Climate Shocks, Vulnerability, Resilience and Livelihoods in Rural Zambia

Hambulo Ngoma[1,3], *Arden Finn*[2], *Mulako Kabisa*[1]

[1]Indaba Agricultural Policy Research Institute, Lusaka, Zambia
[2]The World Bank, Poverty and Equity Global Practice, Washington, DC
[3]International Maize and Wheat Improvement Center (CIMMYT), Harare, Zimbabwe

Abstract

To what extent do the behavioral choices Zambian smallholder farmers make influence the negative effects of climate shocks, and what impact do these choices have on vulnerability and resilience? Both the frequency and intensity of weather shocks in Zambia are increasing, pushing households into poverty, or locking them into it. Despite some broad research in Zambia at the intersection of climate risk, poverty, and livelihoods, there has not been much explicit assessment of the effects of climatic shocks on vulnerability and resilience, and on options for building smallholder resilience. This paper uses nationally representative three-wave household-level panel data of 6,531 households from the Rural Agricultural Livelihoods Survey (RALS) to address this gap. We define household vulnerability and resilience based on whether a household is “poor”, “never poor”, “escaped poverty”, or “fell into poverty” over the three-survey waves, as measured in the third wave in 2019. Our empirical estimation employs an instrumental variable probit regression model which also controls for the endogeneity of key choice variables.

Our main empirical findings are:

- Droughts are the most prevalent climate shock rural smallholder farmers in Zambia face, but extent of exposure differs spatially, with the Southern and Western Provinces being the hardest hit. Nationally, about three-quarters of all smallholder farmers are vulnerable and only about one-quarter are resilient.
- Increased climate shocks correlate with both increased vulnerability and reduced resilience, with short and long-term deviations in seasonal rainfall worsening vulnerability and resilience.
- Higher asset endowments and education level of the household head reduce vulnerability and increase resilience among smallholder farmers. Female-headed households are more vulnerable and less resilient, on average.
- The use of climate-smart agriculture (CSA) practices—namely, minimum tillage and use of inorganic fertilizers or hybrid maize seed—significantly improves household resilience in the short-term.

We draw two main policy implications from our findings. First, our results point to an urgent need to invest in Research and Development for climate shock-tolerant crop varieties and in broader climate-smart agricultural technologies to scale-out and scale-up context specific practices through innovative digital platforms. Second, more investment is needed in risk mitigation strategies such as weather indexed insurance, targeted social cash transfers and how to make these work effectively for smallholder farmers. Other important complementary elements include investment in innovative digital platforms that can facilitate timely delivery

of climate information services and facilitating asset accumulation and education that can enable farmers to improve climate shock resilience over time.s

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List of Acronyms

CA	Conservation Agriculture
CHIRPS	Climate Hazards Group Infrared Precipitation with Station Database
CSA	Climate-Smart Agriculture
GDP	Gross Domestic Product
ha	Hectare
IPCC	Intergovernmental Panel for Climate Change
MT	Minimum Tillage
PPP	Purchasing Power Parity
R&D	Research and Development
RALS	Rural Agricultural Livelihoods Survey
SCT	Social Cash Transfer
SPI	Standard Precipitation Index
SSA	Sub-Saharan Africa
US$	United States Dollar

1. Introduction

As in other sub-Saharan Africa (SSA) countries, both the frequency and intensity of climate and weather shocks is increasing in Zambia, pushing or locking rural households—especially smallholder farmers—into poverty (Thurlow, et al., 2012; Al Mamun, et al., 2018; Braimoh, et al., 2018; Ngoma, et al., 2019). It is estimated that climate variability reduced growth in Zambia's agricultural Gross Domestic Product (GDP) and national GDP by 4 percent and 10 percent, respectively, between 2006 and 2016 (Thurlow, et al., 2012), with an associated increase in the national poverty rate of 2 percent.[1] In severe drought years, such as the 1991/1992 season, Thurlow et al. (2012) estimated that GDP reduced by 6.6 percent and poverty increased by 7.5 percentage points. [2]

Climate change and variability are therefore important contributors to the high poverty incidence of 76.6 percent in rural Zambia.[3] Reliance on rainfed agriculture drives the high prevalence of poverty in rural Zambia and among smallholder farmers. This dependence means that rural households are particularly strongly exposed to climate shocks. According to the 2015 Living Conditions Monitoring Survey (LCMS), poverty among small-scale farming households was 78.9 percent compared to 64. 5 percent among medium-scale farmers (CSO, 2015). Poverty is highest in the Northern (79.7 percent), Eastern (70 percent), Southern (57.6 percent), and Central (56.2 percent) Provinces. Except for the Central and Northern Provinces, all have a higher population density than the national average, indicating a combination of high poverty rates and high absolute numbers of poor people.[4]

Because rural households are not all the same, it is important to understand the extent to which different groups are exposed to and vulnerable to climate shocks. It is also important to assess the extent to which behavioral choices, such as adoption of climate-smart agriculture (CSA), might mitigate the negative effects of climate shocks on vulnerability and resilience. Apart from differences in geographic location, households also differ by socio-economic status, making some agricultural households systematically more exposed and vulnerable to climatic risks than others—for example, those primarily dependent on rainfed agriculture. In the same way, some households may be better equipped to mitigate or build resilience before climate shocks or cope and adapt with them afterwards through adoption of sustainable or CSA farming practices such as conservation agriculture (CA).

Despite a growing body of literature linking climate risk, poverty, and livelihoods more broadly in Zambia, little attention has been devoted to carefully define and measure, and

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[1] The Thurlow et al., (2012) paper imposes changes in climate in 2025 on economic outcomes over the period 2006 – 2016.

[2] These are years during which total rainfall during the growing season is between 405mm and 499mm.

[3] The comparative rate of poverty in urban areas is 23.4percent.

[4] According to the Zambia data portal https://zambia.opendataforafrica.org/lfigqzd/zambia-atlas-fact-dataset-4-feb-2013, the average population density in Zambia by 2015 was 20.16 persons per km^2. It higher in Eastern and Southern Provinces at 34 and 21 persons per km^2, respectively.

assess how the vulnerability and resilience of rural households vary by household types, geography, and wealth (Jain, 2007; Thurlow, et al., 2012; Wineman and Crawford, 2017; Al Mamun, et al., 2018; Braimoh, et al., 2018; Alfani, et al., 2019; Ngoma, et al., 2019; Hamududu and Ngoma, 2019). It is equally not well understood the extent to which exposure to different climatic shocks affects vulnerability and resilience at national and subnational levels. There is also a dearth of information on the relative importance of CSA practices such as minimum tillage, improved inputs (fertilizer and seed), and crop diversification to mitigate the effects of climate shocks on livelihoods. This paper contributes to filling these gaps and evaluates the common types of climate shocks Zambian households face and how these shocks affect household vulnerability and resilience. It also assesses the types of strategies households use to cope with shocks, particularly assessing if CSA practices can mediate damaging climate shock effects on vulnerability and resilience.

This paper extends the literature on climate change and poverty in Zambia in four ways:

(i) It uses detailed longitudinal household-level data to analyze the types of climate shocks households face in rural Zambia, how these shocks differ by geography and household types, and how these shocks affect vulnerability and resilience. This unlike several papers that focus on explaining poverty dynamics in Zambia. See for example Chapoto et al., (2011) covering the period 2001 – 2008, Ngoma et al., (2019) for the period 2012 – 2015 and Diwakar et al., (2020) for the period 2012 – 2019. The last two papers use the same RALS datasets as in this paper.
(ii) It incorporates unique exogenously defined drought and flood risks to measure vulnerability and exposure to climate risk using detailed three-wave household-level panel data.
(iii) It assesses how exposure to climate risk affects vulnerability and resilience.
(iv) Finally, the paper assesses whether adopting common CSA practices mediates the effects of climate shocks on vulnerability and resilience in Zambia, and if so, by how much.

The multidimensionality of poverty, resilience and vulnerability and their causes make measuring any of these indicators a daunting task. For this paper and given our focus on the last two metrics, we follow Barrett and Constas (2014) and define resilient households over three waves of data as those that were never poor or those that escaped poverty by the third wave. We classify vulnerable households as those that are poor in all the three waves, or poor in the first and third wave but not in the second wave, or those poor in the second and third waves but not in the first wave, or indeed those that were not poor in the first and second waves, but fell into poverty in the third wave.

Vulnerable households are more likely to be adversely affected due to either exposure or lack of capacity to cope and adapt. Exposure refers to the presence of rural households or economic activities in places or areas that are more likely to be negatively affected by climate shocks.

The data used in the analysis are from the nationally representative Rural Agricultural Livelihood Surveys (RALS) conducted in 2012, 2015, and 2019 in Zambia. The poverty metric used in this paper is based on total household income captured in RALS. For our poverty estimates to be comparable to those based on consumption expenditure,[5] we used the RALS 2015 data to determine an income threshold or "poverty line" that would make the income-based poverty rate equal to the expenditure-based rural poverty rate estimated in the 2015 Living Conditions Monitoring Survey (LCMS) in Zambia.[6] Besides our focus on resilience and vulnerability, the use of an income-based poverty line that equates the 2015 poverty rate in RALS to the expenditure-based poverty rate for that year is another major difference between this paper and others that use RALS data to study poverty dynamics in Zambia, see Chapoto et al., (2011); Ngoma et al., (2019) and Diwakar et al., (2020).

The paper proceeds as follows. Section 2 briefly reviews the links between climate shocks, vulnerability, and resilience. Section 3 presents a conceptual framework on the linkages between climate change, vulnerability, and livelihood outcomes. Section 4 presents the data and methods. Section 5 presents our results, which we discuss further in section 6. Section 7 concludes the paper and offers some reflections.

