Multidimensional Household Food Security Measurement in Rural Zambia

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Abstract

Food security is recognized as a multifaceted condition of complex causality that is related to, yet distinct from, poverty and hunger. Given its broad definition, it is no surprise that food security eludes precise measurement. This study considers there to be three components of household food security (quantity, quality, and stability), and attempts to address the "concept-to-measurement" gap in food security by building an index that spans these three dimensions. A panel data set is used for descriptive analysis of food security indicators in rural Zambia in 2000/01, 2003/04, and 2007/08 for different types of households, including female-headed households. A multidimensional index of food security for rural Zambia is then developed using principal component analysis. This composite index is used to explore the spatial patterns of food security in Zambia over time, to assess correlates of food insecurity, and to measure the impacts of climate shocks on food security. Results indicate that both seasonal rainfall and temperature have a significant impact on a household's food security score, although not for all individual components of the food security index. The paper concludes with a consideration of the merits and shortcomings of developing a composite food security index.

Key Words: climate, food security measurement, principal component analysis, Zambia

JEL Codes: C38; Q12; Q54; I32

1. Introduction

This paper will analyze a longitudinal data set of households in rural Zambia in order to measure household food security, inclusive of vulnerability to future food shortfalls. Accurate measurement drives the diagnosis of food insecurity, the exploration of its determinants, and the design of effective policies to bolster household welfare. Measurement is necessary to understand whether a situation is growing better or worse and whether food insecurity is chronic or transitory. It reveals information about who is food insecure in a population and where insecurity is concentrated. Measurement, if done well, can also bring to light the nature of food insecurity, detailing whether it is a problem of food availability or economic access, of diet quantity or quality.

This paper aims to broaden our understanding of food security measurement and dynamics, first by analyzing the relationships among various food security indicators and tracking these individual measures over time. It then develops a relatively simple measure of food security in the form of a single composite index that incorporates indicators of its multiple dimensions. This composite index is applied to household data from rural Zambia to address the following questions: Where are food insecure households found within Zambia? What is the nature of the food insecurity problem, and what are the correlates of food insecurity? Through what avenues do climate shocks affect food security? Few other existing studies use a multidimensional measure of household food security to address these kinds of questions, and to the author's knowledge, no other study thoughtfully reflects on the merits and shortcomings of using such a composite index. This paper seeks to fill this gap in the literature.

Sections 2 and 3 present background information on agro-ecology in Zambia and food security measurement. Section 4 describes the data sources used in this study. Section 5 provides descriptive statistics of various food security indicators in Zambia, disaggregated by region and gender of household head. Section 6 details the construction of a food sufficiency index and food security index using principal component analysis and includes descriptive statistics of the indices. Section 7 presents several applications of the indices, including econometric analyses of the determinants of food security and the impact of climate shocks on food security. Section 8 offers conclusions and a summary of lessons learned from this exercise.

2. Agro-ecology and rural livelihoods in Zambia

Zambia is a landlocked country characterized by low population density, where roughly 45% of the population live in rural areas and depend on agriculture for their livelihoods (Jain 2006). Zambia's farmers can be grouped into three categories: small-scale farmers (with up to five hectares of farming land), emergent farmers (with 5 to 20 hectares), and large-scale commercial farmers (with over 20 hectares). As of 2003, approximately 94% were small-scale farmers, 5.5% were emergent farmers, and commercial farmers accounted for less than 0.5% (Siegel and Alwang 2005).

Zambia is divided into four agro-ecological zones distinguished by distinct rainfall patterns (Figure 1). Zone I, located in the south, is relatively dry with unpredictable and poorly distributed rainfall and limited potential for crop production. Zone IIa covers the central-eastern part of the country and has the highest agricultural potential, with fertile soil and rain that is evenly distributed throughout the growing season. Zone IIb is characterized by low rainfall, sandy soils, and a high risk of drought. Finally, zone III in the north experiences high rainfall, although this pattern has produced leached and acidic soils (Jain 2006).

The farming systems also vary by agro-ecological region: Zone I is dominated by subsistence crop production and is suitable for drought tolerant crops (e.g. cotton, sesame, sorghum, millet), though poor soils and unreliable rainfall make farming risky. Zone IIa is characterized by a maize regime and is the most mechanized and commercialized region. This is also the most populous zone with better access to infrastructure and higher use of inputs (Siegel and Alwang 2005). Zone IIb exhibits substantially lower capacity for crop production, while zone III is planted with a dual cassava-and-maize regime, and farmers tend to use low-input shifting and semi-permanent cultivation techniques (Saasa et al. 1999). Farmers there rely almost entirely on hand hoes rather than oxen.

Year-to-year variability in rainfall and other climatic conditions are important determinants of crop output in most parts of Zambia. Drought has been the biggest shock to food security during the last two decades (Muchinda 2001, cited in Jain 2006), with large shortfalls in maize yield consistently occurring in seasons with below normal rainfall. At the same time, Zambia sometimes experiences heavy localized floods that also threaten agricultural production. The general climate outlook for southern Africa is characterized by a rise in temperatures and a higher frequency and severity of extreme rainfall events (Kotir 2011). Thus, the general consensus among climatologists is that climate change will act as a multiplier of existing threats to food security in southern Africa.

3. Food security measurement

The definition of food security is generally understood as a situation whereby "all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO 2002). Food insecurity is related to, yet distinct from, concepts such as poverty and malnutrition (Webb et al. 2006), and is experienced at a range of spatial scales from households to regions, as well as a range of time scales.

The failure of early attempts to alleviate food insecurity has arguably been due to their overwhelming emphasis on food availability (Ziervogel et al. 2006). While food security clearly depends on agricultural conditions and aggregate food production, it also depends on socio-economic conditions, including the distribution, access, and affordability of food. It is important to note that aggregate food availability is a poor predictor of other food insecurity indicators, and food insecurity "does not arise exclusively –or even predominantly– because of covariate shocks to an entire population" (Barrett 2002). Thus, the correlates and causes of food insecurity are likely to be found at the level of households and individual livelihoods.

This paper considers there to be three components of household food security: food *quantity* available in the household, food *quality* as captured by dietary diversity and the presence of important nutrients, and the *stability* of adequate food supplies (Figure 2). It should be noted that this is not intended to be the most comprehensive framework, but rather the one most appropriate for the present analysis, given data availability and the household level of analysis.

While accurate measurement of household food security is essential for effective research and well-targeted policies and programs, there is no standard methodology for measuring food security, and despite an improved theoretical understanding of food security, the FAO notes that there exists no "perfect single measure that captures all aspects of food insecurity" (FAO 2002). The absence of such a 'gold standard' makes it unreasonable to use a single benchmark to proxy food security. In light of its multidimensional nature, it is generally agreed that a suite of indicators and methods are needed for the assessment of food security.

Several papers have combined various food security indicators into a single composite index. This seems to build on the literature of multidimensional poverty indices (e.g. Alkire and Foster 2007), and it allows for the ranking of different countries, regions, or households in terms of the severity of food insecurity. Such an exercise may be useful in order to target resources toward those most in need and to track changes over time. The World Food Program's Vulnerability Analysis and Mapping Unit applies principal component analysis (PCA) to generate a food security and vulnerability index for household profiling (WFP 2009). Demeke et al. (2011) also use PCA to create a food security index for Ethiopia that includes several household-level variables related to food availability, access and vulnerability.

While the argument for creating an index is compelling, there may be drawbacks to combining diverse factors into one score, particularly when trying to understand the determinants of food security and the channels of impact. Ravallion (2011) notes that while poverty is multidimensional, the value of a single index for sound development policy-making merits skepticism. In practice, policymakers can already refer to multiple indicators to measure different aspects of poverty, while the use of a single index necessarily relies on assumptions regarding which aspects of poverty should be included and how they should be weighted. The same argument can be levied at the construction of a multidimensional food security index, and it is not clear that collapsing these dimensions into a single composite index can be useful. This paper will explore this very question.

4. Data sources

This analysis uses nationally representative panel data on rural farm households in Zambia. Households were surveyed in 2000/01, 2004, and 2008 and asked about their activities and income over the previous 12 months, as well as household changes over the previous 4 years. Hence the surveys refer to the 1999/2000, 2002/03, and 2006/07 agricultural years, and the 2000/01, 2003/04, and 2007/08 marketing years. The first wave is comprised of both the 1999/2000 Post-Harvest Survey conducted by the Zambian Central Statistical Office (CSO) and Ministry of Agriculture and Cooperatives (MACO), and the CSO/MACO/Michigan State University Food Security Research Project (FSRP) Supplemental Survey. The second and third waves are Supplemental Surveys. The number of households interviewed was 6,922 (2001), 5,419 (2004), and 8,094 (2008). In total, 4,286 households were re-interviewed in all three waves of the panel survey.

