Estimating Multidimensional Development Resilience

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Abstract: Resilience measurement has received substantial attention over the past decade or so. Existing measures, however, relate resilience to a single well-being indicator. This may be problematic in contexts where households face deprivations in multiple dimensions. We explore how sensitive estimates of household-level resilience are to the specific well-being indicator used and show that measures are only weakly correlated across different, reasonable indicators based on expenditure-based poverty, dietary diversity, and livestock asset holdings. We then introduce a multidimensional resilience measure, integrating the probabilistic moment-based resilience measurement approach of Cissé and Barrett (2018) with the multidimensional poverty measurement method of Alkire and Foster (2011). Applying the new method to household panel data, we show that univariate and multidimensional resilience measures can yield varied inferences on the ranking of households as well as potential impact of development interventions.

Keywords: assets, consumption expenditures, dietary diversity, Ethiopia, livestock, nutrition, poverty

1 Introduction

Over the past decade or two, governments, development organizations and donors have invested heavily in interventions that aim to improve the resilience of households or communities to shocks and stressors. While early empirical work in this area contained a multitude of definitions and measures of resilience, more recent work has organized these along three lines: (1) resilience as the capacity to withstand exposure to negative stressors or shocks; (2) resilience as return to equilibrium after a shock; and (3) resilience as a normative condition, the sustained capacity of an entity to avoid falling below some normative threshold standard of living (Barrett et al. 2021).

While this improvement in understanding of the concept of resilience is welcome, two significant methodological issues have arisen. First, the manner in which resilience is operationalized affects the assessment of the extent to which households are seen to be resilient; further, these difference measures are often only weakly correlated (Upton, Constenla-Villoslada, and Barrett 2022). Second, assessment of resilience may vary depending on the well-being indicator(s) chosen and it is not obvious that any one indicator is superior to another. Because a household's productive asset holdings determine its stochastic conditional income distribution over time, some studies define development resilience with respect to productive asset holdings, measured in terms of livestock or an asset index (Cissé and Barrett 2018; Phadera et al. 2019; Scognamillo, Song, and Ignaciuk 2023; Yao et al. 2023). Because resilience measurement has commonly been tied to food security interventions, others anchor resilience measures to various food security or nutritional indicators (Upton, Cissé, and Barrett 2016; Knippenberg, Jensen, and Constas 2019; Vaitla et al. 2020; Upton, Constenla-Villoslada, and Barrett 2022). Still others tie resilience measures directly to consumption expenditures and official poverty lines (Abay et al. 2022; Premand and Stoeffler 2022; Upton, Constenla-Villoslada, and Barrett 2022).

The choice of measurement method and indicator(s) matters because resilience measures constructed based on different indicators may not generate similar orderings of households. It also affects evaluations of the effectiveness of interventions intended to improve development resilience. Some interventions may be more effective in improving some dimensions of resilience than others. For example, Phadera et al. (2019) find that although a livestock transfer program in rural Zambia significantly improved short-term welfare outcomes, many households who received the treatment have a low likelihood of escaping expenditure-based poverty sustainably. Similarly, Sabates-Wheeler et al. (2021) concluded that while Ethiopia's Productive Safety Net Program has been successful in smoothing consumption shortfalls, it underperformed in building household assets and hence ultimate graduation out of poverty. Abay et al. (2022) likewise show that building household resilience may require significant transfers and continuous participation in safety net programs as well as complementary income generating programs.

In this paper, we develop a novel method to address this second methodological issue. Specifically, we develop a family of multidimensional resilience measures. A feature of our measures is that they allow the researcher to make explicit the weight they give to different welfare indicators, and to assess how sensitive their measure of resilience is to variations in these weights. To do so, we draw on two existing methods: (1) the moment-based approach developed by Cissé and Barrett (2018), wherein one estimates the household-level conditional mean and variance of a relevant well-being indicator and uses the resulting estimates and an appropriate distributional assumption to estimate the conditional probability of attaining at least some minimal threshold value of that indicator; and (2) the literature on multidimensional poverty measurement (Alkire and Foster 2011; Alkire and Santos 2014).

We apply this novel method to five rounds of household panel data collected in rural Ethiopia. We show that even using the same data and resilience estimation method, univariate household resilience indicators based on different well-being indicators are only weakly correlated. When we combine multiple indicators into a multidimensional resilience indicator, the household-level rank correlation coefficients among different resilience estimators become appreciably greater, implying that inferences for the purposes of targeting or impact evaluation are more likely robust to reasonable variation in the well-being indicators employed to assess resilience.

2 Data

2.1 Data Source and Sample Description

We use five rounds of household-level panel survey data from rural Ethiopia fielded in the Highland regions of Amhara, Oromia, SNNP and Tigray. They were collected biennially in 2006, 2008, 2010, 2012 and 2014 as part of an ongoing evaluation of Ethiopia's Productive Safety Net Programme (PSNP). The PSNP was introduced in 2005 to respond to chronic and recurring food insecurity by providing regular transfers to food insecure households while also building community assets through labor-intensive Public Works (PWs) (Government of the Federal Democratic Republic of Ethiopia

2004, 2010). Targeting used a mix of geographic and community-based targeting. The PSNP targeted historically food insecure woredas (districts) while the household level selection follows a series of criteria, including food insecurity, asset holdings (e.g., land, oxen) and income sources. The PSNP involves both public work (PW), through which about 80 percent of the PSNP beneficiaries participate in labor-intensive PW projects and a Direct Support (DS) component covering about 20 beneficiaries who lack labor needed for the PW and hence received unconditional transfers (Berhane and Gardebroek 2011; Coll-Black et al. 2011; Berhane et al. 2014; Sabates-Wheeler et al. 2021). In addition to receiving transfers, some PSNP received technical support and agricultural input services along with access to credit services through the Household Asset Building Programme (HABP) (Berhane et al. 2014).

Within these regions, a sample of food-insecure woredas was selected in proportion to the overall number of chronically food-insecure woredas within that region and relative to the number of chronically food-insecure woredas in all four regions. Within each region, woredas were selected with probability proportional to size (PPS) based on the estimated chronically food insecure population; in total, 68 out of 190 woredas were selected. Within woredas, enumeration areas (EAs) where the PSNP was active were identified. Restricting the sample to EAs where the PSNP was operating in 2006, two enumeration areas per woreda were chosen using PPS sampling for Amhara, Oromia, and SNNPR and three in Tigray. Using separate lists of PSNP beneficiary and non-beneficiary households, 15 PSNP beneficiary households and 10 non-beneficiary households were selected for the sample using simple random sampling (Gilligan, Hoddinott, and Taffesse 2009; Berhane et al. 2014). This yielded a sample of approximately 3,700 households. For the purposes of this paper, households are included if: (a) they were surveyed in 2006; (b) they were surveyed at least in two consecutive rounds; and (c) have non-missing values for the outcome variables we consider (consumption expenditure, Household Dietary Diversity Score, and Tropical Livestock Unit).

Table 1 provides summary statistics of our study sample: (1) pooled from 2006 to 2014, and (2) 2006 only. The distribution of the observable characteristics are comparable across the pooled sample and the baseline sample, except for some outcomes such as education and access to electricity which are expected to increase across rounds following the economic grow the country experienced in that decade. [1] The pooled sample shows that 76% of households are male-headed, farming is the primary occupation for about 84% of households and mean household size is 5.4 members. Table 1 shows

1. In Table A1 in the Appendix we report disaggregate statistics, across waves.

that 46 percent of our year-households observations were PSNP beneficiaries. Table 1 shows that 36 percent of households in our sample benefited from the public work (PW) of the PSNP while another 9 percent received direct support (DS). On average, PSNP beneficiaries received 280 Birr per household member.

In this study, we employ three indicators to capture multiple dimensions of well-being and living standards. One is consumption expenditure, a widely used measure of well-being and living standards. Our second measure complements the usual consumption/income-based metrics using a measure that captures access to healthy diets, household dietary diversity (HDDS). HDDS is correlated with both household caloric acquisition (Hoddinott and Yohannes 2002) as well as access to micronutrients (Leroy et al. 2015). The third measure is livestock ownership. We chose livestock for two reasons. First, in Ethiopia livestock production and livestock assets are an important livelihood source. Rural households rely on livestock for generating income and for conducting their farming. Second, livestock sales serve as major insurance against shocks in many parts of rural Ethiopia (Dercon and Christiaensen 2011). Many rural households lack formal source of insurance and hence livestock is the most important liquid asset in rural Ethiopia (Dercon and Christiaensen 2011). This implies that households may face an important trade-off between satisfying their consumption and maintaining their livestock assets. If households are satisfying their minimum consumption by depleting their livestock assets, they may not be sustainably resilient. Thus, livestock captures households' risk bearing capacity.

The last three rows in Table 1 report mean values for these indicators. We express all monetary values in Table 1 in 2014 constant prices.[2] Households spent 6,423 Ethiopian Birr per adult-equivalent per year.[3] Mean Household Dietary Diversity Score (HDDS) in our sample is low, 3.80 food groups. On average, households own 3.87 Tropical Livestock Unit (TLU).

2.2 Selecting Well-being Indicators and Normative Thresholds

We follow the literature conceptualizing resilience as a normative condition. This requires computing resilience as an individual's probability to achieve some minimal threshold which in turn requires us to identify a normative threshold for each indicator.

Defining normative threshold for consumption and poverty-based measures of well-being is straight-

2. This conversion was applied for all welfare outcomes, PSNP transfers, value of productive assets, value of livestock as well as national poverty line.