2. Climate shocks, vulnerability, resilience, and rural livelihoods: A brief review

The linkages between climate shocks, vulnerability, resilience, and livelihoods are complex. Climate change can increase poverty directly by reducing agricultural productivity and production, and by hindering asset accumulation and return on assets. Indirectly, climate change affects poverty through output prices, labor productivity and in the availability of off-farm employment opportunities. This paper focuses primarily on the direct livelihood effects. As in other mainly agrarian SSA countries, the incidence of climate shocks such as droughts, seasonal and flash floods, and extreme temperatures and dry spells is increasing in Zambia. These weather extremes have significant carry over side effects on rural farmers who depend on rainfed agriculture for their livelihoods.

Climate shocks are likely to become more intense and more frequent. Ahmed et al. (2009) predicts that by 2080, climate change will increase the intensity of dry spells and subsequently worsen the incidence of poverty among smallholder farmers by 4.6 percentage points in all agro-ecological regions in Zambia. Average temperatures are predicted to rise by between

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[5] From which the national poverty rate is derived.

[6] At the time of writing, the 2015 LCMS is the dataset that provides the most recent estimate of national, urban/rural, and provincial poverty rates in Zambia.

1.9 and 2.3 degrees Celsius, and annual rainfall is projected to reduce by up to 3 percent by 2100 in Zambia (Petrie et al. 2018a; Hamududu and Ngoma, 2019).

The effects of climate change on poverty are profound in Zambia, where over half of the population lives below the national poverty line (CSO, 2015). In a cross-country study, Al Mamun et al. (2018) found that the El Niño weather phenomenon[7] worsened poverty in Eastern and Southern Africa. The 2015/2016 El Niño was associated with severe droughts and floods in different parts of Zambia. Al Mamun et al. (2018) find that a 10 percent reduction in maize yields increases the national poverty rate by 1 percentage point and the poverty gap by 1.9 percentage points in Zambia. As would be expected, the increase in the poverty rate and gap is respectively about 16 and 10 times higher in rural areas than in urban areas. The analysis also finds that a 10 percent drop in maize prices increases the poverty rate by 1.16 percentage points, and increases the poverty gap by 2.4 percentage points in rural areas. Alfani et al. (2019) found that the 2015/2016 El Niño-induced drought shocks in Zambia were associated with about 20 percent and 37 percent reductions in maize yields and per capita incomes respectively. Climate shocks such as droughts and floods at the Zambian national level reduce cotton production by an estimated 68 percent, and both maize and groundnuts by 33 percent (Braimoh, et al., 2018).

While it is generally believed that climate and weather shocks have the potential to worsen poverty and vulnerability while eroding resilience, it remains unclear how impacts vary across Zambian household types and regions, and the extent to which the poor are exposed to weather shocks. Although CSA technologies have the potential to raise productivity while helping farmers adapt to climate shocks, results in application of CSA have been mixed in different contexts. This is not surprising because what is CSA in one context might not be so in another context and no single practices is CSA all the time and everywhere (Mwongear et al., 2017). For example, Thierfelder et al. (2017) conclude their review of CSA in SSA by saying that CSA principles such as conversation agriculture (CA) have positive effects on adaptation and productivity but a lag of two to five cropping seasons is common before yield benefits become significant. Similarly, Michler et al. (2019) found that although CA did not confer any yield benefits, it helped farmers adapt to rainfall variability in Zimbabwe. Corbeels et al. (2020) find that CA only confers small yield gains over conventional agriculture in 16 SSA countries and conclude that "CA may not be the technology for African smallholder farmers to overcome low productivity and food insecurity in the short-term". Some CSA practices, in particular crop diversification, commercial horticulture, agroforestry and reducing post-harvest loss are associated with positive long-term effects on household welfare in Zambia (World Bank, 2018). Not much work has been done to specifically analyze the extent to which CSA practices mediate climate shock vulnerability and resilience using long-term household data. Such data allows for better measurements of outcomes during and after shocks.

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[7] El Niño is an abnormal weather pattern which affects Zambia through increased drought severity, resulting in adverse effects on agricultural production.

Households can implement strategies before and after shocks to improve resilience and managing the negative impacts of climate variability and change. There are several options for enhancing resilience, including diversifying livelihood sources, accessing social safety nets, and using risk sharing/coping mechanisms such as insurance, CSA, and savings and loan groups (Alfani et al., 2019; Arslan, 2018; Carter et al., 2017; IPCC, 2018). Rural households use a variety of coping strategies such as migration, diversifying income sources, selling productive assets, reducing food intake, borrowing and lending in formal and informal markets, and over-exploiting natural resources to cope with climate stress (Arslan, 2018; Alderman and Paxson, 1994; Hansen et al., 2017). Mulenga et al. (2017) found that smallholder farmers in Zambia switch to drought-tolerant and heat-resistant crop varieties and livestock breeds, stagger planting, use of CA, and diversify livelihood portfolios away from agriculture to adapt to climate change and variability.

Climate change is also expected to lead to a decline in crop suitability in SSA. Chapman et al. (2020) suggests that crops like soybeans will be less affected by rising temperature but staples like maize are projected to be worst affected and will become less suitable for production in SSA. This will require that farmers in the region adopt heat tolerant and drought resistant crop varieties.

The absence of well-functioning insurance and credit markets in SSA, coupled with weather variability and associated crop price volatility, leads to large income shocks for households dependent on agriculture (Miura and Sakurai, 2015; Alderman and Paxson, 1994). Despite the known benefits of insurance, uptake among smallholder farmers is hampered by high upfront premium payments (which can be addressed by access to credit), low trust in financial institutions, and limited knowledge on how insurance products work (Marr et al., 2016; Murray and Farrin, 2014).

3. Conceptual framework[8]

Climate shocks—both floods and droughts—present a risk to rural livelihoods in Zambia given that over 90 percent of smallholder agriculture uses rainfed production systems (Wineman and Crawford, 2017). Reduced agricultural productivity and output are the main negative effects climate shocks have on rural livelihoods, which in turn leads to reduced incomes and consumption (Balisacan et al., 2011; Skoufias and Vinha, 2012; Karfakis et al., 2012).

However, climate shocks affect smallholder farmers in different ways depending on the farmer’s asset base, socioeconomic status, social capital, capabilities, and coping capacities. Effects may be severe for poor households with little or no assets or savings to fall back on in the event of climate-induced agricultural production losses. Asset-poor households are

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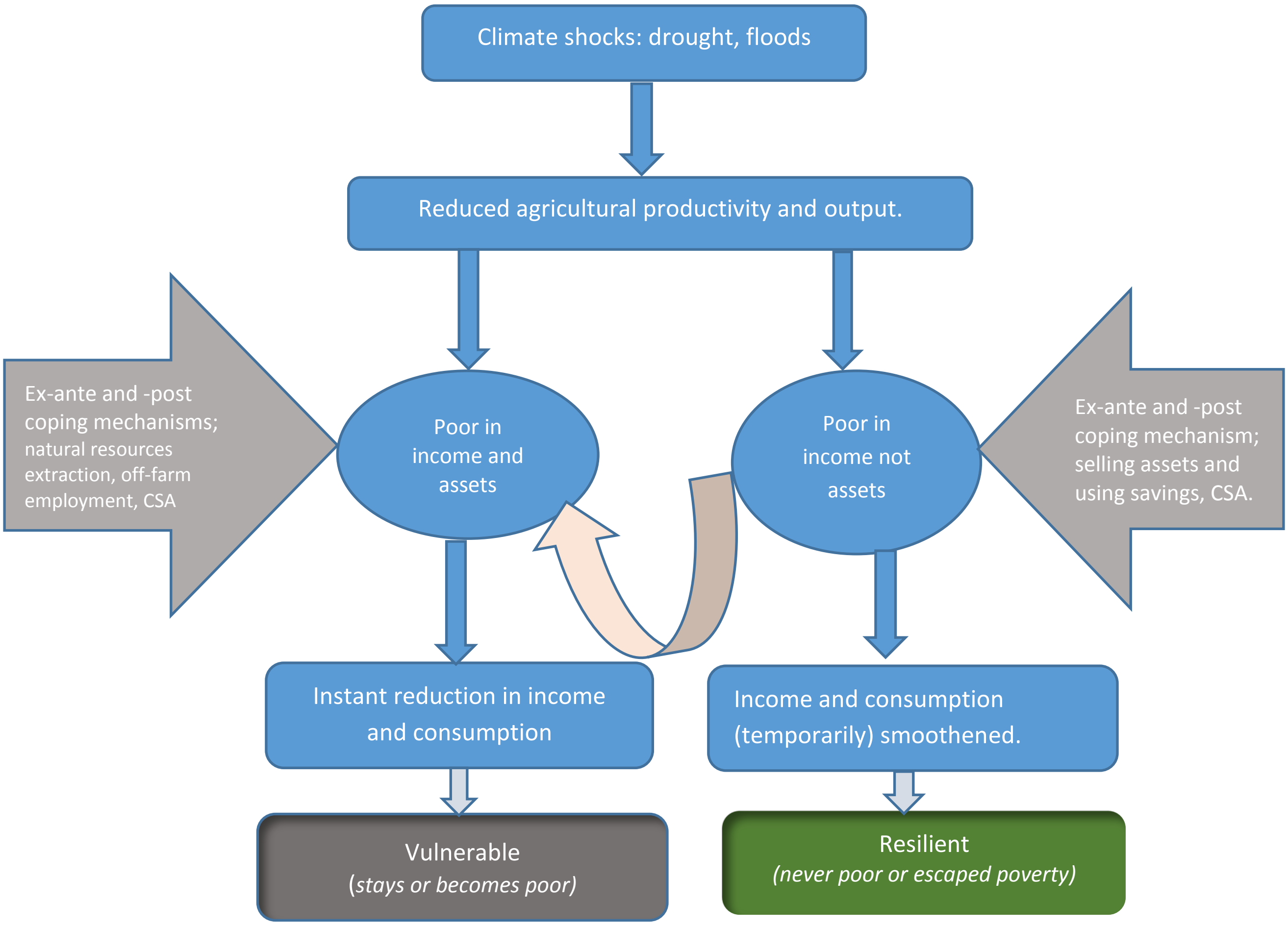
[8] This section draws heavily from a background report: Ngoma et al. (2019). Poverty and weather shocks: a panel data analysis of structural and stochastic poverty in Zambia. Available http://www.iapri.org.zm/images/WorkingPapers/wp150_for_pdf_poverty_final.pdf

generally less resilient and more vulnerable. On the other hand, asset-rich households or those with savings might be less affected by climate shocks because they can liquidate their assets and/or use savings to smooth consumption and avert food and income insecurity. To achieve a more nuanced understanding of how climate shocks impact livelihoods, it is important to classify households into sub-groups that differ along dimensions that inform their vulnerability and resilience.