Data on the calorie content of food items are taken from the Food Consumption Table for Use in Africa (Wu Leung et al. 1968) and the Tanzania food composition table (Lukmanji et al. 2008). Historical rainfall and temperature data are obtained from records collected by 35 meteorological stations run by the Zambian Meteorological Department.

In this paper, panel analyses include the balanced panel of households interviewed in all three waves, and population or panel weights are included in all relevant analyses. In panel regressions where a test for attrition bias rejects the null hypothesis of no bias, attrition-adjusted weights created with the inverse probability weighting procedure (Wooldridge 2002) are used. Monetary values are inflated to 2007/08 values using the consumer price index, and the exchange rate for this year was 1 U.S. dollar = 3,829 ZMK. No effort was made to impute missing data points for the household surveys.

5. Non-monetary food security indicators in Zambia

Food security indicator definitions are provided in Table A1. Panel values are used in all panel analyses, and non-panel values are calculated for 2007/08 and used only for descriptive purposes. It should be emphasized that the calculation of calories available to the household is a rough estimate, though it is not immediately obvious whether it is an over- or under-estimate: The survey does not include information on food eaten away from home, the collection of wild foods, the purchase of non-staple food items, or food obtained in socially unacceptable ways (e.g. stealing). At the same time, it does not account for losses in storage or food provided to guests.

Table 1 provides descriptive statistics of food security indicators over the panel years. These results reflect stagnancy over a range of food security indicators: It is clear that although 2004 was a relatively good year for households in Zambia, by 2008 several food security indicators had returned to their 2001 levels. Yet it does seem that households are marketing an increasing proportion of their crop production, producing more skilled off-farm workers, and collecting income from a greater number of sources. The cutoff point for a household being considered food energy deficient is at the age- and gender-specific calorie requirements suggested by Smith and Subandoro (2007) for three different activity levels. However these cutoffs produce markedly divergent rates of food energy deficiency.

A transition matrix of household calorie status (Table 2) indicates that households do shift around with regard to calorie consumption. The calorie status categories are formed as quintiles of calories/adult equivalent/day for years 2004 and 2008. Of households in the lowest calorie bracket in 2004, just 26% remained in that bracket four years later. This is somewhat surprising, as it is often found that consumption (a "realized" welfare achievement) is smoother than income (a "potential" welfare opportunity), whereas these results indicate significant movement in household consumption.

Table 3 presents descriptive statistics for 2008, disaggregated by gender of household head and agro-ecological zone. It is quite surprising that female-headed households (FHHs) display significantly higher calories per capita and correspondingly lower rates of food energy deficiency. One possible explanation to reconcile these results with an *a priori* expectation of lower food security is that only FHHs that are sufficiently empowered remain as independent households, whereas other FHHs are absorbed into the households of extended family. This hypothesis seems to be borne out by the 2008 data, in which 10.12% of households contain a woman who is not the head of household and is widowed, separated, or divorced. Meanwhile, just 2.6% of households contain a man in this position. The discrepancy suggests that the FHHs captured in this household survey may represent the “survivors”, and this pattern underscores how the categorization of households as male- or female-headed does not truly capture the gender dynamics of food security. FHHs do report a higher average number of months without any food stocks and lower measures of dietary diversity. Among stability indicators, FHHs cultivate smaller areas of land, have fewer productive assets, and are less likely to participate in a transfer network.

Food security indicators in Zambia also differ according to agro-ecological region (Table 4). For example, zone III in the north exhibits a much higher proportion of households in 2008 that report that they consistently had food stocks in the previous 12 months. This is likely due to the dominance of cassava in the region, as cassava can often be left in the field until it is ready to be consumed, rather than requiring a seasonal harvest. Figure 3

presents the cumulative distribution of calories in each agro-ecological zone. As zone IIa first-order stochastically dominates the other zones, it is clear that this region fared better in 2008 in terms of this indicator.
Figure 4 presents the same information in a radar graph of normalized z-scores, such that a higher score farther from the center of the graph is relatively good, while a value closer to the center is bad. Zones I, IIa, and III exhibit relatively "smooth" circles, though zone I stands out in terms of the low number of months with food stocks, and zone III stands out in terms of high crop diversity. Zone IIb consistently scores low for indicators of food security, and the low value for number of crops and fruits/vegetables retained seems to stem from the much lower prevalence of gardens in this region (Table 4).

6. The multidimensional food security indices

6.1 Construction of the indices

From the array of food security indicators calculated in section 5, it can be difficult to extract a household's overall status of food security. To do so, it may be useful to construct a multidimensional index that incorporates the most important indicators from each dimension of food security. However, the construction of such an index can be highly subjective, particularly with regard to the weights assigned to each element of the index. This paper uses principal component analysis (PCA) to construct a composite food security index, such that the weights are derived objectively from the data. PCA is a type of factor analysis that can reduce dimensions, or uncover latent variables, by extracting linear combinations that best describe the co-variance among all elements (Abeyasekara 2005). The first principal component captures the greatest variation, and as data reduction is the primary objective of this exercise, only the first component will be used. This is converted into factor scores which serve as weights for the creation of an index.

Once the first component is identified, the food security index for each household is derived as follows:

$$FSI_j = \sum F_i [\frac{X_{ji} - X_i}{S_i}]$$

where FSI_j is the Food Security Index, which follows a normal distribution with a mean of 0. F_i is the weight for the i^{th} variable in the PCA model (the squared factor score of i), X_{ji} is the j^{th} household's value for the i^{th} variable, X_i and S_i are the mean and standard deviations of the i^{th} variable for overall households. Essentially, the FSI is the sum of the weighted z-scores for each variable.

Each PCA index is based on a scale which is relevant only to that estimation, such that a set of indices from different estimations cannot be meaningfully compared. As this study uses three rounds of household panel data, it is necessary to generate an index that is comparable over time. Following the approach of Cavatassi et al.

(2004), data for the three rounds are pooled and principal components are estimated over the combined data. The resulting weights are then applied to the household data for each round of the survey.

The selection of elements included in the indices is driven by both the food security literature and the goal of maximizing the variation explained by the first principal component. Two versions of the index are created: The first is the Food Sufficiency Index (FSU), based mostly on the quantity and quality measures of food security. The second index is called the Food Security Index (FSI) and is based on the quantity, quality, and stability measures. Thus, the FSI explores the merit of including indicators of future vulnerability in the index. The variables included as elements of each index are listed in Figure 5. Unfortunately, there is no indicator of stability in the FSU for multi-year analysis, as the 2001 survey did not capture information on cassava stocks. It is also unfortunate that no measure of income diversification is included in the FSI. Analysis of the data suggests that non-farm income options are so limited in rural Zambia that they cannot be meaningfully regarded as a component of a household's underlying food security status.

The factor loadings of the indices are given in Table 5. The data reduction of the PCA explains 35% of the original variation of the data for the FSU, and 29% for the FSI. These values are similar to those seen in other studies that use PCA to develop a wealth or food security index (e.g. Filmer and Pritchett 1998; Dasgupta and Baschieri 2010; Demeke et al. 2011). The factors that load most heavily on the FSU are calories and crop diversity, and the value of the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy is 0.52. A large KMO value (greater than 0.5) indicates that correlations between pairs of components can be explained by the other variables in the index (Kaiser 1974). It should be noted, however, that this value is close to the cutoff of acceptability. In deciding to pool the data from all panel years, it is important to verify that the pattern of factor loadings does not change fundamentally from year to year when the exercise is repeated for each year independently (Vyas and Kumaranayake 2006). The same is true of pooling data across all four of Zambia's agro-ecological zones. An inspection of the values for individual years and regions in Table 5 confirms that it is acceptable to create a pooled index.

6.2 Descriptive statistics

The distribution of these indices in 2008 are shown in Table 6. It is clear that FHHs have lower average scores, as compared with the general population. Among agro-ecological zones, the drier regions (zone I and IIb) experience lower average food sufficiency, and only zone IIa has a positive average value for both the FSU and FSI. Interestingly, zone I fares much better with regard to its average FSI, while zone III fares much worse. This is surely because of the high disease burden for livestock in zone III, compared with the important cultural role of livestock in zone I.

The spatial pattern of how food security has changed over time can be seen in Figure 6. While the relative degree of food insecurity does change, there are clearly pockets of insecurity, namely in zones IIb and III. One might also want to assess the predictive power of food security indicators in 2004 (Table 7). The correlation between the FSI in 2004 and 2008 is 0.55, which makes sense as many of the components of this index might be consistent within a household from one year to the next. In terms of predicting a household's food sufficiency experience in 2008, the FSI outperforms the FSU. This is as expected, as the FSI specifically includes indicators of vulnerability to future food shortfalls.