3. Birr is the Ethiopian currency and at the latest survey round (2014) 1 USD was equivalent to 17 Ethiopian Birr.

Table 1: Summary Statistics

	Pooled (2006-2014)			2006 Only		
	# of observations	Mean	SD	# of observations	Mean	SD
Male headed household	14681	0.76	0.42	3028	0.79	0.41
Age of household head	14681	47.52	15.01	3028	45.05	15.25
Household head no education	14681	0.68	0.47	3028	0.77	0.42
Household head married	14681	0.73	0.44	3028	0.73	0.44
Household size	14681	5.38	2.21	3028	5.13	2.15
Main occupation farming	14681	0.84	0.36	3028	0.85	0.36
Landholding per aeu (hectares)	14672	0.32	0.38	3028	0.34	0.34
Livestock asset value	14681	12719.24	16481.40	3028	12307.10	14457.05
Production asset value per AEU	14278	189.15	758.78	2953	158.86	516.02
Household has electricity access	14681	0.14	0.34	3028	0.04	0.20
Distance to the nearest town(km)	14681	14.55	10.69	3028	14.56	10.78
Average annual rainfall this year (mm)	14681	972.88	293.10	3028	1025.29	275.78
PSNP beneficiaries	14681	0.46	0.50	3028	0.52	0.50
PSNP direct support (DS) beneficiaries	14681	0.09	0.29	3028	0.10	0.30
PSNP public work (PW) beneficiaries	14681	0.36	0.48	3028	0.42	0.49
HABP beneficiaries	14681	0.44	0.50	3028	0.28	0.45
PSNP and HABP beneficiaries	14681	0.22	0.41	3028	0.16	0.37
PSNP benefit amount per capita (birr)*	6716	279.96	277.78	1570	258.06	239.16
Annual real consumption per aeu	14681	6423.07	7000.34	3028	4774.62	4132.58
Household Dietary Diversity Score (HDDS)	14681	3.80	1.78	3028	3.37	1.49
Tropical Livestock Unit (TLU)	14681	3.87	3.32	3028	3.87	3.27

*Including only PSNP beneficiaries. Non-beneficiaries have zero-value.
All monetary variables are in Ethiopian birr, 2014 constant price. AEU stands for adult equivalent units.

forward because we can assess these relative to Ethiopia's national poverty line. The poverty line for Ethiopia is estimated as the cost of food to satisfy the minimum daily caloric requirement as well as basic non-food items. As we are expressing all monetary values in in 2014 constant prices, we also need to apply the same procedure for the national poverty line. The national poverty line for Ethiopia was 3781 Birr in 2011 which is equivalent to 4930.4 in 2014 prices (The World Bank 2015).

Although the minimum threshold for household dietary diversity is not commonly defined, FAO and FHI360 (2016) offers some guidance using women's dietary diversity outcomes. FAO and FHI360 (2016) sets that five or more food groups to be the minimum threshold for women's diet quality (micronutrient adequacy). We follow this benchmark and apply it to our sample.[4] As shown in Figure 2 HDDS broadly follows a normal distribution.

We build on two empirical and contextual patterns to define the minimum threshold for livestock holdings. First, rural households in Ethiopia and many other African countries use two oxen for ploughing land. Similarly, to maintain herd size, households need some minimum number of cows or heifers.[5] Consistent with this average livestock holding and considering the case of rural households in Zimbabwe, Hoddinott (2006) shows that households with one or two oxen(cows) were much

4. It should be noted, however, that the food groups used to construct HDDS are not identical to the groups used to construct the Minimum Dietary Diversity for Women (MDD-W).
5. The average TLU of Ethiopian households in 2012 was 2.4, which supports this hypothesis (FAO 2024)

less likely to sell than households with more than two of these animals. Following these contexts, Hoddinott (2006) argue that two oxen or two cows provide a minima ”threshold” for successful asset or consumption smoothing. In a slightly different context, Balboni et al. (2022) identifies a similar level and value of livestock asset ownership threshold, above which households accumulate assets and grow out of poverty.

Second, we empirically evaluate the relationship between livestock ownership and other measures of well-being to gauge the level of livestock that is positively associated with higher welfare. Figure 1 shows a nonlinear relationship between consumption and livestock assets (measured in Tropical Livestock Units, TLU): consumption is positively associated with livestock ownership but only after a minimum of two TLU. This confirms the contextual evidence that two oxen (or two cows) are needed to maintain minimum herd size. We note that our sample comes from the highland regions in Ethiopia, where households rely on mixed farming practices.[6] We replicate a few key analyses under different TLU thresholds to test robustness of our results.

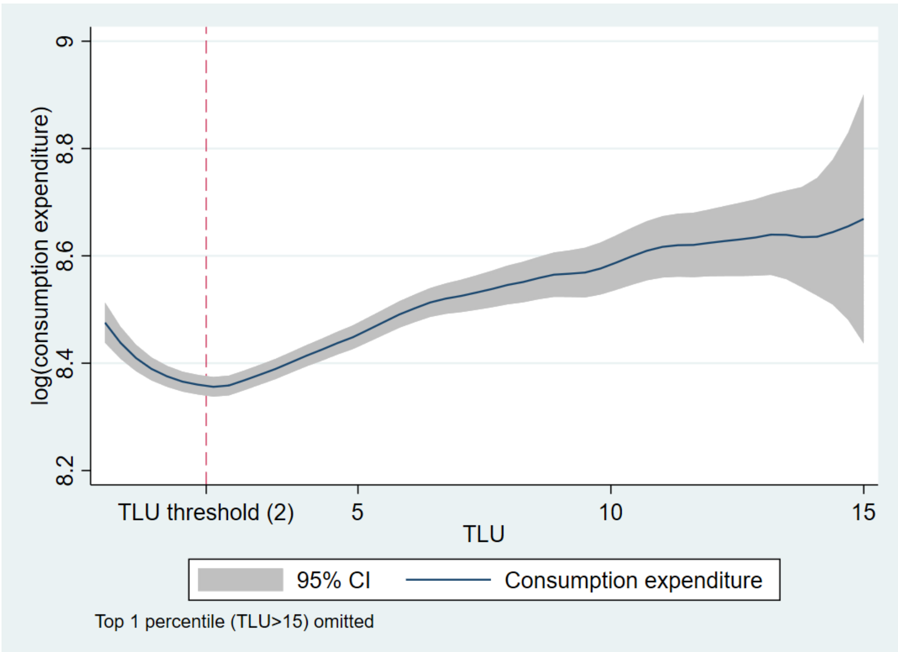

Figure 1: Distribution of Consumption Expenditure over TLU

Table 2 shows the temporal dynamics of our well-being indicators and welfare outcomes. The first column provides poverty dynamics using consumption expenditure and national poverty line. As expected, poverty rates are much higher than national averages because our sample comes from among

6. Livestock ownership in pastoral communities and lowlands of Ethiopia are larger than the highland regions. These regions rely heavily on livestock production as source of income and livelihood. Thus, as shown by Lybbert et al. (2004) or Cissé and Barrett (2018) the threshold for these communities is likely to be higher than two TLU. However, only 2.6% of our observations reside in localities where pastoralism is the main source of income.

Table 2: Welfare dynamics

	Consumption expenditure Below poverty line	HDDS Below 5	TLU Below 2
	(1)	(2)	(3)
2006	0.80	0.80	0.28
2008	0.82	0.72	0.28
2010	0.62	0.68	0.27
2012	0.59	0.64	0.30
2014	0.45	0.59	0.32
Total	0.66	0.69	0.29

Source: Authors' computation based on household surveys in 2006, 2008, 2010, 2012, and 2014.

the poorest areas of the country. The second column in Table 2 shows the share of households consuming below the minimum dietary diversity score. The third column reports the share of households owning below the minimum (2) TLU. All three indicators show improvement over time.

All three outcomes are positively correlated with each other, but the magnitude of these correlations differs. Household consumption expenditure and the HDDS are only modestly correlated (0.33), the HDDS and the TLU are weakly correlated (0.17), and household consumption and TLU are very weakly correlated (0.09). These weak correlation patterns are consistent with the notion that these three outcomes capture slightly different dimensions of wellbeing.

Figure 2 shows the distribution of consumption expenditure, HDDS and TLU. The log of expenditure is normally distributed. The HDDS is not sufficiently continuous outcome, but its overall shape is similar to normal distribution centered around its mean (3.8). The inverse hyperbolic sine of the TLU is approximately normal, except having a large share of households near 0.

3 Constructing Resilience Measures

3.1 Univariate Resilience Measures

We begin by constructing a probabilistic moment-based approach of households' resilience for three outcomes (Cissé and Barrett 2018). Estimation involves three steps. First, we estimate expected outcomes (consumption expenditure, household dietary diversity score and tropical livestock units) of households i in district d in year t (W_{idt}) as a function of lagged well-being (W_{dit-1}), lagged outcomes squared (W^2_{dit-1}), a vector of household and community characteristics (X_{it}) including household