Figure 1 depicts our conceptualization of the pathways through which climate shocks could increase household vulnerability and reduce resilience, and the different household responses or coping mechanisms. Following Skoufias and Vinha (2012), this framework shows possible pathways through which climate change affect livelihoods. In general, weather and climate variability affect rural household consumption and incomes, more so for those who depend on rainfed agriculture for their livelihoods. In the event of disruptions to agricultural production, poor households are likely to intensify extraction of natural resources and to engage in non-farm employment (Mulenga et al., 2014; Angelsen and Dokken, 2018). Increased natural resources extraction, such as charcoal production and logging, speed environmental degradation, which disproportionately affects smallholder farmers. Moreover, intensification of environmentally degrading livelihood activities can aggravate poverty for households whose livelihoods depend on these natural resources.

Households with a higher asset base could liquidate some to help smooth income and consumption, but this is only a temporary coping strategy. If climate or weather shocks persist for a longer period, households may deplete their assets and savings, causing a further slide into poverty. Absent formal insurance or social protection, this creates a vicious cycle in which climate shocks increase poverty and environmental degradation that create more climate shocks. Households my also use incomes earned from non-farm employment to smooth consumption in places where such works is available. The final outcome in this framework will either be vulnerability or resilience, depending on whether (i) a household stays or becomes poor, or (ii) was never poor or escaped poverty.

Figure 1. Pathways through which climate shocks may affect livelihoods.



Source: Adapted from Ngoma et al (2019) based on Skoufias and Vinha (2012)

4. Data and methods

4.1 Data sources

We draw data from the three-wave, nationally representative RALS survey conducted by the Indaba Agricultural Policy Research Institute (IAPRI) in collaboration with the Ministry of Agriculture and the Central Statistical Office (CSO) of Zambia. The first round of RALS was conducted in May/June 2012, the second in June/July 2015, and the third in June/July 2019. This timing coincides with harvesting for the previous agricultural production season and the agricultural marketing season (from May year *t* to April year *t+1*). The dekadal (10-day) rainfall data from the Climate Hazards Group Infrared Precipitation with Station database (CHIRPS) for the period 1981 to 2018 compliments these data, with the CHIRPS merged into the RALS dataset using household geo-coordinates.[9] We use the dekad CHIRPS data to compute growing season rainfall spanning November of the previous year to March of the following

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[9] CHIRPS is a quasi-global (50'S-50'N), gridded 0.05' resolution with satellite and observation-based precipitation estimates. It combines station based rainfall data with satellite data (Funk et al., 2014).

year. We take advantage of the long time series to compute 30-year, long-term average rainfall, and long-term measures of rainfall variability such as the standard precipitation index (SPI), rainfall stress, and coefficient of variation.

The RALS data are large datasets collected from 8,839 households in 2012, 7,934 households in 2015, and 7,241 in 2019. All three RALS waves were designed to be statistically representative of the rural population at the provincial and national levels, and 6,531 panel households were successfully interviewed over all three waves. This paper only uses data for these households who formed a balanced panel. Sampling and survey details can be found in CSO/MAL/IAPRI (2012); and CSO/MAL/IAPRI(2015).

4.2 Variables used in the main regressions

4.2.1 Dependent variables*:*

This paper aims to explain the effects of climate shocks on vulnerability and resilience. We computed poverty incidence using real household income deflated using consumer price indices (CPI) for the relevant survey years. We then estimated a level of real income that would equate the rural poverty rate in the 2015 RALS to the official national rural poverty rate reported in the 2015 LCMS. This gave us a national poverty line of ZMW 2,697 per adult, per year in 2015 Kwacha. That is, a household is deemed "poor" if real per adult income is less than the threshold of ZMW 2,697 per year.

We are also interested in understanding transitions in and out of poverty between 2012 and 2019. A household is chronically poor if it is recorded as being poor in all the three survey waves. A household that has escaped poverty is one that was poor either in 2012 and/or 2015 but not in 2019, while household entering poverty is one that was not poor in 2012 and/or 2015 but fell into poverty in 2019. It is worth noting that the preceding poverty transitions span a long period between 2012 and 2019 and that we are only able to observe poverty outcomes in the survey years. Thus, even if a household is observed as poor throughout the three waves, it is possible that it moved in and out poverty in the intervening years. Unfortunately, our data does not capture those transitions between survey years, so our observations reflect the minimum true extent of poverty mobility.

As stated before, our focus is not to explain drivers of poverty dynamics in Zambia, which in our view are well captured Ngoma et al., (2019) for the period 2012 – 2015 and Diwakar et al., (2020) for the period 2012 – 2019. Both analyses are based on the RALS data. We are interested here in the examining correlates among climate shocks, CSA, vulnerability, and resilience. We define vulnerability and resilience in the spirit of Barret and Constas (2014), where we explicitly consider welfare movements in and out of poverty over the three survey waves. Vulnerable households are those that were poor in all three survey waves or those that fell into poverty by the third wave.[10] A household is resilient if it was never poor in all three survey waves or escaped from poverty by the third wave.[11] Because we can only observe whether a household is vulnerable or resilient at the third survey wave, we generally use covariates in the third wave in a cross-sectional sense.

4.2.2 Independent Variables

In addition to the usual socioeconomic and demographic factors that may influence whether a household is vulnerable and its level of resilience, we computed variables to measure rainfall variability and exposure to climate shocks. We computed a *Standard Precipitation Index* (SPI) that measures rainfall variability following Patel et al. (2007). Using 30-year spatial rainfall data, we computed the SPI as in Equation 1:

$$SPI_{it} = (cag_{rainit} - \overline{cag_{rain30}})/sdag_{rain30} \qquad (1)$$

where SPI_{it} is the SPI for household *i* in year *t*, cag_{rainit} is total rainfall for the agricultural season in year *t*, *bar_cag*$_{rain30}$ is the average seasonal rainfall over the last 30 years, and $sdag_{rain30}$ is the standard deviation for seasonal rainfall over the last 30 years.

We adapt the approach of Azzarri et al. (2020) to compute a *drought risk variable* that measures exposure to climate risk as seasonal rainfall that is less than the average seasonal rainfall at the enumeration area level minus two standard deviations of the enumeration area seasonal rainfall. We define *flood risk* as seasonal rainfall that is more than the average seasonal rainfall at the enumeration area level plus two standard deviations of the enumeration area seasonal rainfall. We measured *rainfall variability* using the coefficient of variation of the 30-year rainfall and a measure of *rainfall stress*. Following agronomic recommendations as implemented in Ngoma et al., (2015), we define *rainfall stress* as the number of consecutive 20-day periods with less than 40mm of rainfall.[12]

We also include *30-year average rainfall* to measure the long-term effects and the current growing season corresponding to the survey reference period to measure short-term effects. In addition to these climate shocks, we also control for CSA adoption, crop diversity,[13] and access to credit, since these might influence how climate shocks affect vulnerability and

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[10] In terms of poverty transitions, vulnerable households are those who are chronically poor, or those who fell into poverty by the third survey wave regardless of whether they were poor or not in the first and second survey waves. This includes households that were poor in the first and third wave but not in the second wave, those poor in the second and third waves but not in the first wave or indeed those that were not poor in the first and second waves but fell into poverty in the third wave.

[11] This includes households that were never poor across the three survey waves, those poor in the first and second waves but not in the third wave, or poor in the first wave but not in the second and third waves, or ones that were not poor in the first and third waves but were poor in the second wave.

[12] We constructed this measure based on personal communications with agronomists based at the Zambia Agricultural Research Institute (ZARI).

[13] Computed as Simpson index based on area cultivated per crop relative to total area cultivated.

resilience. We generate a binary proxy measure for CSA if a household used at least one of either hybrid maize seed, inorganic fertilizer, or minimum tillage (MT).[14]

Before conducting our analysis, we expected a positive correlation between climate shocks and vulnerability, and a negative correlation between climate shocks and resilience. Table 1 defines the remaining variables. We chose all the variables used in the regressions based on the conceptual framework in section 2, drawing from several examples in the literature (see for example Jain, 2007; Thurlow et al., 2012; Wineman and Crawford, 2017; Al Mamun et al., 2018; Braimoh et al., 2018; Alfani et al., 2019; Ngoma et al., 2019; Azzarri et al, 2020).