Are households merely "bouncing around" the food security indices without a pattern? Table 8 presents the percent of households that are always, sometimes, and never secure, in terms of food sufficiency or food security. While about 40% of households are never insecure, a greater proportion have indeed moved in and out of insecurity. Table 9 breaks down the proportion of households that experience the following trajectories in terms of their FSU score and FSI score: A positive change from 2001 to 2004 and another positive change from 2004 to 2008 (+ +); a positive followed by a negative change (+ -); a negative followed by a positive change (- +); and two negative moves down the index (- -). For both indices, approximately 22% of households are on an upward trajectory, 34% consistently fell lower, and 43% experienced a change in their direction of movement.

7. Applications of the food security indices

7.1 Correlates of food sufficiency and food security

In this section, the food sufficiency and food security indices are applied to various exercises aimed at identifying the correlates and determinants of food security. The selection of variables included in the models is guided by the food security literature and the significant determinants that have been identified in similar contexts (Feleke et al. 2005; Misselhorn 2005), the variables that seem like they may plausibly affect food security, and data availability. It should be noted that because the dependent variable is a normalized food security score unique to this population, the coefficients are a bit difficult to interpret. Readers are encouraged to focus on the sign, significance, and relative magnitude of the coefficients rather than their specific value.

The first model exploits the variation found within multiple observations on a single household to understand the correlates of food security. The model is

$$Y_{it} = \gamma + \beta X_{it} + \alpha_i + \varepsilon_{it}$$

where Y_{it} = the dependent variable of household *i* at time *t*, X_{it} = a vector of socioeconomic characteristics and agricultural practices of household *i* at time *t*, and α_i = unobserved household fixed effects that are time-invariant. The appropriateness of a fixed-effects model is confirmed with Hausman tests, which in each case reject the null hypothesis (Prob > χ^2 = 0.000) that there is no systematic difference in coefficients between a random effects and fixed effects model. All explanatory variables that are time-invariant, such as geographic location or relationship to the village chief, are necessarily omitted from this analysis.

Column 1 of Table 10 presents the results of this model when FSI_{it} is the dependent variable. As a regression-based test for attrition bias rejects the null of no bias (p-value = 0.000), attrition-adjusted weights are used. *Ceteris paribus*, a higher dependency ratio is associated with sufficiency; this is surprising, given the importance attributed to the burden of a high dependency ratio in other studies (Kennedy and Peters 1992). The indicator for a widowed FHH is included here, though the coefficient represents the marginal effect of *becoming* a widow, rather than the effect of a long-term status as a widowed FHH. However, it is noteworthy that becoming a widow has a significantly negative impact on food security. This may be driven by the choice of dependent variable, as the FSI index includes both productive assets and land cultivated, which are held in smaller amounts by FHHs (Table 3), though not necessarily smaller amounts per adult equivalent.

Column 2 of Table 10 presents the results of this model when FSU_{it} is the dependent variable. Attrition bias (p-value = 0.000) is again addressed with attrition-adjusted weights. The variables related to a household's asset endowment tell a consistent story: A higher value of productive assets (including work oxen) and larger area of land cultivated are significant determinants of sufficiency. Interestingly, a higher proportion of crop value marketed is negatively associated with food sufficiency, though the relationship may be driven by inclusion of a dummy variable for cash crop production. It is also interesting that becoming a widow is not a determinant of food sufficiency. The insignificance here does not negate the fact that widowed households have significantly lower FSU than the general population (Table 6), but once these other factors are controlled for, there is no residual causal relationship between widowhood and food insufficiency. Rather, their status is explained by the other household characteristics included as controls in this regression.

Participation in a transfer network (the receipt or provision of cash or goods) is associated with being food sufficient, though this potentially exhibits reverse causality as it may have been directly determined by a household's food security experience. For example, if households receive remittances during times of distress, this would attenuate the detected relationship between social capital and avoidance of food insufficiency. However, a cursory glance at transfer network patterns in 2008 suggests that participation alone does not unambiguously relate to food sufficiency: 15% of households participate only as receivers, 25% participate as givers, 43% both give and receive within their transfer network, and the remaining 17% neither give nor receive in 2008. Only the last category receives a value of zero for "transfer network participation", with the intention of capturing a household's access to a network rather than specifically whether they are recipients or benefactors of assistance. One option to address this potential endogeneity would have been to use a household's lagged transfer network status. However this option was not taken in order to retain the first panel year.

It might be worrisome that these indices do not incorporate a variable for the stability of current food supply. To explore how this omission affects the results, the analysis is repeated for just years 2004 and 2008 when data are available for the indicator of having maize or cassava in storage from the previous harvest. This indicator is used in the construction of a brand new FSU index, and the results are presented in column 3 of Table 10. This model does not exhibit attrition bias, and it seems clear that the pattern does not change markedly when this stability variable is included in the FSU index.

Because both rainfall and temperature enter the model in a quadratic manner, the coefficients can be used to determine the "optimal" levels for food sufficiency or food security. In column 2, the optimal rainfall (from mid-December through February) occurs at 647.68 mm, and the optimal average growing season temperature occurs at 21.50°C (Figure 7-1). The household average for season temperature over the panel years is 23.06°C, which indicates that any additional warming will be harmful to food sufficiency. This is potentially an important finding in light of the expected higher average temperatures in southern Africa associated with climate change (Kotir 2011). Similarly, the household average for rainfall during this interval is 543.82 mm, which indicates that any decrease in precipitation would be harmful to food sufficiency.

7.2 Persistent effects of food security and food sufficiency

In order to explore the persistent effects of a household's FSU or FSI score, it is useful to implement a dynamic panel method that includes the lagged FSU or FSI score as a regressor. In a cross-sectional regression, a lagged dependent food security score will be biased upward in the presence of serial correlation, which is found to be present in regressions of the FSU and FSI ($\hat{u}_{2008}$ regressed on $\hat{u}_{2004}$; p-value = 0.000 in both cases). A fixed effect model can address the household effects that influence both past and current food security experiences. However the inclusion of a lagged dependent variable within a fixed effects model results in a coefficient that is biased downward, a phenomenon known as the Nickell bias (Nickell 1981). This is especially true in a "small T, large N" context. To overcome this problem, the Arellano-Bond Generalized Method of Moments estimator (Arellano and Bond 1991) is used here, in which a first-differenced model is used in combination with an instrumental variable method to address the endogeneity of the lagged dependent variable. The instrumental variables used for the lagged variables include all level terms of the regressors from the previous period, and for this reason, only one lag can be included with this three-wave panel. The model is

$$\Delta Y_{it} = \alpha + \beta_1 \Delta Y_{i,t-1} + \beta_i \Delta X_{it} + \Delta \varepsilon_i$$

where ΔY_{it} is the differenced dependent variable (e.g. $FSU_{2008} – FSU_{2004}$) and $\Delta Y_{i,t-1}$ is the differenced lagged dependent variable (e.g.$FSU_{2004} – FSU_{2001}$). The instrumental variables for $\Delta Y_{i,t-1}$ include all $X_{i,t-2}$ (e.g. control variables from 2001). Results are presented in Table 11, and although only the coefficients on the lagged variables are reported, all other household characteristics are included as controls.

In column 1, the FSI is regressed on the household's lagged FSI score. The lagged value is strongly significant, indicating that the FSI indeed exhibits persistence and is not determined only by current shocks to the household. In column 2, the FSU score is regressed on the lagged FSU score, and again the coefficient is significant. In column 3, the FSU is regressed on lagged FSI with the aim of discerning whether the FSU or the FSI is the stronger determinant of future food sufficiency. The slightly larger coefficient on the lagged FSI suggests that the extra variables included in the FSI, with the aim of capturing a household's vulnerability to future food shortfalls, do a better job of predicting future food sufficiency. However, the difference seems rather small.

7.3 Impact of climate shocks on food sufficiency

In Table 12, the impact of rainfall on food sufficiency is studied with the samples restricted to those households that are poor or not poor (according to the $1-per-day cutoff) in any year. Although only the coefficients on climate variables are reported, all other household characteristics are included here as controls. Among poor households (column 2), the standard relationship is found in which there is an optimal amount of rainfall that maximizes food sufficiency. However, among non-poor households (column 1), the coefficients on rainfall variables are not significant, and F-tests of joint significance confirm that neither rainfall nor temperature is significant. Several other climate variables are also determinants of FSU for poor households: A longer rainy season in associated with a higher food sufficiency score, and this is probably because a longer rainy season is more likely to provide adequate rain early in the season to feed a rainfall-sensitive maize crop. In addition, a longer rainy season provides the opportunity to add mixed beans or other fast-maturing crops to the household's harvest. Average season temperature is also significant. These findings highlight the vulnerability of poor households to climate outcomes, while wealthier households are buffered from such climate risks.