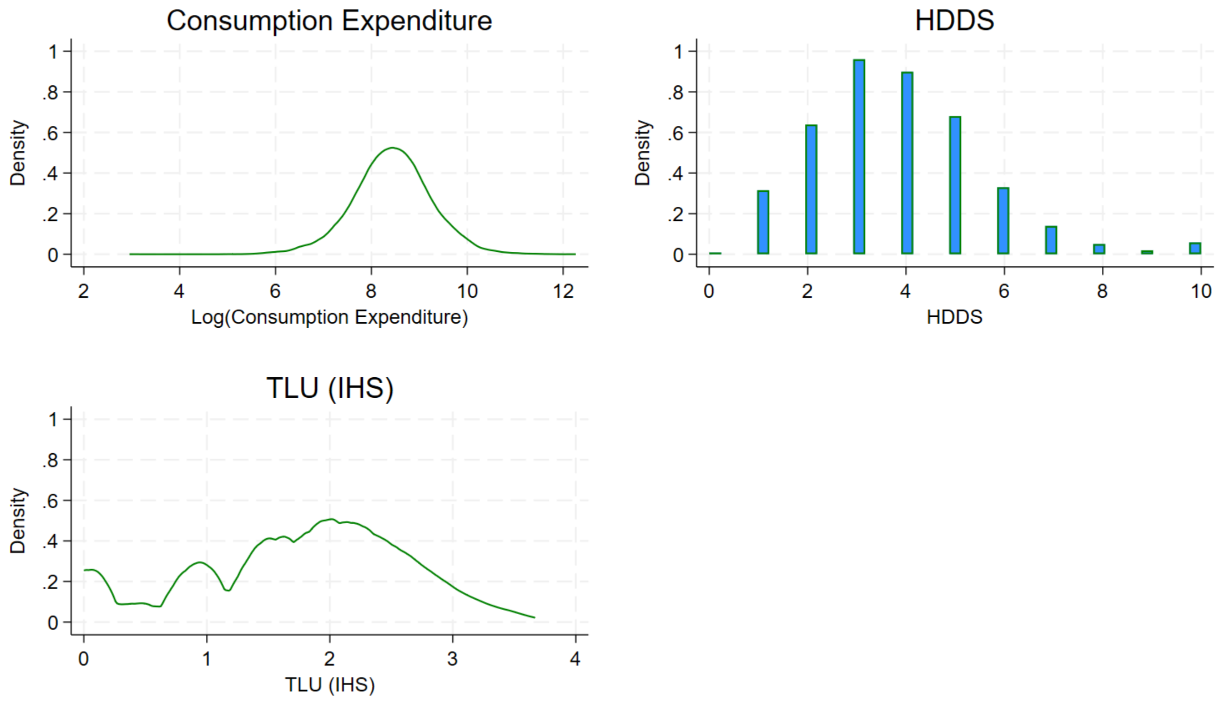

Figure 2: Distribution of Welfare Outcomes

demographics (age, gender, etc.), socio-economic status (education, farm size, etc.), PSNP/HABP status (participation and benefit received) and rainfall (average and deviation from 30-year average). We control for year and locality(district) fixed effects (γ_t and μ_d respectively.)

$$W_{idt} = \alpha_0 + \alpha_1 W_{idt-1} + \alpha_2 W^2_{idt-1} + \alpha_X X_{it} + \gamma_t + \mu_d + \mu_{idt} \quad (1)$$

Next, we model variation in the dispersion of welfare (the second moment). We use the same specification as that shown in equation (1) to characterize the variance of household well-being. Taking the residuals from the regression estimation of equation (1) and squaring them provides an estimate of the variance of household welfare ($\sigma^2_{idt} = E[\mu^2_{idt}]$), given that $E[\mu_{idt}] = 0$, which we characterize using the following empirical specification:

$$\sigma^2_{idt} = \hat{u}_{idt} = \beta_0 + \beta_1 W_{idt-1} + \beta_2 W^2_{idt-1} + \beta_X X_{it} + \delta_t + \lambda_d + \epsilon_{idt} \quad (2)$$

where we use the predicted value $\hat{\sigma}^2_{idt}$ as the conditional variance of household well-being.[7]

Finally, we estimate households' resilience (τ_{idt}) as the conditional probability that a households' outcome in each period lies above a normative threshold $\underline{W}$:

$$\tau_{idt} = Pr(W_{it} \geq \underline{W}|X_{it}, W_{it-1}) = 1 - F_{W_{it}}(\underline{W}; \hat{W}_{idt}, \hat{\sigma}^2_{idt}) \tag{3}$$

where $F_{W_{it}}(\cdot)$ is household-time-specific conditional cumulative density function (CDF) of well-being. Assuming each outcome follows a normal distribution (see Figure 2), we estimate $F_{W_{it}}(\underline{W}|\cdot) = \Phi(Z_{idt}|\cdot)$ where $\Phi(\cdot)$ is the CDF of the standard normal distribution and $Z_{idt} = \frac{\underline{W} - \hat{W}_{idt}}{\sqrt{\hat{\sigma}^2_{idt}}}$ is the normalized Z-score. As described above, we use the following thresholds: for consumption expenditure we use the national poverty line; for Household Dietary Diversity Score (HDDS) we use 5 food groups; and for livestock, we use 2 TLU.

We assess the robustness of the assumption used in the third step by replacing the normal distribution with a Gamma distribution. Specifically, we calibrate the Gamma distribution parameters using the method of moments such that $\left(\alpha = \frac{\hat{W}^2_{idt}}{\hat{\sigma}^2_{idt}}, \beta = \frac{\hat{\sigma}^2_{idt}}{\hat{W}_{idt}}\right)$, and construct the CDF $F_{W_{it}}(\cdot)$ with these parameters.

3.2 Multivariate Resilience Measures

Next, we construct multivariate resilience measures. Analogous to multidimensional poverty measurement, computing and aggregating different dimensions of resilience requires choice over how to aggregate the univariate measures of resilience. We follow Alkire and Foster (2011) by offering a family of multivariate measures. We present three approaches.

First, we construct weighted average resilience measures of each possible combination of the M univariate measures used. In our case, one can use $M = 2$ for any pair of consumption expenditures, HDDS, and TLU, or $M = 3$ for all three together. (Note that one could use weights specific to each univariate measure, w_m, if one dimension was assumed to be more important than others):

$$\tau_{ave,idt} = [\sum_{m=1}^{M} w_m {\tau_{idt}}^m]/M \tag{4}$$

We use equal weights, so that $w_m = w, \forall m$. This equally weighted average measure is intuitive,

7. Table A2 in the Appendix reports the regression outcomes from the equation (1) and (2) from the three welfare outcomes: log of consumption expenditure, HDDS and TLU (IHS)

treating a probability point change in each measure as equally important.

Second, we construct *adjusted headcount ratio* of resilience following the multidimensional poverty literature (Alkire and Foster 2011) as follows:

$$M_0(y,k) = H(y,k) \times A(y,k) \tag{5}$$

$y = (y_1, ..., y_d)$ is a vector of d univariate resilience measures and k is the number of univariate resilience measures below certain cut-off which determines households as “non-resilient. We use 0.5 as a cut-off for each univariate resilience measure and applied equal weights to them, but it is researchers’ choice to choose the cut-off point depending on the context. For instance, $k = 1$ implies that a household is defined as non-resilient if *any* of the univariate resilience in y is below cut-off, and $k = d$ implies that a household is defined as non-resilient only if *all* of the univariate resilience measures are below cut-off. $H(y,k)$ is the share of non-resilient households (or *unadjusted* headcount ratio), and $A(y,k)$ is the average number of univariate resilience measures below cut-off among non-resilient households (or intensity of non-resilience).

Third, we construct bivariate and trivariate resilience measures using the concepts of union and intersection. We start with two well-being indicators (consumption expenditure & diet, expenditure & livestock, and diet & livestock), assuming they follow bivariate normal distribution with some correlation coefficient ρ. We use the Pearson’s correlation coefficient $\hat{\rho}$ between two welfare outcomes in the data as our estimate of ρ. For each pair of the outcomes, we construct two different types of bivariate resilience measures as the equation (6) and (7) below.

$$\begin{aligned} \tau_{uni,it} &= Pr(W_{1it} \geq \underline{W_1} \text{ or } W_{2it} \geq \underline{W_2} | \cdot) \\ &= 1 - F_{W_{1it},W_{2it}}(\underline{W_1}, \underline{W_2}; \hat{W}_{1idt}, \hat{\sigma}^2_{1idt}, \hat{W}_{2idt}, \hat{\sigma}^2_{2idt}, \hat{\rho}_{12}) \end{aligned} \tag{6}$$

$$\begin{aligned} \tau_{int,it} &= Pr(W_{1it} \geq \underline{W_1}, W_{2it} \geq \underline{W_2} | \cdot) \\ &= 1 - F_{W_{1it}}(\underline{W_1}; \hat{W}_{1idt}, \hat{\sigma}^2_{1idt}) - F_{W_{2it}}(\underline{W_2}; \hat{W}_{2idt}, \hat{\sigma}^2_{2idt}) \\ &+ F_{W_{1it},W_{2it}}(\underline{W_1}, \underline{W_2}; \hat{W}_{1idt}, \hat{\sigma}^2_{1idt}, \hat{W}_{2idt}, \hat{\sigma}^2_{2idt}, \hat{\rho}_{12}) \end{aligned} \tag{7}$$

$\tau_{uni,idt}$ in equation (6) captures the conditional probability that either welfare outcome is above the normative threshold, while $\tau_{int,idt}$ in the equation (7) captures the conditional probability that both welfare outcomes are above their thresholds. Similarly, we estimate the trivariate resilience measures using equation (8) and (9).

$$\begin{aligned}\tau_{uni,it} &= Pr(W_{1it} \geq \underline{W_1} \text{ or } W_{2it} \geq \underline{W_2} \text{ or } W_{3it} \geq \underline{W_3}|\cdot) \\ &= 1 - F_{W_{1it},W_{2it},W_{3it}}(\underline{W_1}, \underline{W_2}, \underline{W_3}; \hat{W}_{1idt}, \hat{\sigma}^2_{1idt}, \hat{W}_{2idt}, \hat{\sigma}^2_{2idt}, \hat{W}_{3idt}, \hat{\sigma}^2_{3idt}, \hat{\rho}_{12}, \hat{\rho}_{13}, \hat{\rho}_{23})\end{aligned} \tag{8}$$

$$\begin{aligned}\tau_{int,it} &= Pr(W_{1it} \geq \underline{W_1}, W_{2it} \geq \underline{W_2}, W_{3it} \geq \underline{W_3}|\cdot) \\ &= 1 - F_{W_{1it}}(\underline{W_1}; \hat{W}_{1idt}, \hat{\sigma}^2_{1idt}) - F_{W_{2it}}(\underline{W_2}; \hat{W}_{2idt}, \hat{\sigma}^2_{2idt}) - F_{W_{3it}}(\underline{W_3}; \hat{W}_{3idt}, \hat{\sigma}^2_{3idt}) \\ &+ F_{W_{1it},W_{2it}}(\underline{W_1}, \underline{W_2}; \cdot) + F_{W_{1it},W_{3it}}(\underline{W_1}, \underline{W_3}; \cdot) + F_{W_{2it},W_{3it}}(\underline{W_2}, \underline{W_3}; \cdot) \\ &- F_{W_{1it},W_{2it},W_{3it}}(\underline{W_1}, \underline{W_2}, \underline{W_3}; \hat{W}_{1idt}, \hat{\sigma}^2_{1idt}, \hat{W}_{2idt}, \hat{\sigma}^2_{2idt}, \hat{W}_{3idt}, \hat{\sigma}^2_{3idt}, \hat{\rho}_{12}, \hat{\rho}_{13}, \hat{\rho}_{23})\end{aligned} \tag{9}$$