4.3 Empirical strategy

Although the RALS is a longitudinal dataset, vulnerability and resilience are defined as single states over all three waves. This implies that most of our estimating equations are cross-sectional rather than fully exploiting the panel dimension of the data. We estimate a probit regression model, as specified in Equation 2:

$$\begin{aligned} y_{ij} &= \beta_0 + \boldsymbol{ClimS}_i\boldsymbol{\beta}_1 + \boldsymbol{X}_i\boldsymbol{\beta}_2 + \beta_4 credit_i + \beta_5 CSA_i \\ &\quad + \beta_6\left(\boldsymbol{ClimS}_i * CSA_i\right) + \beta_7 distmkt_i + \beta_8 Dist_i + \mu_i \end{aligned} \tag{2}$$

where *y* is a j^{th} dependent variable (*j* = vulnerable or resilient) for household *i*; ***ClimS*** is vector of exogenous climate shocks described above; ***X*** is vector of socio-economic and demographic factors such as assets, crop diversity, age and education level of the household head; *credit* is a dummy = 1 if any household member obtained credit from any source; *CSA* is a dummy =1 if a household used any MT (ripping, basins, and/or zero tillage for main tillage on at least one plot), hybrid maize seed and inorganic fertilizer; *distmkt* is the distance in kilometers from the homestead to the nearest main market; *dist* is a dummy controlling for district-specific attributes such as topology and other things, and μ_i is the idiosyncratic error term. In addition to the variables in levels, we also include interactions between CSA and each of the climate shock measures to assess if adopting CSA influences climate shocks effects on outcomes.

4.4 Identification strategy

Proper identification of Equation 2 requires addressing the endogeneity[15] of CSA adoption, crop diversity, and access to credit. Without this, the parameter estimates of the effects of climate shocks will be biased because these variables reflect farmer choices and may "co-determine" the outcomes. For example, farmers that adopt CSA, have diversified crops, and

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[14] MT is defined as the use of either ripping, planting basins, or zero tillage as the main tillage method at plot level. Minimum tillage is the most prevalent form and the basic CSA principle in Zambia. MT practices are known to help farmers adapt to water stress by improving water collection and retention in planting stations, while hybrid maize seed and inorganic fertilizers are key in helping farmers build resilience.

[15] In econometrics, "endogeneity" broadly refers to situations in which an explanatory variable is correlated with the error term.

accessed credit may be those with high intrinsic motivation so that they would likely be less vulnerable and more resilient even with climate shocks.

We used Wooldridge's (2010) approach to control for endogeneity. This involved estimating a reduced form equation of the endogenous variable (CSA, crop diversity, and access to credit, separately) with instrumental variables (IVs) and the rest of the right-hand side variables, and then predicting generalized residuals, which are then included in the main outcome equations together with the endogenous variable(s). We instrumented CSA adoption using a dummy variable = 1 if a household *accessed MT extension* in the 2015 survey round*,* crop diversity with a dummy = 1 if a household received advice related to crop diversification, and access to credit using a dummy =1 if anyone in the household is a *member of a loan or savings group*. We posit and test that access to CSA extension at *t-1* is likely to increase CSA uptake, as does membership to a loan or saving group for access to credit and access to information on diversification for crop diversity. These instruments are unlikely to affect outcomes directly except through their influence on the choice variables. Similar informational IVs have been used to study agricultural technology adoption in Africa, see for examples Alem et al., (2016); and Ngoma et al., (2016).

The final estimable equation (Equation 3) includes residuals for the CSA *(CSAres),* crop diversity *(div_res)* and access to credit *(creditres)* from the first stage regressions*:*

$$\begin{aligned} y_{ij} = {} & \beta_0 + \mathbf{ClimS}_i\boldsymbol{\beta}_1 + \mathbf{X}_i\boldsymbol{\beta}_2 + \beta_4 credit_i + \beta_5 CSA_i + \beta_6\left(\mathbf{ClimS}_i * CSA_i\right) \\ & + \beta_7 distmkt_i + \beta_8 Dist_i + \beta_9 CSAres_i + \beta_{10} divres_i + \beta_{11} credres_i + \mu_i \end{aligned} \tag{3}$$

Table 1: Summary statistics of key variables used in the regressions.

Variable	Description	mean	min	max	n
Dependent Variables					
Vulnerable	If poor in all the three survey waves or fell into poverty by the third wave in 2019 (yes =1)	0.76	0.00	1.00	6531
Resilient	If never poor over the three survey waves, or escaped poverty by the third survey wave in 2019 (yes=1)	0.24	0.00	1.00	6531
Independent variables					
Climate risk/exposure variables					
Drought risk (yes =1)	Seasonal rainfall < 2SD of 30-year average rainfall	0.17	0.00	1.00	6531
Flood risk (yes =1)	Seasonal rainfall > 2SD of 30-year average rainfall	0.56	0.00	1.00	6531
Seasonal rainfall	November – March rainfall amount	971	611	1463	6531
30 –year average rainfall	Average seasonal rainfall over 30 years	929	584	1330	6531
30-year rainfall coeff. variation	30-year rainfall coefficient of variation	0.16	0.09	0.24	6531

Standard precipitation index	Current rainfall less 30-year average divided by 30-year SD	0.24	0.00	2.00	6531
Rainfall stress	Number of 20-day periods with < 40mm of rain	0.29	-0.90	1.60	6531
Other independent variables					
Used CSA	Used min till, hybrid maize seed or fertilizer (yes = 1)	0.82	0.00	1.00	6531
Accessed credit (yes =1)	Accessed credit from any source	0.18	0.00	1.00	6531
Crop diversity	If Simpsons crop diversity index > median (yes =1)	0.45	0.00	1.00	6529
Asset index	Asset index from PCA	0.10	-2.56	23.91	6524
femalehead	Female head of household (yes = 1)	0.23	0.00	1.00	6531
ageh	Age of household head (years)	52.01	19.00	105.00	6531
eduhead	Education of household head (years)	6.04	0.00	18.00	6531
dep_rat	(Number of members aged < 14 + =>65)/# aged 15 – 64	162.46	0.00	1300.00	6319
mem0_5	# of members 0 – 5 years old	0.51	0.00	7.00	6531
mem5_10	# of members 5 – 10 years old	0.96	0.00	7.00	6531
mem10_15	# of members 10 – 15 years old	1.14	0.00	7.00	6531
mem15_64	# of members 15 – 64 years old	3.65	0.00	15.00	6531
mem_65	# of members 6 5 years and older	2.08	0.00	23.00	6531
farmsize	Farm size (ha)	5.19	0.00	517.10	6520
dmarket	Distance to market (km)	24.32	0.00	258.00	6531
Instrumental variables					
CSA-advice	Received advice on aspects of CSA	0.90	0.00	1.00	6531
div-advice	Received advice on crop diversity	0.74	0.00	1.00	6531
Mem-loan	Member of a loan/credit group	0.13	0.00	1.00	6531

5. Results

5.1. What climate shocks do farmers face in Zambia and do these vary by locality, household type and socio-economic status?

This is based on the 2019 wave of the RALS survey which includes retrospective questions on whether households experienced any droughts or floods during the 2015/2016, 2016/2017, 2017/2018 and 2018/2019 seasons. Over these four agricultural seasons, droughts were the most prevalent climate shock at the national level . The worst droughts—affecting nearly 63 percent (or 1,041,217) farm households—occurred during the 2018/2019 agricultural season (Tables 2 and S2). The worst floods—affecting about 12 percent or about 202,257 farm households— occurred during the 2017/2018 agricultural season in Zambia (Tables 2 and S1). The Southern and Western Provinces were the worst affected by droughts, with 99 percent and 95 percent of households respectively, reporting to have had at least one field crop affected by droughts during the 2018/2019 season. In terms of gender, 11.3 percent of female-headed households and 12.3 percent of male-headed households experienced floods in the 2018/2019 season (Figure S7). In general, and on average (except for the 2017/2018 season), male household heads are more likely than are female household heads to selfreport exposure to floods and droughts over the other four seasons captured in this study (Table 2 and Figure S7). Households owning farms between 5-10 hectares (ha) were more vulnerable to floods across in all four agricultural seasons compared to the rest of the farmland size groups. The average farm size in Zambia was between 4 and 5 ha across the three survey waves (Table 2). Households owning 5-10 ha, a relatively small group, are generally comprised of emergent farmers. The bivariate results in Table 2 do not show a clear difference in exposure to self-reported climate risks by poverty status.

Table 2: Proportion of Zambian households that experienced floods and/or droughts in any part of their fields by season, gender, farm size, and Province.

	2015/2016 season		2016/2017 season		2017/2018 season		2018/2019 season		
	Floods	**Droughts**	**Floods**	**Droughts**	**Floods**	**Droughts**	**Floods**	**Droughts**	**n**
All households	9.6	12.7	11.2	17.2	12.3	39.7	12.03	63 .4	7,240
Female headed	8.14	11.4	10.7	16	13.7	37.4	11.3	63.3	1729
Male headed	10.2	13.2	11.4	17.7	11.8	40.6	12.3	63.4	5511
Poor	9.63	12.34	11.45	16.82	12.11	41.30	11.81	65.46	6530
Farm size									
0-2 ha	7.15	14.0	9.28	17.9	10.7	40.8	13.0	60.1	3283
2-5ha	11.7	12.4	12.4	18.1	12.4	42.0	13.2	62.1	2712
5-10ha	10.5	11.4	12.4	15.6	14.3	36.2	9.33	68.1	861
>10ha	11.5	9.43	14.0	10.6	18.0	27.0	4.89	80.6	384
Net Income									
25th Percentile	7.49	13.6	8.78	19.4	11.6	43.7	14.2	63	1810
50th Percentile	10.6	14.2	12.9	19.1	13.7	40.6	13.5	63.5	1810
75th Percentile	10.9	10.6	12.4	15.5	13.2	36.1	9.68	61.4	1810
Gendered household type									
Female adults	7.54	11.6	8.85	15.8	13.4	36.3	11.0	63.9	821
Male adults	8.09	11.1	9.39	16.5	13.3	37.7	10.4	64.1	366
Male and Female adults	10.1	13.1	11.7	17.5	12.1	40.4	12.3	63.2	6048
Children	0	0	0	0	0	78.0	0	83.4	5
Province									
Central	12.9	4.92	15.2	8.21	10	50	5.24	77.2	566
Copperbelt	3.3	16.5	2.53	22	1.93	52.7	1.64	68.3	502
Eastern	7.06	23.9	9.37	34.4	9.65	66.8	33.1	46.1	1917
Luapula	3.37	7.31	5.98	8.62	8.49	20	5.48	40.2	615
Lusaka	5.99	6.08	10.6	6.54	6.67	26.6	2.31	85.2	404
Muchinga	6.08	12.3	8.18	16.2	12.9	33.3	21.2	33.8	679
Northern	6.54	21	5.72	30.3	13.1	35.8	17.3	43.7	707
North-Western	3.68	1.58	7.47	3.91	7.82	14.7	4.69	57.2	486
Southern	16.1	10.3	11.9	11.3	7.82	41.8	0.33	99	810
Western	22.6	8.68	30.6	8.37	39.2	19.9	3.51	95.1	554

Source: Own calculations from RALS (2019).