The final application of the food security indices is to explore the avenue of impact of rainfall and temperature shocks on food security. In all regressions, household characteristics are included as controls in the econometric analysis, although the coefficients on these controls are not presented here. The model is

$$Y_{it} = \gamma + \beta W_t + \beta X_{it} + \alpha_i + \varepsilon_{it}$$

where W_t= a vector of rainfall and temperature variables of the household's district during the agricultural season relevant to time *t*. For all but one regression in this section, a test of attrition bias fails to reject the null of no bias at a 5% level of significance, and attrition-adjusted weights are therefore used. In column 1 of Table 13, the FSU is regressed on climate and control variables. As we have seen before, the relationship between rainfall/ temperature and food sufficiency is quadratic. In columns 2–5, this regression is repeated for each element of the FSU index separately, with the aim of understanding the causal path through which climate affects this index.

The relationship between rainfall and calories is similar to that found with the total index, and similar coefficients are also seen when the number of crops retained is the dependent variable. However rainfall has a different relationship with the production of milk/eggs, and is not a significant determinant of TLU. At the same time, temperature seems to be important for all elements of the FSU, though there does not seem to be an "optimal" temperature when the dependent variable is calories. The lesson seems to be that climate affects the various elements of this food sufficiency index differently. In terms of food security policy development, this disaggregated analysis is important to identify the interventions that might bolster household resilience to climate shocks. For example, certain livestock management practices may diminish the relationship between climate shocks and a household's likelihood of producing milk or eggs.

8. Discussion

8.1 Summary of results

This paper first offers information on a range of household-level food security indicators in Zambia. Most explorations of the time trends reveal stagnancy in the food security situation of Zambian households over the study period. In 2008, it seems that female-headed households generally experienced higher levels of food quantity, although lower average values of other indicators suggest that they do not unambiguously experience higher levels of food security. It is therefore difficult to conclude whether FHHs experience an overall level of food security that differs from other households in Zambia, and this underscores the potential value of generating a composite index of food security. Geographic patterns of food security are immediately evident, as zone IIa consistently exhibits favorable values of food security indicators, often followed by zone III. Zone I has a relatively high average value of TLU, although other food security indicators are low, while the reverse is true for zone III. In addition, the cassava belt (zone III) exhibits much higher levels of food stability than other regions. Although the government of Zambia has recently focused much of its agricultural policy on promoting maize production, this finding highlights the importance of cassava to Zambia's food security.

The high level of mobility in calorie status suggests that households may be less able to smooth consumption than is commonly thought. For example, a household in the fourth calorie bracket in 2004 was equally likely to find itself in the first (lowest) bracket as to remain in the same bracket by 2008. This represents a wide spectrum of potential welfare for the household, and it calls attention to the importance of consumption-smoothing mechanisms to the maintenance of household welfare.

The FSU and FSI are constructed from a subsample of food security indicators that seem to best span multiple dimensions of food security. It is clear that FHHs have lower food sufficiency and food security scores, on average, than the general population. In general, it is surprising that the FSU and FSI scores in 2004 are not more tightly correlated with food security indicators in 2008.

The final portion of this paper employs the food sufficiency and security indices in econometric analyses to discern the correlates and determinants of food security. Many of the results are as expected: Assets associated with agricultural production and information access are positively correlated with food sufficiency. Planting a cash crop is associated with higher food security, even as households may become more dependent on the market to acquire food. The use of crop rotation, intercropping, and minimum tillage land preparation are all positively associated with food sufficiency. This short-term effect is interesting, as the impacts of conservation farming techniques are expected to be seen over a longer time horizon (Haggblade and Tembo 2003). However, the relationship is not necessarily causal, and the impact of conservation farming on food security merits further attention.

The final exercise relates to the impact of climate shocks on FSU. Rainfall and temperature are understood to be exogenous, which allows for a causal interpretation of the coefficients. Specifically for poor households, the early-growing season rainfall positively affects food sufficiency until a maximum point, after which it reduces the FSU score. Given the occurrence of both droughts and floods in Zambia, this pattern makes sense. At the same time, the climate variables seem to have little or no explanatory power for households that are not poor. This affirms the vulnerability of poor households to climate shocks, and points toward the possible value of weather-indexed insurance or other measures that reduce this vulnerability. Climate affects each element of the FSU index differently. Although informative, this complicates the challenge of developing interventions to improve household resilience to climate shocks.

8.2 Evaluation of the food security indices

Does using a food security index shed light on the story of food security? As noted earlier, the idea of using a multidimensional index of welfare, whether in reference to poverty or food security, is regarded with some skepticism (Ravallion 2011). The benefit would seem to be that the food security score encompasses the many dimensions of food security and reveals a household’s latent food security status. This allows for a straightforward description of the state of food security in Zambia and enables a statistical analysis that links explanatory variables with a household’s overall experience of food security.

However, the results of section 7.3 do reveal the shortcomings of such an index: The initial result shows that seasonal rainfall is a significant determinant of food security in a quadratic relationship. Yet the policy implication is not entirely clear until the index is decomposed and a regression is run on each of its components separately. The realization that temperature is a determinant of the number of crops retained suggests that agricultural extension officers may encourage crop mixes that include more heat-tolerant crops, even if these are less profitable or produce fewer calories per hectare. The realization that climate shocks in the preceding agricultural season do not affect TLU indicates that including livestock in a household's livelihood portfolio may reduce the household's vulnerability to climate shocks. These avenues of impact and potential intervention would not be readily deduced when using the index in its composite form.

A final note on the information lost when constructing a food security score is that it is possible for households with very different characteristics to receive the same score. For example, a household in zone I may have many livestock along with an extended season without food stocks. A household in zone III may have few livestock but still experience consistency in its food supply. The score for each household will be similar, even though the underlying experience of food security is quite different and merits a unique intervention or policy response.

The inclusion of variables associated with vulnerability (i.e. the extra variables added to the FSI) seems useful but does not add a great deal to the analysis. For example, the correlation coefficient between the FSU in 2004 and the FSU in 2008 is 0.33, while the value linking the FSI in 2004 and the FSU in 2008 is 0.40. *A priori*, it might have been expected that the FSU would be more variable, while the asset and social network variables included in the FSI render it a better representation of the household's overall capacity to mitigate negative shocks to food security. However it is not clear that this paper would have suffered had it excluded consideration of these indicators of vulnerability, despite their conceptual appeal.

Several caveats are warranted that have not been adequately emphasized: This data set was not collected with the intention of measuring consumption or food security, and it is therefore necessary to identify proxies for even the three dimensions of food security considered here: quantity, quality, and stability. For example, rather than capturing whether households consume specific nutrients (e.g. protein) in their diet, the livestock ownership and homestead production of milk or eggs are used as proxies for the likely presence of animal protein in the diet. Yet there may be a weak relationship between household production and consumption of these products. Given that there is no "gold standard" indicator of food security available in the data set, it is difficult to validate the two indices constructed in this study, and the merit of the indices is largely based on their conceptual soundness rather than statistical validation.

Future research might build on this exercise by attempting to validate the indices using another data set that includes additional information on household experiences, such as consumption and anthropometric outcomes. Another direction for research relates to the differences between households that are categorized into different trajectories of the FSU and FSI. Are households on an upward track systematically different from those on a downward path or those whose scores fluctuate back and forth? What life events or household decisions seem to characterize households in these different categories? Finally, in order to understand the determinants of food security, it may be useful to disaggregate the entire exercise by agro-ecological zone. While it would preclude cross-zone comparison, this would allow the weights on the index elements to differ by region and may reveal stronger local correlates of food security.