One can understand the multidimensional measure as offering the analyst different options for weighting among well-being measures that are imperfectly correlated. The union and intersection measures are necessarily limiting constructs. Adopting the intersection measures imposes the strict normative standard that a household is only considered resilient if it meets the resilience criterion in each dimension. By contrast, the union measure is a relatively permissive measure, wherein a household is declared resilient if it appears resilient in just a single dimension. Under these logical frameworks,no tradeoffs are permitted across indicators, so that considerably higher dietary resilience, for example, cannot compensate for modestly lower asset resilience. Indeed, as the number of imperfectly correlated measures grows, the intersection measure weakly falls while the union measure weakly increases. The rate of change in each of those varies inversely with the correlation among the measures. As a result, the union and intersection measures somewhat mechanically generate skewed distributions when one combines multiple weakly correlated measures. The intersection and union measures are informative. But we favor the average measure,$\tau_{ave,idt}$, as the best summary measure because it does not vary mechanically based on the multivariate correlation structure and the number of measures one includes and it can in principle allow the analyst to weight different indicators to permit tradeoffs in different dimensions.

4 Estimation Results

4.1 Univariate Resilience Estimates

Figure 3 shows the distribution of three univariate resilience measures. The first is constructed using consumption expenditure; this is a measure of "resilience in expenditure", or "expenditure resilience". The second measure builds on dietary quality and hence we label it as "dietary resilience" (Zaharia et al. 2021). The third captures households' capacity to maintain minimum productive assets and hence we interpret it as "resilience in livestock holding", or "livestock resilience". [8] Figure 4 shows spatial distribution of 2008-2014 average univariate resilience measures, aggregated at district (woreda) level. Consistent with the weak correlation across the welfare measures, we do not observe significant spatial overlap exhibiting high (low) level of resilience across the three measures. For example, some areas showing high level of consumption-based resilience are characterized by low level of dietary resilience. Again, this reinforces the appeal for multidimensional resilience that captures different dimensions of capacity and resilience. [9] We find the regions with low dietary resilience tend to have higher livestock and consumption expenditure resilience.

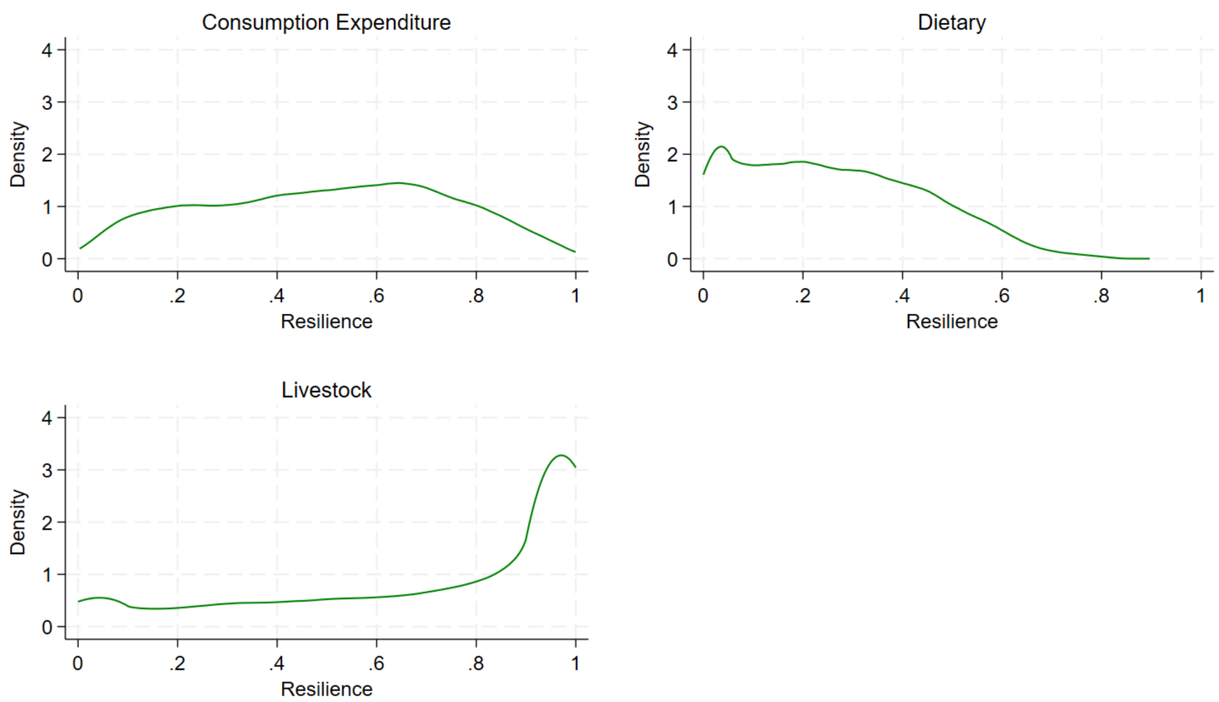

Figure 3: Distribution of Univariate Resilience

8. Figure A1 replicates livestock resilience distributions under different TLU thresholds.
9. Figure A2, A3 and A4 show temporal changes in each univariate resilience measures.

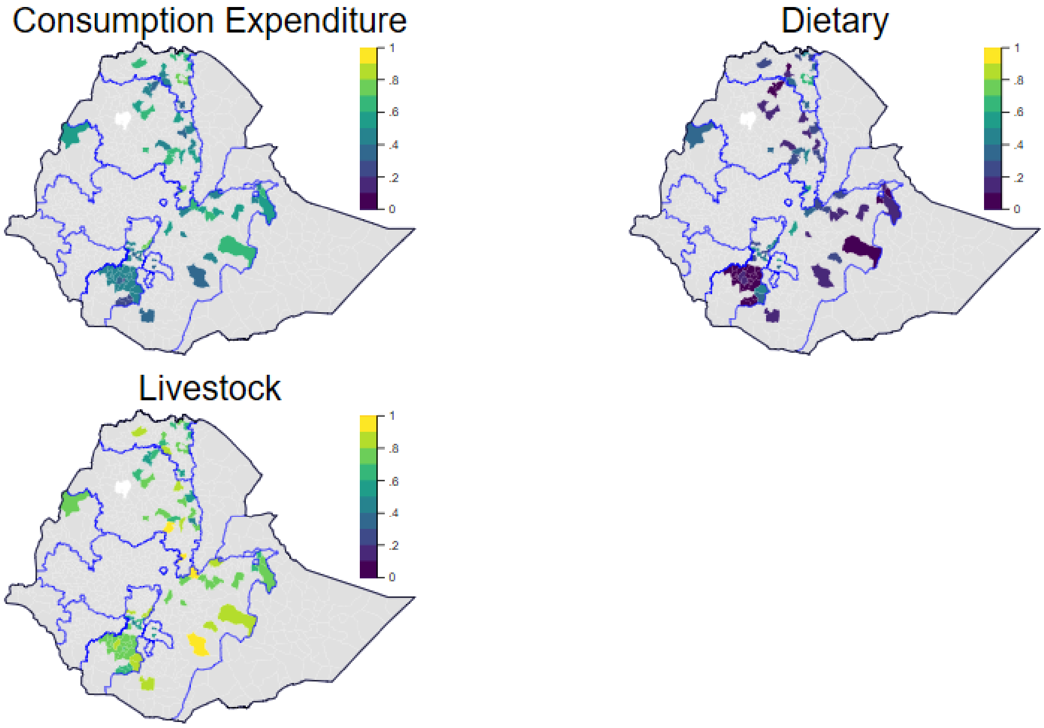

Figure 4: Univariate Resilience, averaged by district (Woreda) - 2008 to 2014

Figure 5 shows the distributions of welfare outcomes and their predicted values under two different distributional assumptions (normal and Gamma). Outcomes are similarly predicted under the two distributional assumptions, but Gamma distribution tends to generate extremely large predicted outcomes, which is why we use normal distribution in this study.

Table 3 shows the temporal dynamics and distribution of the three univariate resilience measures.[10] Households' expenditure resilience has significantly improved across time. Similarly, households' dietary resilience shows modest improvements across time. However, households' resilience and hence capacity to maintain a minimum level of livestock asset remained stagnant across rounds.

