 2579–84.
- Caliński, R. B., and J. Harabasz. 1974. "A Dendrite Method for Cluster Analysis." *Communication in Statistics* 3: 1–27.
- de Brauw, A., P. Eozenou, D. Gilligan, C. Hotz, N. Kumar, and J. V. Meenakshi. 2013. "Biofortification, Crop Adoption and Health Information: Impact Pathways in Mozambique and Uganda." Selected paper at the Agricultural and Applied Economics Association Meeting. August 4-6, 2013, Washington, D.C. <http://ageconsearch.umn.edu/bitstream/150514/2/de%20Brauw%20et%20al%20AAEA.pdf>.
- Duda, R. O., and P. E. Hart. 1973. *Pattern Classification and Scene Analysis*. New York: Wiley.
- Everitt, B. S., S. Landau, M. Leese, and D. Stahl. 2011. *Cluster Analysis*, 5th ed. London: Wiley.
- FAO (Food and Agriculture Organization of the United Nations). 2013. *Food Systems for Better Nutrition*. The State of Food and Agriculture Report. Rome.
- . Various years. Food Security Indicators. www.fao.org/economic/ess/ess-fs/ess-fadata/en/. Rome: FAO Statistics Division.
- Gillespie, S., L. Haddad, V. Mennar, P. Menon, N. Nisbett, and the Maternal and Child Nutrition Study Group. 2013. "The Politics of Reducing Malnutrition: Building Commitment and Accelerating Progress." *Lancet* 382: 552–69.
- Haddad, L. 2013. Bigger "Impacts of Agriculture on Nutrition: What Will It Take?" Presentation at the Science Forum meeting on Nutrition and Health Outcomes: Targets for Agricultural Research, Bonn, Germany, September 25. www.scienceforum13.org/sites/default/files/download/plenary/Wednesday/Lawrence-Haddad-Bigger-Impacts-of-Agriculture-on-Nutrition.pdf.
- Herforth, A., and J. Harris. 2013. "From Agriculture to Nutrition: Pathways and Principles." Presentation at the Feed the Future Agriculture-Nutrition Global Learning and Evidence Exchange (AgN-GLEE). March 19-21, 2013. Bangkok, Thailand. www.spring-nutrition.org/sites/default/files/1.6-Jody.Harris.pdf.
- Ruel, M., and H. Alderman. 2013. "Nutrition-Sensitive Interventions and Programmes: How Can They Help to Accelerate Progress in Improving Maternal and Child Nutrition?" *Lancet* 382: 536–51.
- Smith, L., and L. Haddad. 2000. *Explaining Child Malnutrition in Developing Countries: A Cross-Country Analysis*. IFPRI Research Report 111. Washington, DC: International Food Policy Research Institute.
- United Nations. 2013. *The Millennium Development Goals Report*. New York.
- Ward, J. H. 1963. "Hierarchical Grouping to Optimize an Objective Function." *Journal of the American Statistical Association* 58: 236–44.
- Webb, P. 2013. "Impact Pathways from Agricultural Research to Improved Nutrition and Health: A Literature Analysis and Recommendations for Research Priorities." Expert Paper for the ICN2 (Second International Conference on Nutrition). Rome: FAO (Food and Agriculture Organization of the United Nations). www.fao.org/fileadmin/user_upload/agn/pdf/Webb_FAO_paper_Webb_June_26_2013.pdf.
- WHO (World Health Organization). Global Health Observatory. Various years. Accessed July 28, 2014. <http://www.who.int/gho/countries/en/>.

RECENT IFPRI DISCUSSION PAPERS

For earlier discussion papers, please go to www.ifpri.org/pubs/pubs.htm#dp.
All discussion papers can be downloaded free of charge.