Figures S8 and S9 show the spatial distribution of floods and droughts over the past four agricultural seasons at the Province level. As expected, a larger proportion of households experienced floods in the southern half of the country during the El Niño year in the 2015/2016 agricultural season (Figure S8), but more households in the Western Province reported experiencing some form of floods in their fields from the 2015/2016 season to the 2017/2018 season. While the Southern and the Western Provinces were the worst affected by droughts in the 2018/2019 season, these Provinces were hardest hit by floods during the El Niño years in the 2015/2016 and 2016/2017 agricultural seasons (Table 2). A similar trend is found by agro-ecological zone, see Figure S10. These results suggest an increased occurrence of climate shocks, with droughts and floods experienced in succession.

Self-reported incidences of droughts were more prominent in the historically high rainfall northern and eastern regions of Zambia, and in parts of Central and Copperbelt Provinces in the 2015/2016 and the 2016/2017 agricultural seasons (Figures S8 and S9). The situation was very different during the 2017/2018 and 2018/2019 seasons, when the locus of drought incidences concentrated in agro-ecological zones I, IIa and IIb covering parts of the Southern and Western Provinces, where more than 90 percent of rural farm households reported having experienced some form of drought in parts of their fields (Figures S8 and S9).[16]

Smallholder farmers are perceiving these changes in climate patterns. About 65 percent and of smallholder farmers felt that seasonal rainfall had reduced while 53 percent felt that temperature had increased between the 2015/2016 and 2017/2018 agricultural seasons in Zambia (Figures S1 and S2).

Farmers are adapting and building resilience to these perceived changes in rainfall and temperature. The five most common coping mechanisms against food shortages—which may also help build resilience—include spending household savings (22.2 percent of households), purchasing food on credit (20 percent), borrowing money to buy food (18.2 percent), reducing non-food expenditures such as education, health, and clothes (7.96 percent), and depending on food rations or support from neighbors and relatives for food and income (7.56 percent) (Figures S5 and S6).

5.2. Exposure, vulnerability, and resilience among rural smallholders in Zambia

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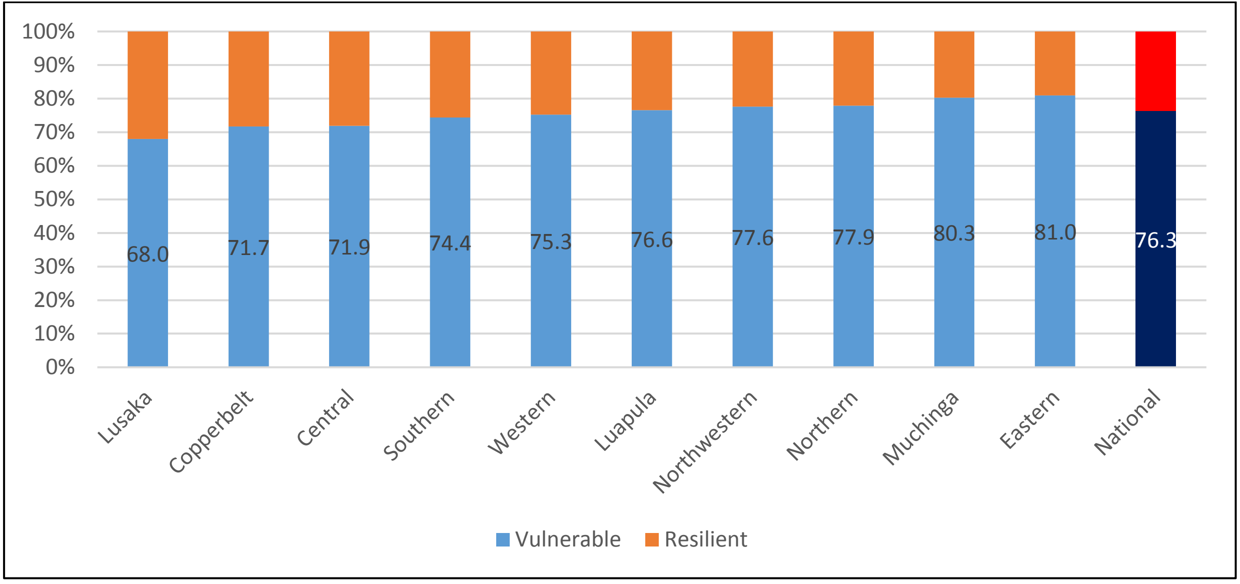
[16] Zambia is divided into four agro-ecological regions. Agro-ecological region 1 receives less than 800mm of rainfall per annum, agro-ecological region IIa receives 800 -1000mm and has clay loamy soils. Agro-ecological zone IIb receives 800 -1000mm of rainfall and has sand soils, while agro-ecological zone III receives more than 1000mm of rainfall per year.

Vulnerability and resilience are measured using income-based poverty transitions. Recall from subsection 4.2.1 that vulnerable households are those that were poor in all three survey waves or those that fell into poverty by the third wave, while resilient households are those that were never poor during the three survey waves or escaped from poverty by the third wave. At the national level, 76 percent and 24 percent of rural smallholder farmers are vulnerable and resilient, respectively (Figure 2). Eastern, Muchinga, Northern, and North-Western Provinces had, on average, a larger proportion of vulnerable households than the national average; while Copperbelt, Central, and Lusaka Provinces had, on average, a larger proportion of rural households that were resilient than the national average (Figure 2).

Figure 2: Proportion of vulnerable and resilient rural households between 2012 and 2019 in Zambia

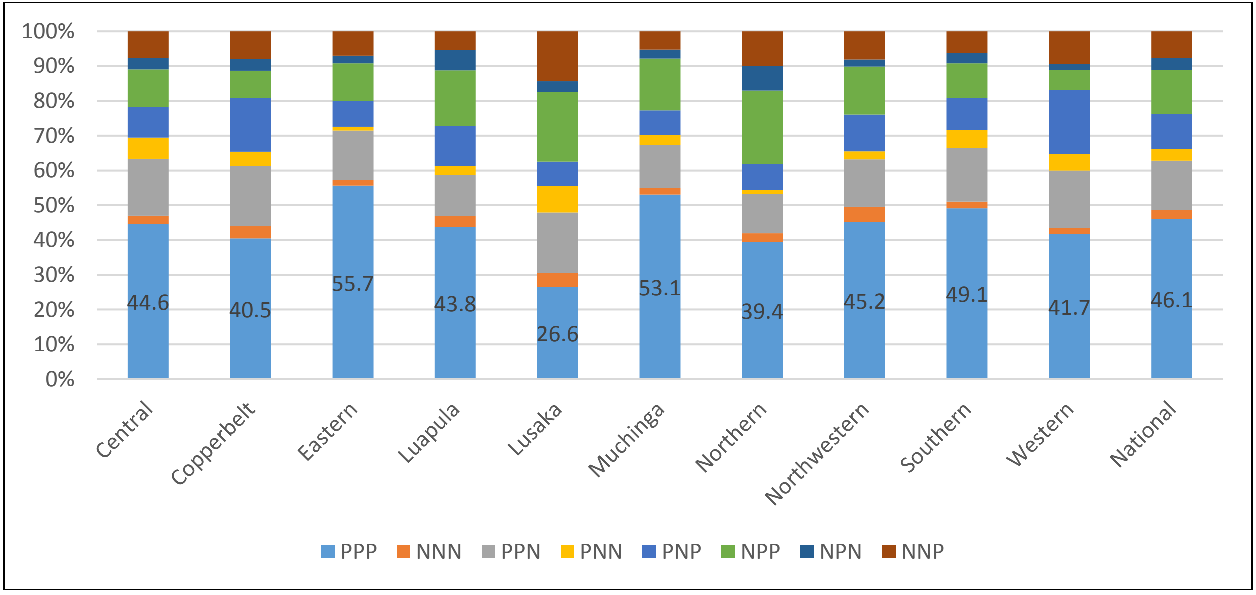


Notes: Own calculations from RALS (2012-2019).

Further disaggregated results in Table S3 show that only about 19 percent of female-headed households were resilient compared to 25 percent for male-headed households. About 81 percent of female-headed households were vulnerable compared to 75 percent among male-headed households. We further disaggregated the results by three household types. Male adult-only households, female adult-only households, and a third category in which the household is comprised of both male and female adults. Among these gender types, about 80 percent of female adults-only households were vulnerable compared to 47 percent for male adults-only, and 77 percent for mixed male and female adult households. A smaller proportion of female adult-only households were less resilient at only 20 percent compared to 53 percent for male adult households, and 23 percent for both male and female adult households (Table S3). Thus, female-headed and female adult-only households are more vulnerable and less resilient. Households that used CSA, as defined in this paper, were more resilient and less vulnerable, but the differences are small.