Table 3: Resilience dynamics

	Consumption Expenditure	Dietary	Livestock
	(1)	(2)	(3)
2008	0.24	0.19	0.73
2010	0.51	0.23	0.73
2012	0.59	0.32	0.71
2014	0.66	0.31	0.72
Total	0.50	0.26	0.72

Table 4 shows the unadjusted (column 1 to 3) and adjusted (column 4 to 6) headcount ratios. Col-

10. Table A6 shows dynamics of livestock resilience under different TLU thresholds.

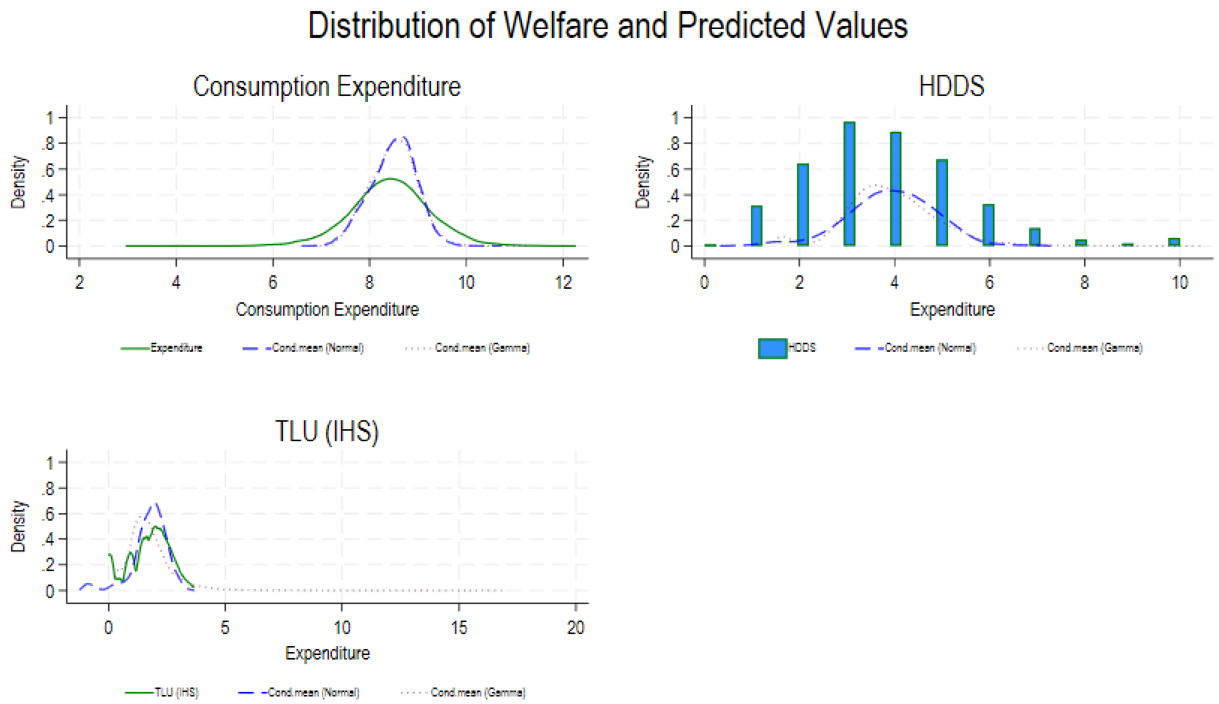

Figure 5: Distribution of Welfare Outcomes and Predicted Values under Normal and Gamma Assumption

umn (1) shows that more than 92% of households are non-resilient with $k = 1$ (at least one resilience measure is below 0.5), and 13% of households are non-resilient across all three resilience measures. Column (4) shows that non-resilient households with $k = 1$ is non-resilient with 1.61 measures on average.

Table 4: Headcount Ratio

	Unadjusted			Adjusted		
	(1)	(2)	(3)	(4)	(5)	(6)
	$k = 1$	$k = 2$	$k = 3$	$k = 1$	$k = 2$	$k = 3$
2008	0.99	0.90	0.22	2.11	2.01	0.66
2010	0.94	0.56	0.13	1.63	1.24	0.39
2012	0.89	0.44	0.10	1.43	0.98	0.30
2014	0.86	0.33	0.06	1.25	0.72	0.18
Total	0.92	0.56	0.13	1.61	1.25	0.39

Table 5 characterizes the distribution of the three univariate resilience measures as a function of household and community characteristics. The distribution of these resilience measures across the observable characteristics exhibit some notable differences. For example, household head's age is concavely associated with consumption expenditure and dietary resilience, but convexly associated with livestock resilience.[11]

Table 5: Regression of univariate resilience measure on household characteristics

	(1) Consumption Expenditure b/se	(2) Dietary b/se	(3) Livestock b/se
Log(household head age)	-0.760***	-0.915***	0.668***
	(0.03)	(0.04)	(0.09)
Log(household head age) squared	0.099***	0.113***	-0.088***
	(0.00)	(0.00)	(0.01)
Male headed household	-0.028***	-0.005***	0.032***
	(0.00)	(0.00)	(0.00)
Household head no education	-0.023***	-0.000	0.009***
	(0.00)	(0.00)	(0.00)
Household head married	-0.005***	-0.001	0.018***
	(0.00)	(0.00)	(0.00)
Household size	-0.033***	0.018***	0.017***
	(0.00)	(0.00)	(0.00)
IHS (distance to nearest town)	-0.030***	-0.073***	0.015***
	(0.00)	(0.00)	(0.00)
Main occupation non-farming	0.039***	0.070***	-0.033***
	(0.00)	(0.00)	(0.01)
IHS (farm size)	0.098***	0.108***	0.037***
	(0.00)	(0.00)	(0.01)
IHS (livestock value per adult)	0.015***	0.007***	0.076***
	(0.00)	(0.00)	(0.00)
IHS (Productive asset value per adult)	0.068***	0.027***	0.028***
	(0.00)	(0.00)	(0.00)
Household has electricity access	0.028***	0.029***	0.007*
	(0.00)	(0.00)	(0.00)
ln(Average annual rainfall (mm))	0.319***	0.367***	0.118***
	(0.01)	(0.01)	(0.02)
Deviation in 30-year average annual rainfall (m)	-0.031***	-0.044***	0.046***
	(0.01)	(0.01)	(0.01)
Constant	-0.510***	-0.362***	-2.519***
	(0.09)	(0.11)	(0.22)
Number of observations	10,767	10,767	10,767
R^2	0.956	0.917	0.859

All models include lagged well-being, district- and year- fixed effects. Standard errors bootstrapped with 500 repetitions.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

4.2 Multivariate Resilience Estimates

We start by characterizing potential correlations between univariate resilience measures. Table 6 is the Spearman's rank correlation matrix among univariate resilience measures.[12] Although these

11. We wondered if these patterns were robust to the exclusion of two zones that were agro-pastoral, Bale and Borena; results without these localities are found in Table A3 in the Appendix.

12. Table A4 reports the rank correlation matrices among multivariate resilience measures.

measures are statistically correlated (all significant at 95%), the strength of the bivariate correlations appear to be weak. For example, the correlation between our livestock-based resilience indicator and expenditure-based indicator is only 0.11. This is not surprising given that rural households face significant trade-offs between maintaining consumption levels above the poverty line and livestock asset accumulation, mainly because livestock sales are major sources of insurance against consumption shortfalls (Dercon and Christiaensen 2011). These weak correlations suggest each metric captures a specific dimension of household resilience, and hence relying on these partial measures of household resilience would generate an incomplete picture of households' capacity and overall resilience.

Table 6: Rank correlation among univariate resilience measures

	Consumption Expenditure	Dietary
Dietary	0.36	1.00
Livestock	0.11	0.15

Figure 6 shows the distribution of multivariate resilience measures (average, union and intersection) of different combinations. Again, these patterns exhibit distinct distributions depending on how we define the multidimensional resilience. As expected, while those measures based on the union and intersection show two extremes, average resilience estimates provide a middle ground. Depending on the specific purposes of empirical analyses, these metrics can capture additional dimensions of household resilience that are not captured in the univariate measures.

Table 7 reports the regression of bivariate and trivariate resilience measures on a number of observable characteristics of households.[13] Again, these empirical regressions show two key insights and patterns. First, the way we aggregate the different dimensions of resilience: average, union and intersection, matters for the distribution of these aggregate outcomes across observable characteristics of households. Second, comparing the implication of program participation on univariate and multivariate suggests that influencing specific dimensions of household resilience may be easier than improving overall resilience.

5 Conclusion and Future Extension

The last decade has seen major progress in the conceptualization, measurement and operationalization of resilience in international development programming. To date, however, resilience measures

13. Table A5 reports the regression of two other bivariate resilience measures.

Table 7: Regression of multivariate resilience on household characteristics - Part 1

	Consumption Expenditure and Dietary			Consumption Expenditure, Dietary and Livestock		
	(1)	(2)	(3)	(4)	(5)	(6)
	Avg	Uni	Int	Avg	Uni	Int
	b/se	b/se	b/se	b/se	b/se	b/se
Log(household head age)	-0.834***	-0.928***	-0.740***	-0.335***	0.090	-0.443***
	(0.029)	(0.037)	(0.039)	(0.036)	(0.067)	(0.052)
Log(household head age) squared	0.105***	0.119***	0.091***	0.041***	-0.011	0.053***
	(0.004)	(0.005)	(0.005)	(0.005)	(0.009)	(0.007)
Male headed household	-0.016***	-0.020***	-0.012***	-0.001	-0.000	-0.003
	(0.001)	(0.002)	(0.002)	(0.002)	(0.003)	(0.002)
Household head no education	-0.011***	-0.018***	-0.005***	-0.005***	-0.000	-0.004***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)
Household head married	-0.003***	-0.007***	-0.000	0.004***	0.006**	0.002
	(0.001)	(0.002)	(0.002)	(0.001)	(0.003)	(0.002)
Household size	-0.007***	-0.017***	0.003***	0.001*	0.005***	0.003***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)
IHS (distance to nearest town)	-0.051***	-0.053***	-0.049***	-0.029***	-0.011***	-0.032***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)
Main occupation non-farming	0.054***	0.059***	0.049***	0.026***	0.017***	0.021***
	(0.002)	(0.003)	(0.003)	(0.003)	(0.006)	(0.005)
IHS (farm size)	0.103***	0.111***	0.095***	0.080***	0.060***	0.069***
	(0.002)	(0.003)	(0.003)	(0.002)	(0.005)	(0.004)
IHS (livestock value per adult)	0.011***	0.014***	0.008***	0.032***	0.038***	0.018***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)
IHS (Productive asset value per adult)	0.047***	0.060***	0.034***	0.041***	0.035***	0.029***
	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Household has electricity access	0.029***	0.034***	0.024***	0.021***	0.009***	0.018***
	(0.001)	(0.002)	(0.002)	(0.001)	(0.003)	(0.002)
ln(Average annual rainfall (mm))	0.343***	0.306***	0.379***	0.267***	0.106***	0.348***
	(0.008)	(0.009)	(0.013)	(0.010)	(0.017)	(0.017)
Deviation in 30-year average annual rainfall (m)	-0.038***	-0.032***	-0.044***	-0.009	0.021**	-0.027***
	(0.004)	(0.005)	(0.006)	(0.006)	(0.010)	(0.008)
Constant	-0.452***	0.005	-0.910***	-1.135***	-0.735***	-1.448***
	(0.073)	(0.091)	(0.109)	(0.095)	(0.172)	(0.147)
Number of observations	10,767	10,767	10,767	10,767	10,767	10,767
R^2	0.951	0.946	0.864	0.917	0.751	0.782