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TABLES AND FIGURES

Figure 1. *Agro-ecological zones in Zambia*

Figure 2. *Household food security framework*

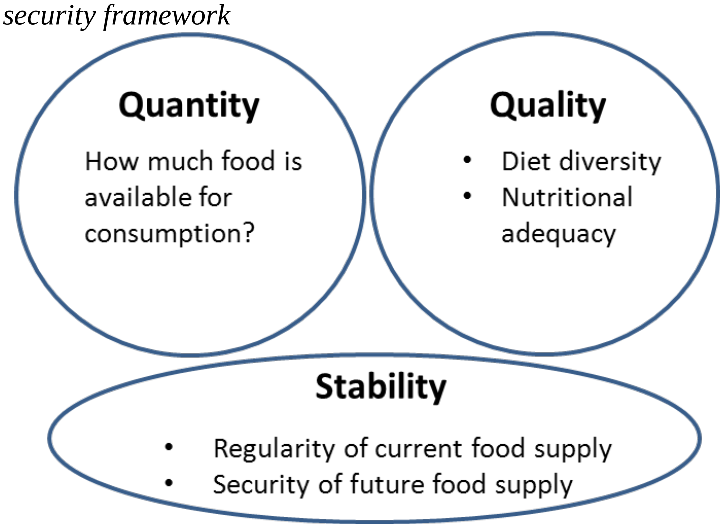


Table 1. *Descriptive statistics of food security indicators over time*

	2001	2004	2008	|t| difference 01/08	|t| difference 04/08
QUANTITY					
Total calories acquired/ ae/ day (median)	2,413.47	2,537.08	2,336.31	0.44	1.93[1]
1=Food energy deficient (light)	0.53	0.50	0.54	1.07	4.39
	(0.50)	(0.50)	(0.50)		
1=Food energy deficient (moderate)	0.61	0.58	0.61	0.12	4.16
	(0.49)	(0.49)	(0.49)		
1=Food energy deficient (intense)	0.68	0.65	0.68	0.17	4.50
	(0.47)	(0.48)	(0.47)		
QUALITY					
Tropical livestock units	1.82	2.58	2.35	4.12	1.25
	(6.90)	(12.87)	(8.42)		
Number of different field crops retained	1.91	2.32	1.89	1.13	20.23
	(1.20)	(1.33)	(1.17)		
1=HH produces eggs or milk	0.31	0.14	0.47	20.34	43.01
	(0.46)	(0.35)	(0.50)		
1=HH produces some vegetables/fruits	0.16	---	0.38	29.08	---
	(0.37)		(0.49)		
STABILITY					
Value of productive assets (ln)	1.82	2.45	2.19	4.69	2.89
	(4.62)	(5.21)	(4.94)		
Number of income sources	1.91	1.85	2.18	19.33	22.45
	(0.84)	(0.84)	(0.85)		
Number of months without any food stocks (of cropping HHs)	---	1.31	1.84	---	12.19
		(2.36)	(2.47)		
1=Maizecass (HH had food in stock at end of survey period)	---	0.60	0.40	---	23.17
		(0.49)	(0.49)		
1=HH participates in transfer network	0.50	0.64	0.83	45.13	24.66
	(0.50)	(0.48)	(0.38)		
Proportion of crop value sold	0.15	0.20	0.29	27.58	18.09
	(0.23)	(0.25)	(0.33)		
No. skilled off-farm workers	0.12	0.15	0.23	14.55	15.26
	0.37	0.40	0.48		
Proportion food expenditure relative to	0.09	0.08	0.12	8.41	10.38

1 Test for difference in mean calories/ae/day

income					
	(0.19)	(0.18)	(0.21)		
Hectares cultivated	1.44	1.56	1.42	0.79	5.3
	(1.34)	(1.47)	(1.63)		
No. observations	6,922	5,419	8,094		

Values are averages with standard deviations in brackets.

Table 2. *Transition matrix of calories/adult equivalent/day for 2004 and 2008*

	Calorie status 08				
Calorie status 04	**1**	**2**	**3**	**4**	**5**
1	0.27	0.26	0.19	0.14	0.14
2	0.25	0.23	0.21	0.17	0.14
3	0.20	0.23	0.23	0.18	0.17
4	0.20	0.18	0.21	0.20	0.21
5	0.11	0.15	0.18	0.26	0.30

Table 3. *Food security indicators by gender of household head in 2008*

	All HHs	**Widowed FHHs**	**|t| Widowed FHHs/ other HHs**
QUANTITY			
Total calories acquired/ ae/ day (median)	2,521.40	2,581.34	4.7
1=Food energy deficient (light)	0.52	0.50	1.53
	(0.50)	(0.50)	
1=Food energy deficient (moderate)	0.59	0.56	2.23
	(0.49)	(0.50)	
1=Food energy deficient (intense)	0.67	0.63	3.1
	(0.47)	(0.48)	
QUALITY			
Tropical livestock units	1.88	1.09	4.15
	(6.92)	(3.64)	
Number of different crops or vegetables/fruits retained	2.72	2.55	3.13
	(1.97)	(1.80)	
1=HH produces eggs or milk	0.47	0.40	4.94
	(0.50)	(0.49)	
1=HH produces some vegetables/fruits	0.38	0.31	5.1
	(0.49)	(0.46)	
STABILITY			
Value of productive assets (ln)	8.31	4.85	19.85
	(6.49)	(6.42)	

Number of income sources	2.18	1.93	4.5
	(0.85)	(0.82)	
Number of months without any food stocks (of cropping HHs)	1.84	2.19	4.97
	(2.47)	(2.62)	
1=Maizecass (HH had food in stock at end of survey period)	0.40	0.44	4.34
	(0.49)	(0.50)	
1=HH participates in transfer network	0.83	0.70	1.83
	(0.38)	(0.46)	
Proportion of crop value sold	0.31	0.24	7.06
	(0.33)	(0.32)	
No. skilled off-farm workers	0.23	0.09	10.31
	(0.48)	(0.32)	
Proportion food expenditure relative to income	0.13	0.15	2.75
	(0.22)	(0.24)	
Land access (ha)	2.65	1.83	3.22
	(9.27)	(4.12)	
Proportion of population	1.00	0.14	
No. observations	8,094	1,095	

The last column refers to the difference in means between widowed FHHs and other HHs.

Table 4. *Food security indicators in 2008, by agro-ecological zone*

	Agro-ecological zones			
	I	**IIa**	**IIb**	**III**
QUANTITY				
Total calories acquired/ ae/ day (median)	2,185.99	2,823.79	1,765.98	2,245.90
1=Food energy deficient (light)	0.57	0.44	0.64	0.56
	(0.50)	(0.50)	0.48	0.50
1=Food energy deficient (moderate)	0.67	0.52	0.70	0.63
	(0.47)	(0.50)	0.46	0.48
1=Food energy deficient (intense)	0.73	0.62	0.74	0.69
	(0.44)	(0.49)	0.44	0.46
QUALITY				
Tropical livestock units	3.30	3.25	1.55	0.55
	(7.44)	(9.64)	(6.30)	(2.24)
Number of different field crops retained	2.25	2.73	1.54	2.99
	(1.57)	(1.86)	(1.10)	(2.13)
1=HH produces eggs or milk	0.54	0.57	0.30	0.40
	(0.50)	(0.49)	(0.46)	(0.49)
1=HH produces some vegetables/fruits	0.29	0.45	0.14	0.37

	(0.45)	(0.50)	(0.35)	(0.48)
STABILITY				
Value of productive assets (ln)	7.93	9.95	3.97	7.71
	(7.01)	(6.22)	(6.22)	(6.21)
Number of income sources	2.11	2.19	2.14	2.18
	(0.84)	(0.86)	(0.76)	(0.85)
Number of months without any food stocks (of cropping HHs)	2.75	2.42	2.36	1.10
	(2.79)	(2.51)	(2.88)	(2.07)
1=Maizecass (HH had food in stock at end of survey period)	0.22	0.21	0.36	0.60
	(0.42)	(0.41)	(0.48)	(0.49)
1=HH participates in transfer network	0.80	0.84	0.78	0.83
	(0.40)	(0.37)	(0.42)	(0.38)
Proportion of crop value sold (out of cropping HHs)	0.18	0.33	0.26	0.31
	(0.28)	(0.32)	(0.38)	(0.34)
No. skilled off-farm workers	0.18	0.27	0.15	0.22
	(0.43)	(0.51)	(0.39)	(0.47)
Proportion food expenditure relative to income	0.16	0.14	0.16	0.12
	(0.26)	(0.21)	(0.25)	(0.21)
Land access (ha)	2.27	2.96	1.46	2.64
	(4.17)	(11.80)	(1.97)	(7.90)
Proportion of population	0.06	0.4	0.08	0.45
No. observations	517	3,108	655	3,798

Figure 3. *Cumulative distribution of calories/adult equivalent/day by agro-ecological zone*