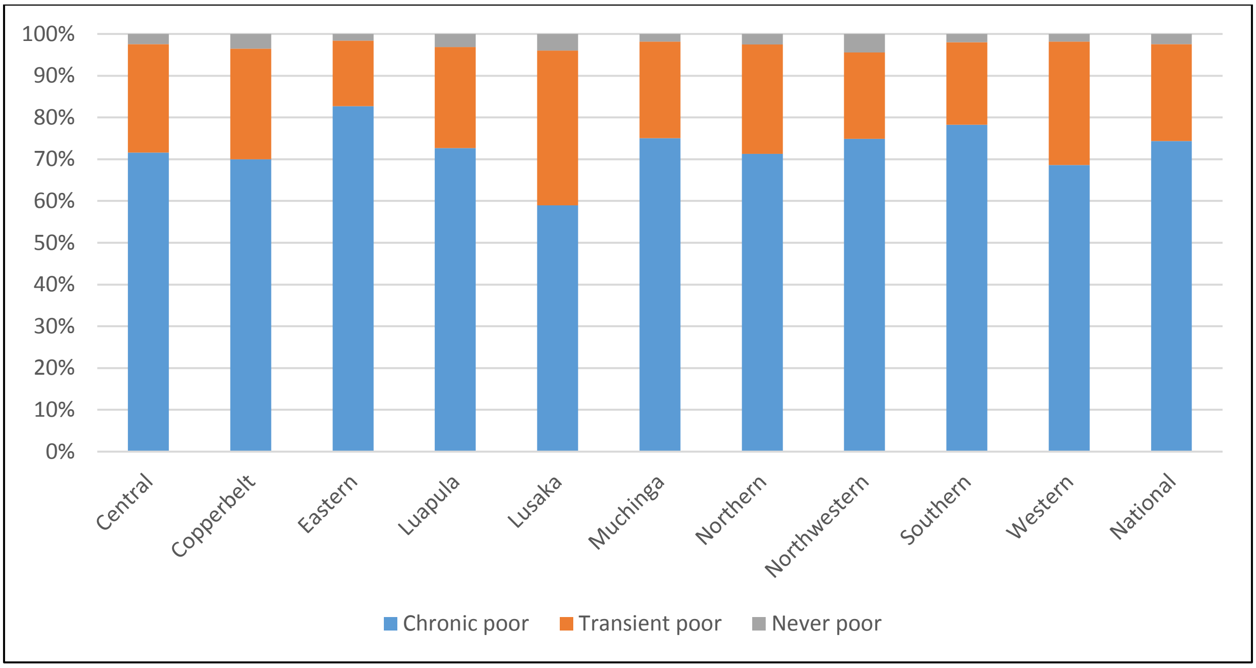
Figure 3 presents transitions in and out of poverty over the three survey waves in 2012, 2015, and 2019. At the national level, 46 percent of smallholder farmers were poor in all three survey waves in 2012, 2015, and 2015, while 2 percent were never poor (Figure 3). The rest of the farmers transitioned from being poor to non-poor status, or vice versa, over the three survey waves. For example, 13 percent of smallholders that were not poor in 2012 fell into poverty in 2015 and 2019, and about 14 percent of smallholders that were poor in 2012 and 2015 escaped poverty in 2019. About 3 percent of smallholders transitioned from being poor in 2012 and escaped poverty in 2015 and 2019. Nearly one-tenth of smallholder farmers were poor in 2012 and 2019 but not in 2015, and about 4 percent were poor in 2015 but not in 2012 and 2019. These transitions in and out of poverty define chronic and transitory poverty in Figure 4. A household that was poor in all three survey waves is chronically poor, while one that was not poor in all waves was never poor. A household is transient poor if they were poor in one or two survey waves.

Figure 3: Poverty transitions among rural households over three surveys: 2012, 2015, 2019



Notes: Own calculations from RALS (2012-2019). PPP and NNN signal poor and not poor in all three waves, respectively, whereas alternating P and N letters signals whether a household was poor (P) or not poor (N) in a given survey year. For example, PPN means poor in 2012 and 2015 but not in 2019.

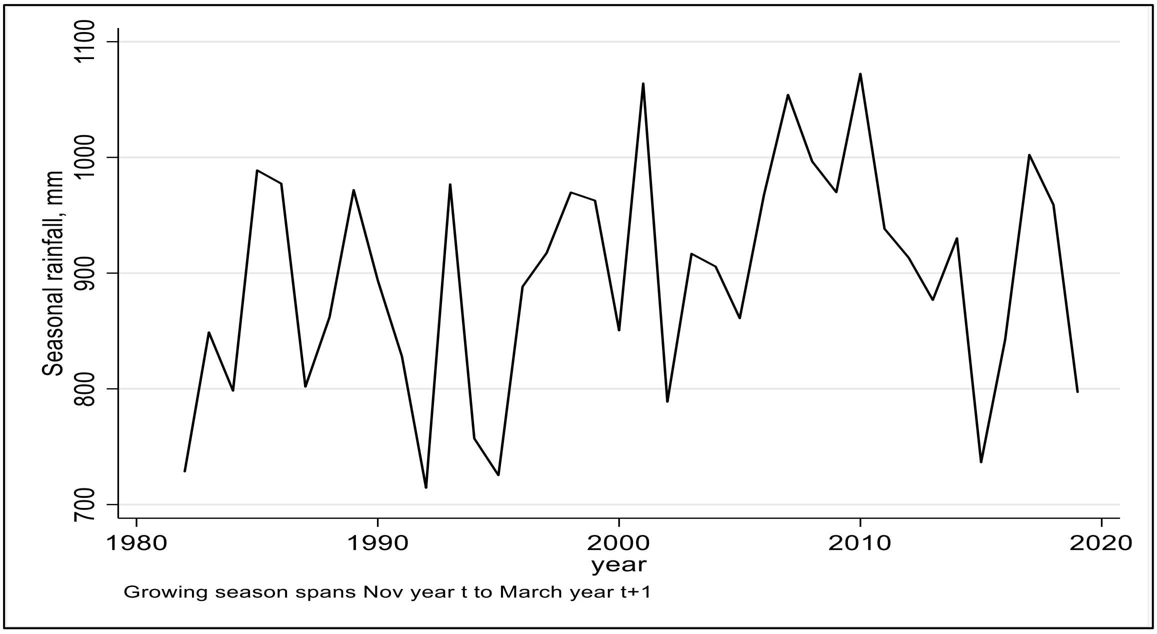
Figure 4: Proportion of chronic, transient, and never poor rural households between 2012 and 2019 in Zambia



Notes: Own calculations from RALS (2012-2019).

We also investigate the variability of seasonal rainfall and how this differs by Province. We then compare this with poverty incidence at the Province level in order to get a sense of the extent of exposure. In line with results in section 5.1, growing season rainfall from November to March is highly variable both at the national and Provincial levels (Figures 5).

Figure 5: Trends in total growing season rainfall (in mm) from 1982 to 2019 in Zambia



Source: Own calculations based on CHIRPS data.

Rainfall variability is more pronounced at Province level, with the Western Province showing high rainfall variability on the lower end of the seasonal rainfall distribution. This is the trend with Provinces in agro-ecological zones I and II experiencing much lower average seasonal rainfall than those in the high rainfall zones such as the North-Western and Northern Provinces. Droughts and floods are therefore more likely to affect households in zones I and II. This corroborates our earlier findings in section 5.1 and earlier studies suggesting that droughts are the most common climate shock in Zambia (Braimoh et al., 2018; Table 2). While it is difficult to say whether these changes in rainfall patterns lead to poverty or not, what is clear from the data is that chronic poverty—that is, households that are poor across all the three survey rounds—concentrates in parts of the Southern, Eastern, Muchinga, and North-Western Provinces (Figure 4). Except for the Southern Province, these also have the highest proportions of vulnerable households (see Figure 2 and Table S4).

5.3. Climate shock impacts on vulnerability and resilience in rural Zambia

Table 3 presents annotated outputs from the first stage probit regressions where we test and confirm that each of the candidate IV strongly correlates with a given endogenous variable. (full results are available in Table S3 in the supplementary materials.)

Table 3: Average partial estimates of the first stage results showing relevance of the chosen instrumental variables for each endogenous variable (model)

	Model 1: Used MT	**Model 2: Access to loans**	**Model 3: Crop diversity**
Received CSA advice at *t-1*	**0.031**** **(2.081)**		
Member loan group		**0.201***** **(11.288)**	
Received advice on crop diversity			**0.068***** **(3.840)**
. . .	. . .	. . .	. . .
Observations	6,302	6,303	6,303

Notes: Models 1 – 3 were estimated as separate probit regressions since with a binary endogenous variable as the dependent variable. IVs for each model are shown in bold as the first three independent variables. Robust t-statistics in parentheses: *** p<0.01, ** p<0.05, * p<0.1

We estimated several different model specifications to assess correlates among climate shocks, vulnerability, and resilience in Zambia. We estimated two model variants where each model includes all the climate shock variables with either seasonal rainfall or the 30-year average for seasonal rainfall. Figures 6 and 7 report selected average partial effects for correlates between climate shocks and vulnerability and resilience, respectively. Table S4 (in the supplementary materials) reports full results for the control function probit and Table S5 reports results for the regular probit. The top panels in Figures 6 and 7 include all the climate shock variables and seasonal rainfall, while the lower panels include all climate shock variables with the 30-year average rainfall. To check for robustness, we report further results in the supplementary materials for alternative models where we separate CSA into its constituent components (minimum tillage, fertiliser, and hybrid maize seed) (Tables S6 and S7). For all estimations, CSA interacts with all climate variables to assess whether using CSA mediates climate shock effects on vulnerability and resilience. We also include the residuals from the first stage in all the reported results. Significance of these residuals confirms statistical endogeneity. We keep the residuals whether they are statistically significant or not because these choice variables are endogenous by construction.