All models include lagged well-being, district- and year- fixed effects. Standard errors bootstrapped with 500 repetitions

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

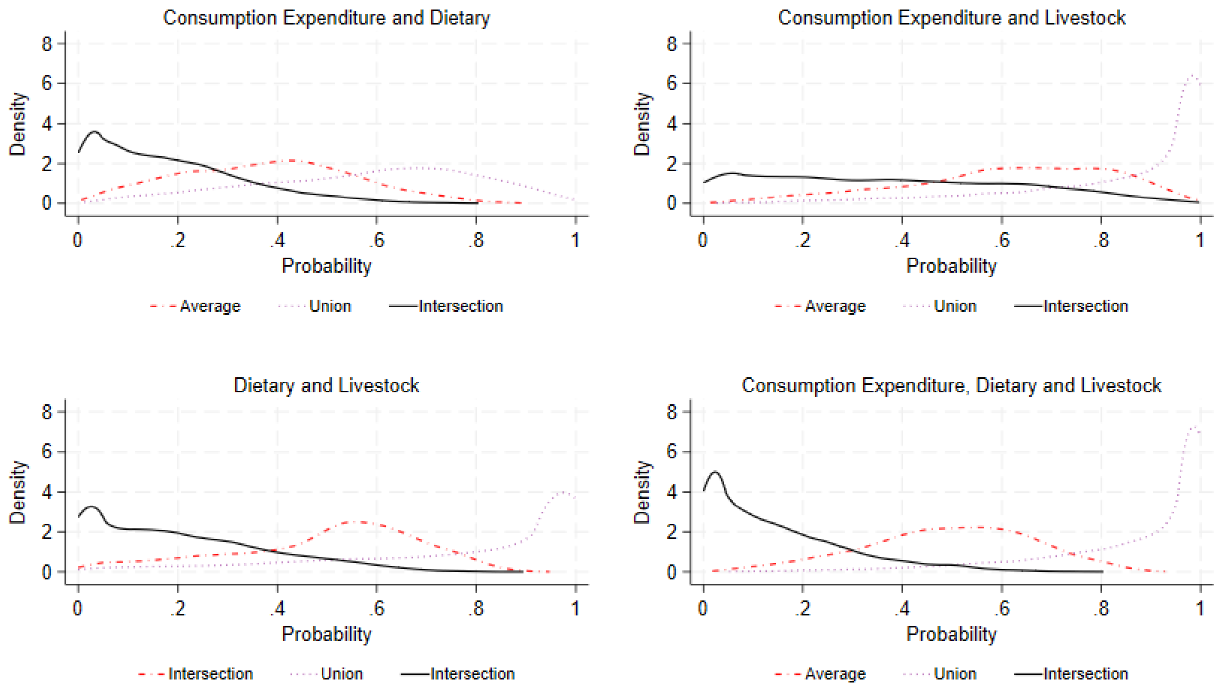

Figure 6: Distribution of Multivariate Resilience

have considered just a single dimension of well-being, although the concept encompasses several dimensions of well-being. As a result, for example, resilience indicators that rely on income-based indicators and poverty thresholds may ignore households' dietary resilience and the resilience of their productive livestock holdings that form the basis for future, sustained capacity to generate a non-poor income and access a healthy diet (Hoddinott 2006). Much as unidimensional poverty measures may provide overly reductionist indicators of current well-being, thereby motivating the use of multidimensional poverty measures (Alkire and Foster 2011; Alkire and Santos 2014), so too might multidimensional resilience measures prove useful to analysts trying to target or evaluate interventions intended to build resilience among populations facing a range of imperfectly correlated deprivations.

Using five rounds of household panel data from Ethiopia, we first evaluate the implication using alternative indicators of well-being for measuring household resilience using the probabilistic moment-based approach developed by Cissé and Barrett (2018). We then extend the existing univariate resilience measurement approach to capture multidimensional well-being indicators. We compute alternative aggregate resilience measures considering multiple dimensions and normative benchmarks (e.g., consumption expenditures-based poverty line, minimum dietary diversity, minimum livestock asset holding).

Our analyses highlight three important findings. First, we find that univariate resilience indicators constructed using alternative normative well-being indicators (consumption expenditures, dietary diversity score, and livestock asset holdings) are only weakly correlated. This implies that households that can be classified as "most resilient" using one indicator and its associated normative threshold may not be classified as resilient by another metric. Where Upton, Constenla-Villoslada, and Barrett 2022 showed that such variation occurs using different resilience measurement algorithms, we show that even using a single algorithm one gets such variation just by varying the underlying well-being indicator.

Second, the univariate and multidimensional resilience measures we construct exhibit significantly different distributions and orderings among households based on their estimated resilience. The variation inherent to one's choice of indicators can thereby influence targeting based on ex ante resilience estimates.

Third, we find that univariate and multidimensional measures of resilience exhibit varying level of association with important observables, suggesting that indicators used for resilience estimation appear to matter to impact evaluation, not only to targeting.

There are some important limitations to our analysis. Most notably,we assume that the alternative welfare indicators are normally distributed (after appropriate transformations), which may not always be true. A natural extension of our approach will allow greater flexibility for heterogeneous distributions among included indicators. We also lack exogenous variation in our explanatory variables, including households' participation in social protection programs, implying that we can only provided correlational evidence, not rigorous multidimensional resilience impact analysis.

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Appendices

A Additional Tables and Figures

Table A1: Summary statistics by survey round

	(1) 2008 mean/sd	(2) 2010 mean/sd	(3) 2012 mean/sd	(4) 2014 mean/sd
Male headed household	0.78	0.76	0.75	0.74
	(0.42)	(0.42)	(0.43)	(0.44)
Age of household head	46.22	47.29	48.93	50.33
	(15.05)	(15.00)	(14.44)	(14.67)
Household head no education	0.76	0.49	0.64	0.74
	(0.43)	(0.50)	(0.48)	(0.44)
Household head married	0.76	0.73	0.72	0.72
	(0.43)	(0.44)	(0.45)	(0.45)
Household size	5.38	5.51	5.52	5.38
	(2.21)	(2.18)	(2.22)	(2.26)
Main occupation farming	0.86	0.83	0.84	0.82
	(0.34)	(0.38)	(0.36)	(0.38)
Landholding per aeu (hectares)	0.31	0.31	0.32	0.29
	(0.33)	(0.31)	(0.44)	(0.44)
Livestock asset value	6,907.25	12,618.57	15,404.61	16,728.25
	(8,948.01)	(15,571.75)	(17,957.08)	(21,490.87)
Production asset value per aeu	89.52	238.48	215.39	248.89
	(203.94)	(1,084.40)	(595.64)	(1,030.76)
Household has electricity access	0.11	0.15	0.13	0.25
	(0.32)	(0.36)	(0.34)	(0.43)
Distance to the nearest town	14.41	14.56	14.72	14.51
	(10.61)	(10.82)	(10.76)	(10.47)
Average annual rainfall this year (mm)	901.93	1,031.04	931.89	974.09
	(276.97)	(268.94)	(266.80)	(348.97)
PSNP beneficiaries	0.49	0.47	0.44	0.36
	(0.50)	(0.50)	(0.50)	(0.48)
PSNP direct support (DS) beneficiaries	0.07	0.10	0.10	0.10
	(0.25)	(0.30)	(0.30)	(0.30)
PSNP public work (PW) beneficiaries	0.42	0.37	0.35	0.26
	(0.49)	(0.48)	(0.48)	(0.44)
HABP beneficiaries	0.39	0.52	0.56	0.47
	(0.49)	(0.50)	(0.50)	(0.50)
PSNP and HABP beneficiaries	0.22	0.26	0.27	0.18
	(0.41)	(0.44)	(0.44)	(0.39)
PSNP benefit amount per capita (birr)*	145.50	222.69	410.21	421.32
	(131.17)	(249.36)	(305.84)	(348.83)
Annual real consumption per aeu	3,859.47	6,694.08	7,673.19	9,366.11
	(3,503.04)	(6,461.03)	(8,486.08)	(9,284.71)
Household Dietary Diversity Score (HDDS)	3.58	3.86	4.12	4.13
	(1.76)	(1.62)	(2.10)	(1.76)
Tropical Livestock Unit (TLU)	3.88	4.00	3.86	3.71
	(3.23)	(3.36)	(3.37)	(3.35)

Table A2: Regression of welfare outcome and conditional variance on household characteristics