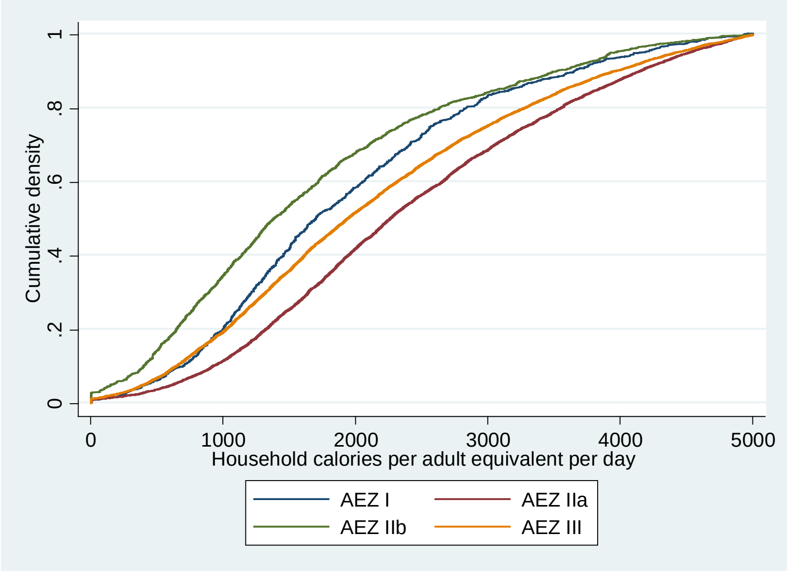


Figure 4. *Radar graph of food security indicators for 2008*

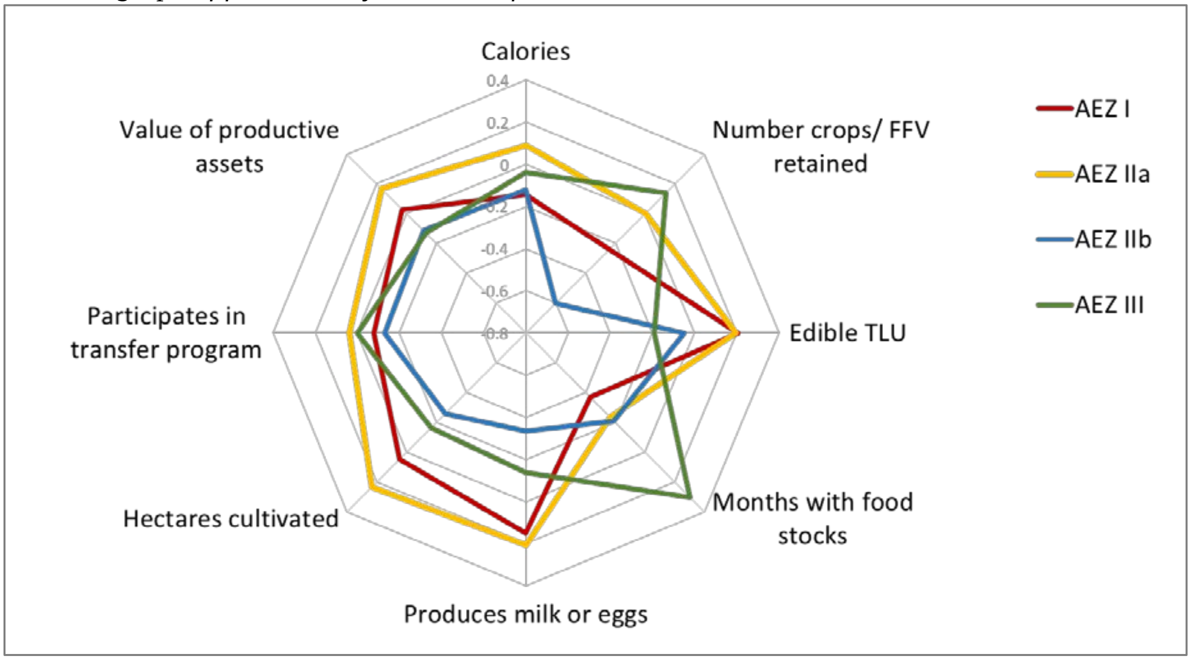
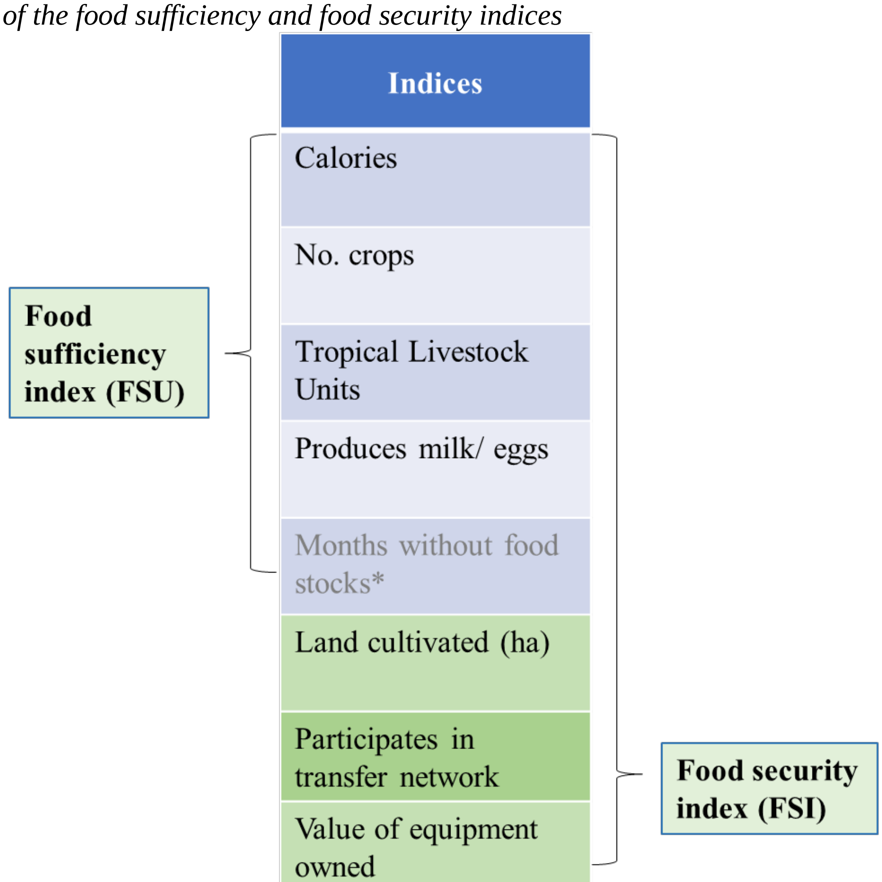


Figure 5. *Elements of the food sufficiency and food security indices*



**Months without food stocks is only included for one analysis that omits 2001.*

Table 5. *Factor loadings for the FSU (top) and FSI (bottom)*

	Factor loadings						
Food sufficiency index (FSU)	**Pooled years**	**2001**	**2004**	**2008**	**I**	**IIa**	**IIb**	**III**
Element								
Calories (ln)	0.64	0.65	0.65	0.55	0.54	0.54	0.53	0.65
No. different crops retained	0.6	0.62	0.56	0.54	0.49	0.54	0.53	0.68
Tropical livestock units	0.33	0.27	0.38	0.56	0.51	0.58	0.55	0.30
Household produces milk or eggs	0.35	0.34	0.35	0.60	0.46	0.59	0.55	0.17
KMO	0.52							
Proportion variation explained	0.35	0.4	0.33	0.39	0.36	0.36	0.38	0.36
Number observations	20,435	6,922	5,419	8,094	1,313	7,967	1,785	9,370

	Factor loadings							
Food security index (FSI)	**Pooled years**	**2001**	**2004**	**2008**	**I**	**IIa**	**IIb**	**III**
Element								
Calories (ln)	0.39	0.41	0.39	0.36	0.36	0.38	0.34	0.41
No. different crops retained	0.34	0.38	0.29	0.33	0.38	0.35	0.44	0.51
Tropical livestock units	0.39	0.40	0.37	0.42	0.40	0.36	0.44	0.37
Household produces milk or eggs	0.31	0.24	0.37	0.34	0.32	0.32	0.29	0.12
Hectares cultivated	0.52	0.53	0.51	0.50	0.50	0.50	0.48	0.55
Participates in transfer network	0.12	0.05	0.18	0.09	0.08	0.19	0.05	0.07
Value of productive assets (ln)	0.45	0.44	0.44	0.46	0.46	0.47	0.43	0.33
KMO	0.65							
Proportion variation explained	0.29	0.29	0.27	0.31	0.30	0.31	0.30	0.28
Number observations	20,435	6,922	5,419	8,094	1,313	7,967	1,785	9,370

Table 6. *Distribution of FSU and FSI in 2008*

			Agro-ecological zones			
	All HHs	**FHH widow**	**I**	**IIa**	**IIb**	**III**
Food sufficiency score	0.00	-0.18	-0.04	0.17	-0.68	0.00
	(1.41)	(1.30)	(1.32)	(1.50)	(1.36)	(1.31)
Food security score	0.00	-0.42	-0.05	0.33	-0.89	-0.13
	(1.51)	(1.35)	(1.44)	(1.67)	(1.38)	(1.31)