We find evidence that using CSA influences climate shock effects and directly improves resilience (Figure 7 and Table S4). Using CSA in the 2019 survey year (which corresponds to the period when outcomes are measured) is associated with a 22-percentage point increase in the probability that a household is resilient (Figure 7 and Table S4). The MT component of CSA seems to be the main driver of these results (Table S8).

The other results in Table S4, S6, and S7 (in the supplementary materials) are as expected. Having assets and higher education level of the household head are associated with reduced vulnerability and increased resilience. Female-headed households and those headed by older heads are associated with higher vulnerability and reduced resilience.

Figure 6: Selected average partial estimates of the effects of climate exposure on vulnerability among smallholders in Zambia.

Figure 6a: Impact on **vulnerability** with estimation including seasonal rainfall

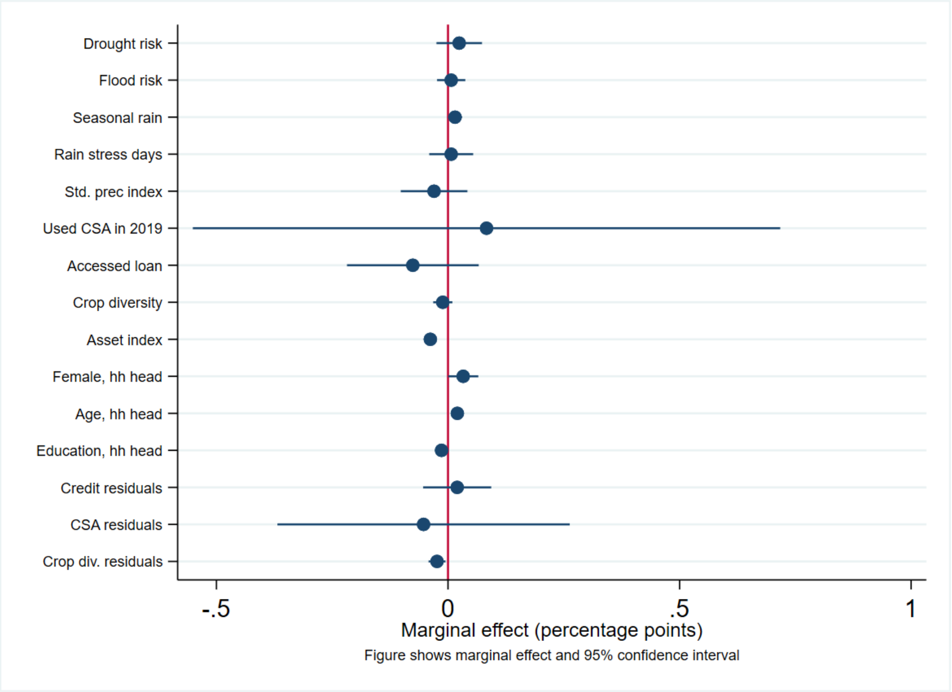
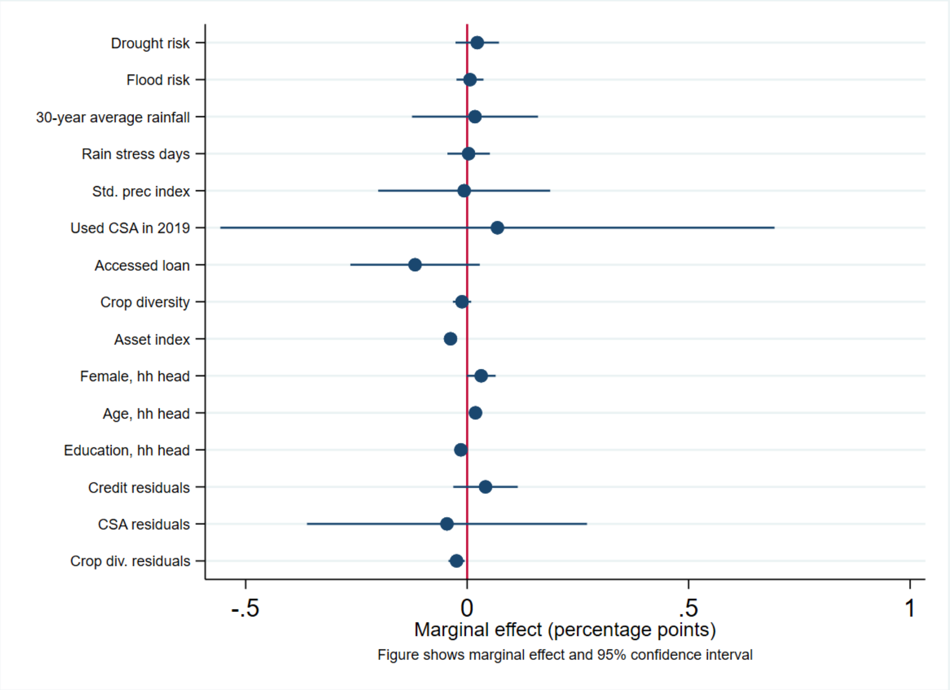


Figure 6b: Impact on **vulnerability** with estimation including 30-year average rainfall



Notes: The top panel includes all weather shock measures and current seasonal rainfall, whereas the lower panel includes 30-year average rainfall. A confidence interval for a point estimate that lies on either side of the zero shows that the estimate is statistically significant.

Figure 7: Selected average partial estimates of the effects of climate exposure on resilience among smallholders in Zambia.

Figure 7a: Impact on **resilience** with estimation including seasonal rainfall

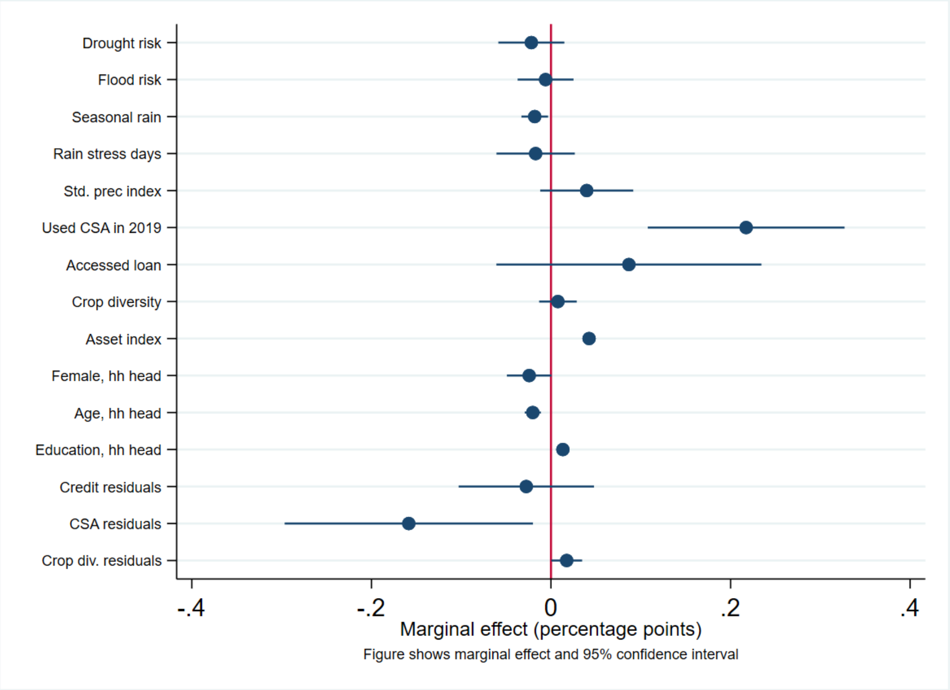
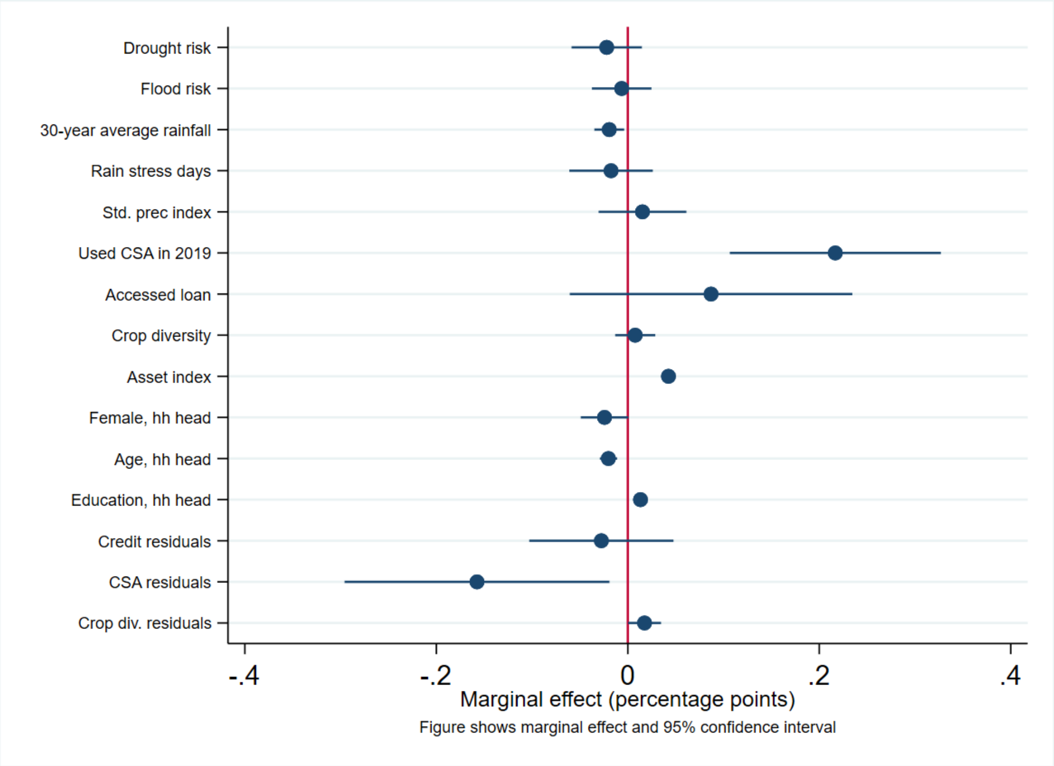


Figure 7b: Impact on **resilience** with estimation including 30-year average rainfall



Notes: The top panel includes all weather shock measures and current seasonal rainfall, whereas the lower panel includes 30-year average rainfall. A confidence interval for point estimate that lies on either side of the zero shows that the estimate is statistically significant.