	Consumption expenditure		HDDS		TLU (IHS)	
	(1)	(2)	(3)	(4)	(5)	(6)
	Welfare outcome	Cond.var	Welfare outcome	Cond.var	Welfare outcome	Cond.var
	b/se	b/se	b/se	b/se	b/se	b/se
Lagged welfare	-0.381**	-0.0448	0.240***	0.450***	0.0466**	-0.0505***
	(0.17)	(0.18)	(0.06)	(0.15)	(0.02)	(0.02)
(Lagged welfare)^2	0.0259***	0.00438	-0.0237***	-0.0525***	0.0713***	0.0171***
	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)	(0.01)
PSNP beneficiaries	-0.396***	-0.0148	0.0955	1.402**	-0.00984	-0.0179
	(0.09)	(0.08)	(0.21)	(0.56)	(0.05)	(0.02)
HABP beneficiaries	0.00362	-0.0230	0.276***	0.165	0.0460***	-0.0152**
	(0.02)	(0.02)	(0.07)	(0.19)	(0.01)	(0.01)
PSNP beneficiaries × HABP beneficiaries	0.0242	-0.0103	-0.123*	0.107	-0.0357**	0.00819
	(0.03)	(0.03)	(0.07)	(0.24)	(0.02)	(0.01)
IHS (PSNP transfer per capita)	0.0564***	0.00329	-0.0302	-0.279**	-0.0111	0.000214
	(0.01)	(0.01)	(0.04)	(0.11)	(0.01)	(0.00)
Log(household head age)	-1.310***	-0.478	-4.358***	-8.966**	0.466	-0.331
	(0.48)	(0.45)	(1.15)	(3.53)	(0.37)	(0.24)
Log(household head age) squared	0.170***	0.0651	0.538***	1.173**	-0.0589	0.0442
	(0.06)	(0.06)	(0.15)	(0.46)	(0.05)	(0.03)
Male headed household	-0.0518**	-0.0129	-0.102**	0.0956	0.0214	-0.00353
	(0.02)	(0.02)	(0.05)	(0.16)	(0.01)	(0.01)
Household head no education	-0.0411**	0.0275	-0.0287	0.264**	0.0128	-0.000555
	(0.02)	(0.02)	(0.05)	(0.13)	(0.01)	(0.01)
Household head married	-0.0220	-0.0182	0.0382	-0.133	0.00976	-0.0191**
	(0.02)	(0.02)	(0.05)	(0.13)	(0.01)	(0.01)
Household size	-0.0617***	0.00366	0.0890***	0.0473*	0.0373***	0.00608***
	(0.01)	(0.01)	(0.01)	(0.03)	(0.00)	(0.00)
IHS (distance to nearest town)	-0.0573***	0.0384**	-0.367***	-0.309	0.0401***	-0.00631
	(0.02)	(0.02)	(0.07)	(0.25)	(0.01)	(0.00)
Main occupation non-farming	0.0856*	-0.0165	0.339***	0.551*	-0.0452*	-0.0361***
	(0.05)	(0.04)	(0.10)	(0.31)	(0.02)	(0.01)
IHS (farm size)	0.236***	-0.00236	0.523***	0.502**	0.135***	0.0807***
	(0.04)	(0.04)	(0.09)	(0.23)	(0.03)	(0.02)
IHS (livestock value per adult)	0.0255***	-0.0108***	0.0440***	-0.0460	0.244***	-0.0488***
	(0.00)	(0.00)	(0.01)	(0.04)	(0.01)	(0.00)
IHS (Productive asset value per adult)	0.130***	-0.0223**	0.133***	0.00880	0.0346***	0.0136***
	(0.01)	(0.01)	(0.03)	(0.09)	(0.01)	(0.00)
Household has electricity access	0.0670*	0.00788	0.116	0.358	0.0168	-0.0103
	(0.04)	(0.02)	(0.13)	(0.39)	(0.02)	(0.01)
Ln (Average rainfall this year (mm))	0.673**	-0.175	1.610***	1.680	0.446**	0.150
	(0.27)	(0.12)	(0.35)	(1.59)	(0.21)	(0.10)
Constant	7.613***	2.478*	1.312	8.315	-4.924***	0.223
	(2.01)	(1.41)	(3.30)	(13.11)	(1.44)	(0.70)
N	11375	11375	11425	11425	11035	11035
R^2	0.347	0.0371	0.258	0.0991	0.769	0.160
District and Year FE	Y	Y	Y	Y	Y	Y

Table A3: Regression of univariate resilience measure on household characteristics - Without Bale and Borena

	(1) Consumption Expenditure b/se	(2) Dietary b/se	(3) Livestock b/se
Log(household head age)	-0.755***	-0.937***	0.679***
	(0.04)	(0.04)	(0.09)
Log(household head age) squared	0.098***	0.115***	-0.090***
	(0.00)	(0.01)	(0.01)
Male headed household	-0.028***	-0.004**	0.035***
	(0.00)	(0.00)	(0.00)
Household head no education	-0.024***	0.000	0.009***
	(0.00)	(0.00)	(0.00)
Household head married	-0.005***	-0.001	0.016***
	(0.00)	(0.00)	(0.00)
Household size	-0.033***	0.019***	0.017***
	(0.00)	(0.00)	(0.00)
IHS (distance to nearest town)	-0.030***	-0.074***	0.014***
	(0.00)	(0.00)	(0.00)
Main occupation non-farming	0.039***	0.069***	-0.031***
	(0.00)	(0.00)	(0.01)
IHS (farm size)	0.096***	0.111***	0.039***
	(0.00)	(0.00)	(0.01)
IHS (livestock value per adult)	0.014***	0.008***	0.076***
	(0.00)	(0.00)	(0.00)
IHS (Productive asset value per adult)	0.068***	0.028***	0.029***
	(0.00)	(0.00)	(0.00)
Household has electricity access	0.028***	0.029***	0.006
	(0.00)	(0.00)	(0.00)
ln(Average annual rainfall (mm))	0.319***	0.365***	0.119***
	(0.01)	(0.01)	(0.02)
Deviation in 30-year average annual rainfall (m)	-0.030***	-0.051***	0.044***
	(0.01)	(0.01)	(0.01)
Constant	-0.512***	-0.307***	-2.553***
	(0.09)	(0.10)	(0.23)
Number of observations	10,079	10,079	10,079
R^2	0.956	0.917	0.857

All models include lagged well-being, district- and year- fixed effects. Standard errors bootstrapped with 500 repetitions.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A4: Rank correlation among multivariate resilience measures

	Consumption Expenditure & Dietary	Consumption Expenditure & Livestock	Dietary & Livestock
(a) Average			
Consumption Expenditure & Livestock	0.64	1.00	0.78
Dietary & Livestock	0.50	0.78	1.00
Consumption Expenditure & Dietary & Livestock	0.78	0.94	0.87
(b) Union			
Consumption Expenditure & Livestock	0.35	1.00	0.96
Dietary & Livestock	0.19	0.96	1.00
Consumption Expenditure & Dietary & Livestock	0.37	1.00	0.97
(c) Intersection			
Consumption Expenditure & Livestock	0.58	1.00	0.62
Dietary & Livestock	0.78	0.62	1.00
Consumption Expenditure & Dietary & Livestock	0.88	0.79	0.93

(a) Correlation across dimensions - multivariate

	Consumption Expenditure & Dietary		Consumption Expenditure & Livestock	
	Average	Union	Average	Union
Union	0.97	1.00	0.82	1.00
Intersection	0.93	0.82	0.97	0.70
	Dietary & Livestock		**Consumption Expenditure & Dietary & Livestock**	
	Average	Union	Average	Union
Union	0.86	1.00	0.79	1.00
Intersection	0.90	0.60	0.92	0.61

(b) Correlation within dimension - multivariate

Table A5: Regression of multivariate resilience on household characteristics - Part 2

	Consumption Expenditure and Livestock			Dietary and Livestock		
	(1)	(2)	(3)	(4)	(5)	(6)
	Avg	Uni	Int	Avg	Uni	Int
	b/se	b/se	b/se	b/se	b/se	b/se
Log(household head age)	-0.045	0.189**	-0.279***	-0.126**	0.264***	-0.517***
	(0.050)	(0.075)	(0.081)	(0.050)	(0.077)	(0.065)
Log(household head age) squared	0.005	-0.023**	0.033***	0.012*	-0.038***	0.063***
	(0.007)	(0.010)	(0.011)	(0.007)	(0.010)	(0.009)
Male headed household	0.002	-0.003	0.006**	0.013***	0.025***	0.002
	(0.002)	(0.003)	(0.003)	(0.002)	(0.003)	(0.002)
Household head no education	-0.007***	-0.002	-0.012***	0.004***	0.010***	-0.001
	(0.001)	(0.002)	(0.002)	(0.002)	(0.003)	(0.002)
Household head married	0.006***	0.006**	0.006**	0.008***	0.015***	0.002
	(0.002)	(0.003)	(0.003)	(0.002)	(0.003)	(0.002)
Household size	-0.008***	0.003***	-0.019***	0.017***	0.018***	0.017***
	(0.000)	(0.001)	(0.001)	(0.000)	(0.001)	(0.000)
IHS (distance to nearest town)	-0.008***	-0.000	-0.015***	-0.029***	-0.013***	-0.045***
	(0.001)	(0.002)	(0.002)	(0.001)	(0.002)	(0.002)
Main occupation non-farming	0.003	0.001	0.006	0.019***	0.013*	0.025***
	(0.004)	(0.007)	(0.008)	(0.005)	(0.008)	(0.006)
IHS (farm size)	0.067***	0.060***	0.074***	0.072***	0.063***	0.081***
	(0.003)	(0.006)	(0.006)	(0.003)	(0.006)	(0.004)
IHS (livestock value per adult)	0.045***	0.044***	0.046***	0.042***	0.060***	0.023***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
IHS (Productive asset value per adult)	0.048***	0.038***	0.057***	0.027***	0.030***	0.025***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Household has electricity access	0.017***	0.007**	0.028***	0.018***	0.014***	0.022***
	(0.002)	(0.003)	(0.004)	(0.002)	(0.004)	(0.003)
ln(Average annual rainfall (mm))	0.218***	0.123***	0.312***	0.241***	0.130***	0.352***
	(0.013)	(0.019)	(0.022)	(0.013)	(0.021)	(0.016)
Deviation in 30-year average annual rainfall (m)	0.008	0.035***	-0.020*	0.002	0.016	-0.012
	(0.008)	(0.011)	(0.011)	(0.007)	(0.012)	(0.009)
Constant	-1.521***	-1.168***	-1.875***	-1.424***	-1.493***	-1.354***
	(0.127)	(0.192)	(0.222)	(0.127)	(0.209)	(0.162)
Number of observations	10,767	10,767	10,767	10,767	10,767	10,767
R^2	0.903	0.764	0.842	0.882	0.827	0.807