1361. *Assessing the economic benefits of sustainable land management practices in Bhutan*. Ephraim Nkonya, Raghavan Srinivasan, Weston Anderson, and Edward Kato, 2014.
1360. *Examining the sense and science behind Ghana's current blanket fertilizer recommendation*. Antony Chapoto and Francis Tetteh, 2014.
1359. *Aid effectiveness in Ghana: How's the L'Aquila Food Security Initiative Doing?* Samuel Benin, Tsitsi Makombe, and Michael Johnson, 2014.
1358. *The other Asian enigma: Explaining the rapid reduction of undernutrition in Bangladesh*. Derek D. Headey, John Hoddinott, Disha Ali, Roman Tesfaye, and Mekdim Dereje, 2014.
1357. *Can market-based approaches to technology development and dissemination benefit women smallholder farmers?: A qualitative assessment of gender dynamics in the ownership, purchase, and use of irrigation pumps in Kenya and Tanzania*. Jemimah Njuki, Elizabeth Waithanji, Beatrice Sakwa, Juliet Kariuki, Elizabeth Mukewa, John Ngige, 2014.
1356. *The impact of shocks on gender-differentiated asset dynamics in Bangladesh*. Muntaha Rakib and Julia Anna Matz, 2014.
1355. *Tractor owner-operators in Nigeria: Insights from a small survey in Kaduna and Nasarawa States*. Hiroyuki Takeshima, Hyacinth Edeh, Akeem Lawal, and Moshud Isiaka, 2014.
1354. *Co-movement of major commodity price returns: A time-series assessment*. Francesca de Nicola, Pierangelo De Pace, and Manuel A. Hernandez, 2014.
1353. *Bargaining power and biofortification: The role of gender in adoption of orange sweet potato in Uganda*. Daniel O. Gilligan, Neha Kumar, Scott McNiven, J. V. Meenakshi, and Agnes Quisumbing, 2014.
1352. *Quality healthcare and health insurance retention: Evidence from a randomized experiment in the Kolkata Slums*. Clara Delavallade, 2014.
1351. *Sins of the fathers: The intergenerational legacy of the 1959–1961 Great Chinese Famine on children's cognitive development*. Chih Ming Tan, Zhibo Tan, and Xiaobo Zhang, 2014.
1350. *Direct seed marketing program in Ethiopia in 2013: An operational evaluation to guide seed-sector reform*. Todd Benson, David Spielman, and Leulseged Kasa, 2014.
1349. *Agriculture for development in Iraq?: Estimating the impacts of achieving the agricultural targets of the National Development Plan 2013–2017 on economic growth, incomes, and gender equality*. Azhr Al-Haboby, Clemens Breisinger, Dario Debowicz, Abdul Hussein El-Hakim, Jenna Ferguson, Roberto Telleria, and Teunis van Rhee, 2014.
1348. *An evaluation of the effectiveness of farmland protection policy in China*. Man Li, 2014.
1347. *Women's individual and joint property ownership: Effects on household decisionmaking*. Cheryl Doss, Sung Mi Kim, Jemimah Njuki, Emily Hillenbrand, and Maureen Miruka, 2014.
1346. *Can smallholder fruit and vegetable production systems improve household food security and nutritional status of women?: Evidence from rural Uganda*. Nassul Kabunga, Shibani Ghosh, and Jeffrey K. Griffiths, 2014.
1345. *Intellectual property rights, technology diffusion, and agricultural development: Cross-country evidence*. David J. Spielman and Xingliang Ma, 2014.
1344. *Market interdependence and volatility transmission among major crops*. Cornelis Gardebroek Manuel A. Hernandez, and Miguel Robles, 2014.
1343. *Importance of rice research and development in rice seed policies: Insights from Nigeria*. Hiroyuki Takeshima, 2014.
1342. *Can transfer programs be made more nutrition sensitive?* Harold Alderman, 2014.
1341. *The impact of cash and food transfers: Evidence from a randomized intervention in Niger*. John Hoddinott, Susanna Sandström, and Joanna Upton, 2014.
1340. *How does climate change alter agricultural strategies to support food security?* Philip Thornton and Leslie Lipper, 2014.

**INTERNATIONAL FOOD POLICY
RESEARCH INSTITUTE**

www.ifpri.org

IFPRI HEADQUARTERS

2033 K Street, NW
Washington, DC 20006-1002 USA
Tel.: +1-202-862-5600
Fax: +1-202-467-4439
Email: ifpri@cgiar.org