Figure 6. *Geographic pattern of average district FSU for 2001, 2004, and 2008*

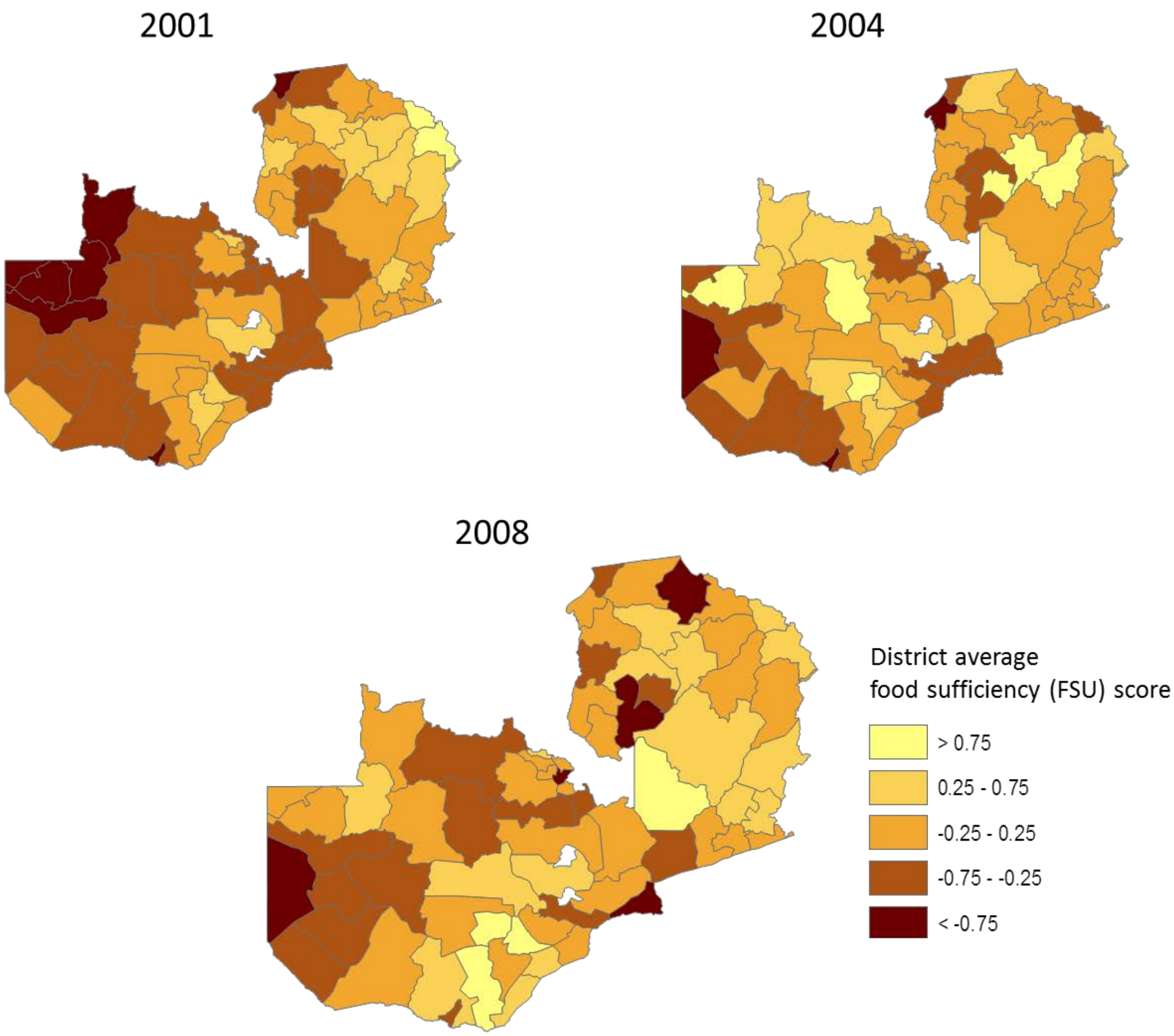


Table 7. *Correlation of food security indicators in 2004 and 2008*

		2008			
		FSI	**FSU**	**Calories (ln)**	**Proportion of calorie requirements met**
2004	**FSI**	0.55***	0.40***	0.19***	0.17***
	FSU	0.35***	0.33***	0.15***	0.13***
	Calories (ln)	0.21***	0.19***	0.16***	0.14***
	Proportion of calorie requirements met*	0.18***	0.14***	0.12***	0.17***

*assuming moderate level of activity

Table 8. *Persistence of food security from 2001 to 2008*

	FSU	FSI
Always food insecure	0.08	0.09
Sometimes	0.54	0.50
Never	0.38	0.41

Here, a household is categorized as "always food insecure" if its FSU or FSI score is in the lowest one-third of the distribution for all three waves of the panel. A household is considered "sometimes" food insecure if its score is in the lowest one-third for one or two years, and never food insecure if its score is never in the lowest one-third.

Table 9. *Proportion of households by FSU and FSI trajectory*

Trajectory	FSU	FSI
+ +	0.22	0.25
+ -	0.14	0.14
- +	0.30	0.29
- -	0.34	0.33

Table 10. *Determinants of FSU and FSI: 2001, 2004, and 2008*

Explanatory variables	(1) FSI	(2) FSU	(3) FSU (2004 and 2008 only)
HH size	0.001	-0.056***	-0.067***
	(0.007)	(0.006)	(0.009)
Dependency ratio	-0.082	0.033	0.064
	(0.082)	(0.070)	(0.109)
Maximum education	0.004	0.001	-0.001
	(0.007)	(0.006)	(0.009)
Maximum women's educ.	0.008	0.004	0.001
	(0.006)	(0.006)	(0.008)
1=FHH widow	-0.199***	-0.081	-0.057
	(0.052)	(0.050)	(0.075)
1=HH head recently died	-0.060	-0.056	-0.081
	(0.073)	(0.066)	(0.079)

Age of HH head	0.042***	0.022**	-0.008
	(0.011)	(0.009)	(0.015)
Age² of HH head	-0.000***	-0.000**	0.000
	0.000	0.000	0.000
1=Owns radio	0.138***	0.087***	0.083**
	(0.027)	(0.024)	(0.034)
1=Transfer network		0.127***	0.091***
		(0.023)	(0.034)
No. skilled workers	0.070*	0.006	-0.038
	(0.037)	(0.032)	(0.044)
1=Woman works off-farm	0.172*	0.079	0.156
	(0.089)	(0.077)	(0.102)
Proportion income on food	-0.528***	-0.341***	-0.734***
	(0.062)	(0.061)	(0.084)
1=Cash crop	0.465***	0.228***	0.291***
	(0.052)	(0.040)	(0.055)
Kgs nitrogen/ ha maize (ln)	0.037***	0.043***	0.036***
	(0.009)	(0.007)	(0.010)
1=Grows maize	0.487***	0.556***	0.536***
	(0.041)	(0.045)	(0.068)
1=Owns water pump	0.608***	0.229*	0.113
	(0.232)	(0.125)	(0.217)
Proportion crop value sold	0.056	-0.704***	-1.031***
	(0.061)	(0.059)	(0.078)
Value of productive assets (ln)		0.023***	0.009*
		(0.003)	(0.005)
Hectares cultivated		0.212***	0.201***
		(0.016)	(0.022)
1=Zero tillage	0.030	0.075**	0.212***
	(0.039)	(0.035)	(0.060)
1=Intercrop	0.209***	0.231***	0.382***
	(0.031)	(0.029)	(0.049)
1=Crop rotation	0.216***	0.212***	0.319***
	(0.028)	(0.026)	(0.037)
mm important rain (ln)	1.342*	1.217*	1.984***
	(0.776)	(0.624)	(0.690)
Important rain²	-0.117*	-0.094*	-0.138**
	(0.063)	(0.051)	(0.056)
Season temperature (°C)	0.570***	0.258	0.274
	(0.202)	(0.199)	(0.297)
Season temperature²	-0.012***	-0.006	-0.007
	(0.004)	(0.004)	(0.006)
1=2004	0.056**	0.047*	

	(0.028)	(0.025)	
1=2008	0.299***	0.175***	-0.252***
	(0.042)	(0.037)	(0.034)
Constant	-12.689***	-7.946**	-9.496**
	(3.407)	(3.097)	(4.080)
Observations	11,869	11,869	7,846

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Figure 7. *Seasonal weather and food sufficiency*