All models include lagged well-being, district- and year- fixed effects. Standard errors bootstrapped with 500 repetitions

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

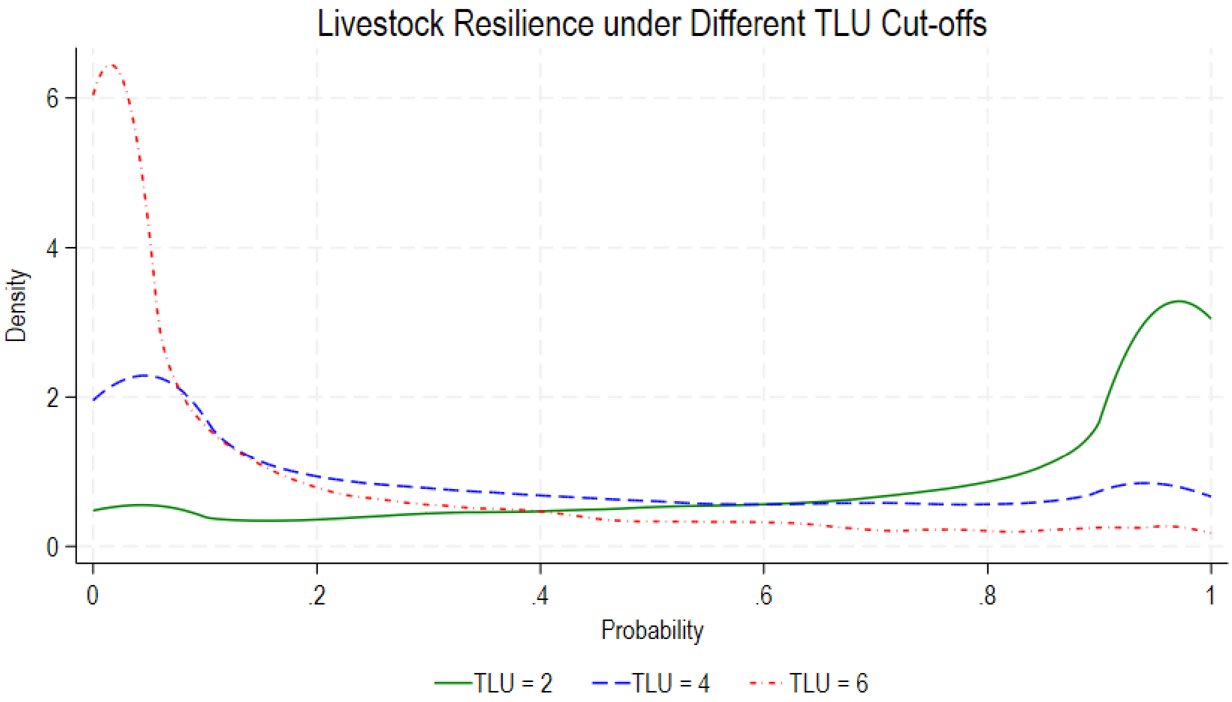

Figure A1: Livestock Resilience under Different Cut-offs

Table A6: Resilience dynamics

	$Cutoff = 2$	$Cutoff = 4$	$Cutoff = 6$
	(1)	(2)	(3)
2008	0.73	0.37	0.17
2010	0.73	0.37	0.18
2012	0.71	0.37	0.18
2014	0.72	0.38	0.19
Total	0.72	0.37	0.18

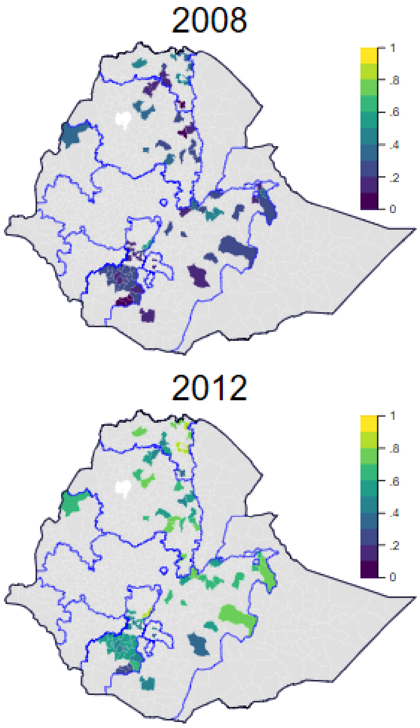

Figure A2: Consumption Expenditure Resilience by Year

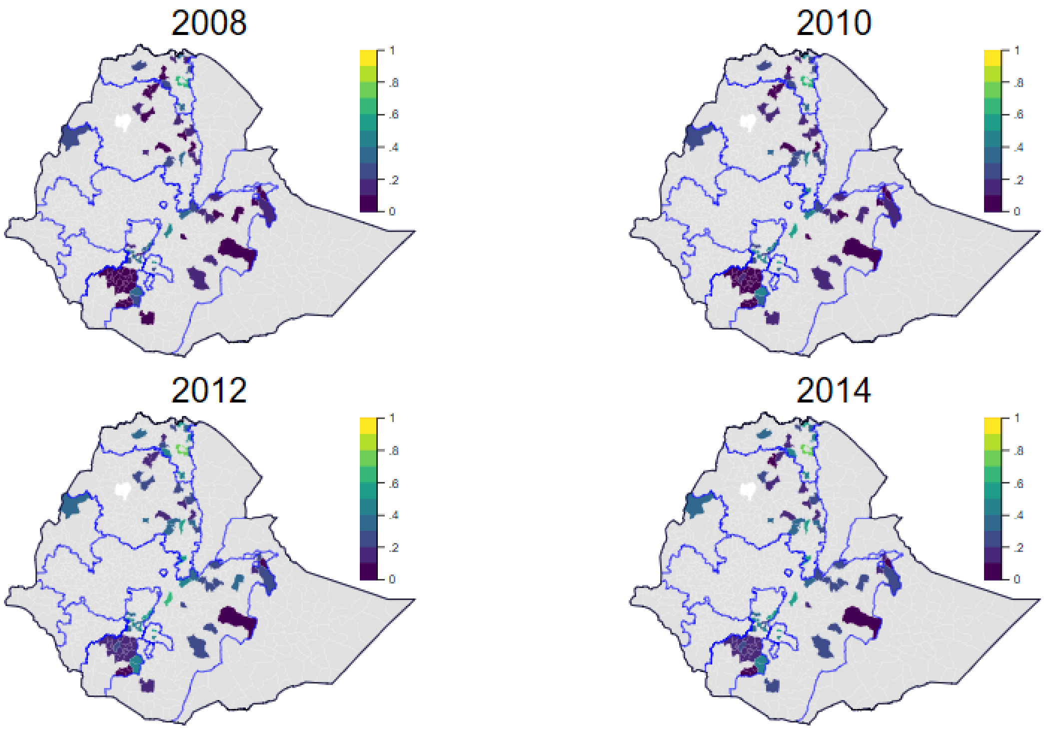

Figure A3: Dietary Resilience by Year

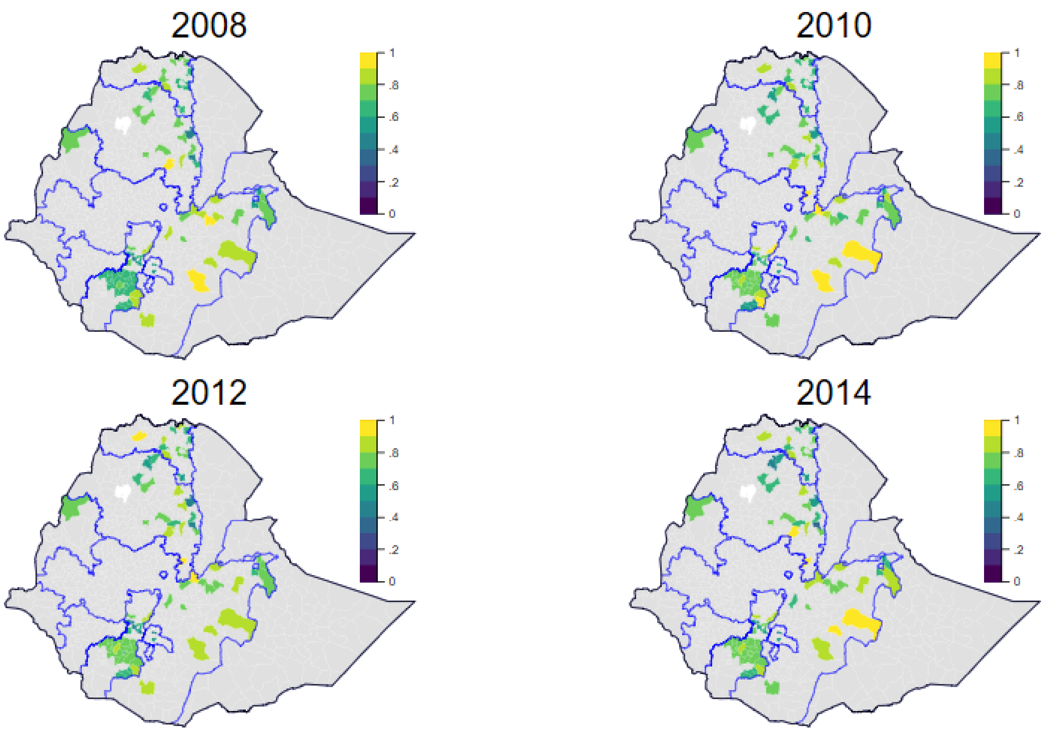

Figure A4: Livestock Resilience by Year