6. Discussion

6.1. Exposure to climate risk resilience and vulnerability in rural Zambia

Our results on the prevalence of drought risk in Zambia is in line with Braimoh et al. (2018), who found that droughts are the main risk facing the agricultural sector in Zambia. Increasing rainfall variability in the country implies that some rural farm households are exposed and vulnerable to both droughts and floods, with significant differences across regions.

On average, and as defined in the paper, proportions of vulnerable and resilient households in Zambia's Southern and Western Provinces are similar to the national averages. However, there were more vulnerable households in Eastern, Muchinga, Northern, and North-western provinces than the national average. Copperbelt, Lusaka, and Central provinces had larger proportions of resilient households. These findings call for tailored and targeted agricultural development interventions to help farmers adapt to these observed and projected weather changes.

Although Zambia's Southern and Western Provinces are in low rainfall agro-ecological zones, our results suggest that they can be exposed to floods during extreme weather events. For example, during the El-Niño years in 2015 and 2016 nearly half (47 percent and 42 percent, respectively) of all Zambian smallholder farmers affected by floods were in these two provinces. While droughts are a major climate shock or risk to agricultural production and livelihoods in Zambia, our findings suggest that floods *are* an important risk. Thus, risk mitigation and management require strategies to address both droughts and floods in smallholder agriculture.

6.2. Impacts of climate risk on vulnerability and resilience in rural Zambia

Our econometric findings link exposure to climate shocks to worsened vulnerability and reduced resilience. This demonstrates that weather shocks have negative consequences for livelihood. Our findings suggest that higher current growing season rainfall increases the chances that a household will be vulnerable and reduces their resilience. This is in line with Alfani et al. (2019) and Al Mamun et al. (2018), who find that El-Niño weather events reduced productivity and increased poverty in Zambia. Our findings are also in line with Azzarri et al. (2020), who find that flood shocks increase poverty and reduce expenditures among households in SSA. Poverty, expenditure, vulnerability, and resilience are clearly linked. Our findings are also in line with Thurlow et al. (2012) and Ngoma et al. (2020), who find that climate change is likely to reduce agricultural productivity and worsen poverty and household welfare in Zambia. This is also in line with findings in the Zambia Climate Smart Investments Plan, which suggest that climate change is likely to reduce crop productivity by up to 25 percent (World Bank, 2018).

Long-term and current seasonal rainfall are associated with increased vulnerability and reduced resilience, as weather shocks have both short-term and enduring negative effects. While we do not measure how long-term rainfall might affect vulnerability and resilience directly in the paper, we can speculate that rainfall alters farmer behavior. As suggested in Sesmero et al. (2017) and Mulenga et al. (2017), past weather events may influence farmers' expectations of future weather patterns. These expectations in turn might influence current production decisions, including the choice of seed varieties and farming technologies.

In line with Sesmero et al. (2017), we find that higher assets and education enhance resilience. These factors also seem to reduce vulnerability. Our results find that the gender of the household head affects household vulnerability and resilience in Zambia, bringing to the fore the gendered effects of climate shocks: female-headed households are significantly more likely to be vulnerable and have less resilience. According to a Food and Agriculture Organization (FAO) report on women in agriculture, female-headed households do not usually have access to similarly productive resources and land as males (FAO, 2011). This inequitable access to productive resources, coupled with the heavier societal burdens of home chores, likely worsens women's vulnerability and reduces their resilience.

Our results suggest that adopting CSA practices might help enhance resilience, in line with expectations. This finding corroborate those of Michler et al. (2019), who found that CA helped farmers adapt to rainfall variability in Zimbabwe, those of Ngoma et al (2016), who suggest that droughts increase the probability of farmers adopting MT in Zambia and

Zambia’s CSA investment plan which finds that CSA increases household welfare in the long term (World Bank, 2018). These results should not be understood to suggest that CSA is some kind of “magic bullet”. If carefully packaged, some CSA practices may have potential to raise resilience. In our case, CSA includes the use of MT, inorganic fertilizer, and hybrid seed, and the use of MT seems to be the biggest factor in improving resilience (Table S7)even if we do not further investigate the causal chain. Prioritizing what works where and under what circumstances is key in scaling CSA. Zambia’s CSA investment plan identify cereal-legume crop diversification, commercial horticulture, agroforestry and reducing post-harvest losses as some of the most promising CSAs in the country (World Bank, 2018).

We urge some caution in interpretating the results of this paper:

- First, while we attempted to address some key endogenous factors and their effects on vulnerability and resilience—namely, CSA adoption, crop diversity, and access to credit—the success of our approaches depends on how good the instruments used are, and how well the exclusion restrictions are met. These are difficult empirical issues and ones that every economist will question. Collapsing RALS data to cross sectional data that allows us to measure vulnerability and resilience after three-waves complicates matters. We are, however, confident that our approaches—which allow us to better measure vulnerability and resilience and apply instrumental variable probit models—add value to existing studies linking climate shocks, CSA, vulnerability, and resilience.

- Second, we acknowledge that CSA as defined in this paper (minimum tillage, inorganic fertilizer, and hybrid seed) captures only short-term effects. This is because we are not able to assess for how long farmers have used these CSA practices on the same plots. We propose that future research should control for long-term plot-level CSA effects on vulnerability and resilience.

- Lastly, although our income-based poverty measures are presumably broadly aligned with consumption expenditure-based measures, they may be an imperfect substitute for expenditure-based metrics, which are more commonly used in the country.

7. Conclusion

This paper assessed the extent to which smallholder farmers in Zambia are exposed to climate shocks using both exogenous and self-reported shock measures. It then evaluated the impacts of climate shocks on vulnerability and household resilience and assessed the extent to which climate-smart agriculture (CSA) practices—defined as minimum tillage, inorganic fertilizers, and hybrid maize seed—influence outcomes. We used a three-wave household panel data obtained from the nationally representative Rural Agricultural Livelihoods Survey (RALS). We restricted our analysis to a subset of households re-interviewed over the three-waves for a total sample of about 6,531 households and applied an instrumented probit regression that allows us to control for endogeneity of some choice variables. Vulnerability and resilience are defined based on whether a household is “poor”, “never poor”, “escaped poverty”, or “fell into poverty” over the three-survey waves and measured in the third wave in 2019.

We found that smallholder farmers in Zambia are more exposed and therefore vulnerable to droughts, the more prevalent climate shock rural households face. The extent of exposure differs both spatially and over time, but on balance, Zambia’s Southern and Western Provinces are most exposed to climate shocks. About three-quarters of all smallholders are vulnerable and nearly one-quarter are resilient nationally. There are important differences between Provinces, with the Eastern, Muchinga, Northern, and North-western Provinces being the most vulnerable. Our multivariate analysis suggests significant correlation between (i) climate shocks and worsened vulnerability, and (ii) between climate shocks and reduced resilience. We also found some evidence suggesting that assets and education reduce vulnerability and increase resilience among smallholder farmers in Zambia, and that female-headed households are more vulnerable and less resilient. Using CSA is associated with increased chances that a household will be resilient in the short-term.

We therefore conclude that most smallholder farmers in Zambia are exposed to climate shocks and are vulnerable, and that climate shocks are associated with vulnerability and resilience. The current use of CSA is associated with improved resilience among smallholder farmers. We draw two main implications from these finding:

First, based on the positive association between CSA and resilience, there is an urgent need to invest in CSA Research and Development to scale-out and scale-up context specific CSA practices. In the context of CSA as adaptation options, this implies a need for timely delivery of climate information services, perhaps through innovative digital platforms.

Second, there given the significance of climate shocks on resilience and vulnerability, there is need for more investment in risk mitigation strategies, such as weather indexed insurance and targeted social cash transfers and how to make these work effectively for smallholder farmers. This will enable farmers to access coverage against climate shocks that make their households vulnerability and reduce their resilience. While there have been attempts to implement insurance programs in Zambia, it is not clear if they have been successful or how to make such programs work for smallholders. Other important complementary elements include facilitating asset accumulation and education that can increase resilience.

About the authors

Ngoma (h.ngoma@cgiar.org) is formerly Research Fellow and Lead, Climate Change and Natural Resources Management at the Indaba Agricultural Policy Research Institute, Lusaka, Zambia; and is now Agricultural Economist at the Southern Africa Regional Office, International Maize and Wheat Improvement Center (CIMMYT).

Finn (afinn1@worldbank.org) is an Economist in the Poverty and Equity Global Practice at the World Bank, Washington, DC.

Kabisa (mulako.kabisa@iapri.org.zm) is Research Associate at the Indaba Agricultural Policy Research Institute, Lusaka, Zambia.

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