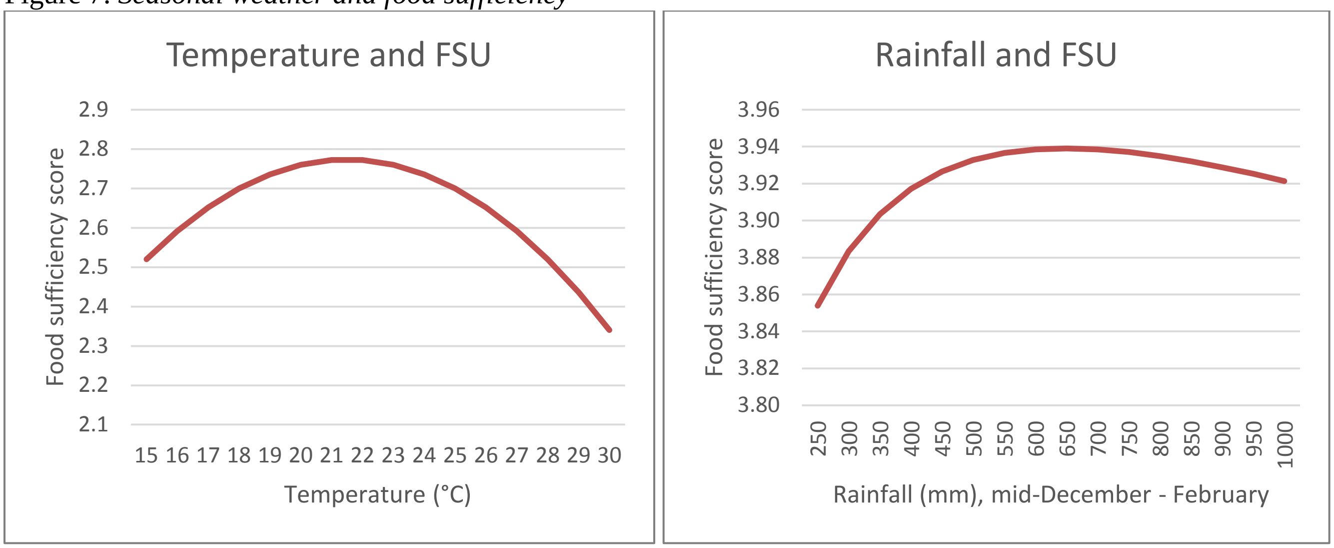


Table 11. *Persistent effect of lagged FSU and FSI: 2001, 2004, and 2008*

Explanatory variables	(1) FSI GMM	(2) FSU GMM	(3) FSU GMM
Lagged FSI	0.248***		0.160***
	(0.031)		(0.033)
Lagged FSU		0.138***	
		(0.031)	
Observations	4,155	4,155	4,155

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 12. *Impact of climate shocks by poverty level: 2001, 2004, and 2008*

Explanatory variables	(1) FSU (Not poor) OLS	(2) FSU (Poor) OLS
Rainfall (mm) (ln)	0.481	1.844***
	(2.938)	(0.645)
Rain²	-0.018	-0.145***
	(0.247)	(0.053)
Deviation from mean rainfall (ln)	0.043	-0.008
	(0.055)	(0.013)
Start of rainy season	-0.083	0.014
	(0.130)	(0.022)
Length of rainy season (days)	-0.734	0.559***
	(1.191)	(0.199)
Season temperature (°C)	-0.774	0.413*
	(1.247)	(0.239)
Season temperature²	0.020	-0.010**
	(0.025)	(0.005)
No. hot dekads	-0.157	0.011
	(0.070)	(0.009)
F-test rainfall (Prob > F)	0.428	
F-test temperature (Prob > F)	0.736	
Observations	1,326	10,732

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 13. *Effect of climate on individual elements of the FSU: 2001, 2004, and 2008*

Explanatory variables	(1) FSU OLS	(2) Calories (ln) OLS	(3) Crops retained OLS	(4) Milk/ eggs Probit	(5) TLU OLS
mm important rain (ln)	1.373**	1.269**	0.832	-0.052	-1.571
	(0.670)	(0.606)	(0.581)	(0.825)	(8.963)
Important rain²	-0.107**	-0.099**	-0.051	-0.004	0.083
	(0.054)	(0.049)	(0.048)	(0.852)	(0.707)
Season temperature (°C)	0.417*	-0.088	0.925***	0.184***	1.068
	(0.221)	(0.237)	(0.223)	(0.001)	(1.047)
Season temperature²	-0.010**	0.000	-0.020***	-0.004***	-0.018
	(0.005)	(0.005)	(0.004)	(0.002)	(0.022)
F-test rainfall (Prob > F)			0.000	0.000	0.443
F-test temperature (Prob > F)		0.000			0.084
Observations: 12,058					

OLS coefficients or average partial effects (column 4) with robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

APPENDIX

Table A1. *Food security indicator definitions*

	Construction	
Indicator	**Panel**	**Non-panel**
QUANTITY		
Total calories acquired	Sum of: calories produced from field crops minus sales; calories from milk and eggs produced minus sales; and calories from staple food purchases, of food items common to all years	Sum of: calories produced from field crops and vegetables/ fruits minus sales; calories from milk and eggs produced minus sales; calories from staple food purchases, of all food items included in SS 2008; calories from food items received as in-kind wages; and calories from food items received as remittances
Calories per adult equivalent per day	Adult equivalents per household calculated from formula of Smith and Subandoro (2007), with males aged 30 – 60 years considered to be 1 adult equivalent	
Food energy deficient (light)	1 if HH meets its calorie requirements (assuming light activity level), 0 otherwise	1 if HH meets its calorie requirements (using non-panel calculation of calories and assuming light activity level), 0 otherwise
Food energy deficient (moderate)	1 if HH meets its calorie requirements (assuming moderate activity level), 0 otherwise	1 if HH meets its calorie requirements (using non-panel calculation of calories and assuming moderate activity level), 0 otherwise
Food energy deficient (intense)	1 if HH meets its calorie requirements (assuming intense activity level), 0 otherwise	1 if HH meets its calorie requirements (using non-panel calculation of calories and assuming intense activity level), 0 otherwise
QUALITY		
Tropical Livestock Units (TLU)	Units of panel livestock owned at start of the reporting period (12 months prior to interview)	Units of non-panel livestock owned at start of the reporting period, excluding oxen
Number of different field crops or vegetables retained	Number of panel field crops retained by HH after sales	Number of non-panel field crops and vegetables/fruits retained by HH after sales
Household produces eggs or milk	1 if HH produces eggs or milk, 0 otherwise	
Household produces some vegetables/fruits	1 if HH produces vegetables or fruits, 0 otherwise (only available for 2001 and 2008)	
STABILITY		
Number of months without any food stocks	(not used in panel analyses)	No. months since the HH last reported running out of a food stock
HH had maize or cassava in stock at end	1 if HH had either maize or mature cassava in stock/ in the field at end	

of reporting period	of reporting period, 0 otherwise	
Value of productive assets	Value of panel equipment owned at start of the reporting period (ploughs, harrows, and ox-carts)	Value of all non-panel equipment, machinery, and oxen owned at start of reporting period
Number of income sources	Number of income sources from the following groups: on-farm income, agricultural wage income, non-agricultural wage or salary income, business income, and remittances	
Transfer network	1 if HH gave *or* received any cash or commodities (remittances or gifts), 0 otherwise	
Proportion of crop value sold	Proportion of value of crops produced that were sold	Proportion of value of non-panel crops produced that were sold
No. skilled off-farm workers	Number of individuals in HH that engage in non-agricultural/ skilled income generating activities	
Proportion food expenditure	Proportion of HH net income (panel) spent of food purchases	Proportion of HH net income (non-panel) spent of food purchases
Hectares cultivated	Ha cultivated	
Land access (ha)		Landholding size plus land rented or borrowed in

Table A2. *Rainfall and temperature variable definitions*

Variable	**Construction**
Season rainfall (mm)	Total precipitation recorded from November through March
Deviation from long-term mean	Absolute deviation from average growing season rainfall (1990/91 – 2009/10)
Length of growing season (days)	Number of days from first dekad with > 20 mm rainfall to last dekad with >20 mm rainfall
Rain start	Number of dekads after November 1 until > 20 mm rainfall within a dekad
Rain stress	Number of 20-day periods in growing season with < 40 mm rainfall
Rainfall (mm)	Total precipitation from mid-December through February (the critical growth period for maize)
Average temperature (Celsius)	Average dekadal temperature over the growing season
No. hot dekads	Number of dekads during growing season with average temperature over 25°C

Note: Missing observations were imputed using an average of the observations of nearby meteorological stations of similar altitude. In total, 13.75% (245/1,782) of dekadal rainfall observations were imputed in this manner, and 34.23% (616/1,782) of temperature observations were imputed. Though the rate of missing temperature observations is high, it was determined that because temperature is less localized than rainfall, imputation would likely produce suitable temperature estimates.