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Farm diversification as an adaptation strategy to climatic shocks and implications for food security in northern Namibia

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ABSTRACT

Limited non-farm opportunities in the rural areas of the developing world, coupled with population growth, means agriculture will continue to play a dominant role as a source of livelihood in these areas. Thus, while rural transformation has dominated recent literature as a way of improving welfare through diversifying into non-farm sectors, improving productivity and resilience to shocks in smallholder agricultural production cannot be downplayed. This is especially so given the changing climatic conditions affecting agricultural production, and thus threatening many livelihoods in rural areas. Farm diversification is an important strategy for creating resilience against climatic shocks in farm production. Using cross-sectional data from northern Namibia, the study assesses the barriers and success factors related to effective crop and livestock enterprises diversification and the effect of these on food security outcomes. A Seemingly Unrelated Regression model is used to assess the joint factors explaining total farm diversification, while a step-wise error correction model is used to evaluate the conditional effect of diversification in each of the two farm enterprises on two measures of food security: food expenditure and dietary diversity. We find that past exposure to climate shocks informs current diversification levels and that access to climate information is a key success factor for both livestock and crop diversification. In terms of food security, greater diversification in either crop or livestock production leads to higher food security outcomes, with neither crop nor livestock diversification showing dominance in affecting food security outcomes. However, an overall higher level of diversification in both livestock and crop enterprises is dominant in explaining food security outcomes.

1. Introduction

Risk is inherent in small-scale rain-fed agricultural production. Farmers have to contend with seasonal weather uncertainties, the threat of pests and diseases, and post-harvest losses, among other risks. These risks are being exacerbated by the effects of a changing climate; for example, the severity and distribution of important livestock and crop diseases is changing, while incidents of droughts and floods are on the rise (Elad & Pertot, 2014; Thornton, van de Steeg, Notenbaert, & Herrero, 2009; Wetherald & Manabe, 2002). These effects of climate change are expected to increase poverty incidences in most developing countries and create new poverty pockets in countries with increasing inequality (IPCC, 2014).

Agricultural production has been stagnant in Sub-Saharan Africa (SSA), and there is consensus that the current trend in productivity cannot guarantee food security in the region (Jayne, Chamberlin, & Headey, 2014; Kyalo Willy, Muyanga, & Jayne, 2019; Onyutha, 2018). Climatic shocks that further adversely affect food production are a serious threat to food security and livelihoods in the region. While there are adaptation options that can create resilience in agricultural productivity, studies continue to show low adoption rates across the region (Bradshaw, Dolan, & Smit, 2004; Di Falco, Veronesi, & Yesuf, 2011; Mulwa, Marenya, Rahut, & Kassie, 2017; Singh et al., 2017; Smit & Wandel, 2006). In crop farming, such adaptation measures include using seeds adapted to climate-stressors (for example drought resistant seeds) and spreading risks across different crop types (Howden et al., 2007). In livestock farming, farmers can also choose to adopt livestock breeds that are tolerant to climate-stressors, as well as diversify into different livestock types/species (Melissa Rojas-Downing et al., 2017).

Recent literature on diversification focuses on rural transformations from predominantly agriculture-related sectors to rural non-farm sectors (see for example Barrett, Christiaensen, Sheahan, & Shimeles, 2017). While this is important in reducing the prevalent

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disguised unemployment in peasant agriculture, such non-farm opportunities remain largely non-existent in rural areas of SSA. With the recent phenomena of climate change effects threatening to depress agricultural productivity further and jeopardize livelihoods for many in these regions, evaluating strategies for creating resilience in the sector cannot be overlooked (Bradshaw et al., 2004). This study aims to evaluate households' farm diversification as an adaptation strategy to climatic shocks, and the on effect food security.

Most studies assessing farm diversification focus on either crop or livestock diversification (Adjimoti & Kwadzo, 2018; Makate, Wang, Makate, & Mango, 2016; Mango, Makate, Mapemba, & Sopo, 2018; Megersa, Markemann, Angassa, & Valle Zárate, 2014; Rojas-Downing et al., 2017; Tittonell, 2014). Others extending to both farm and non-farm diversification treat farm diversification as one activity that encompasses crop and livestock farming (Berhanu, Colman, & Fayissa, 2007; Martin & Lorenzen, 2016). An exception is Tibesigwa, Visser, and Turpie (2015) that compared outcomes of farmers who are specialized in either of the enterprises with those of farmers who practice mixed farming. Considering livestock and crop diversification separately may underestimate joint effect on food security, and does not allow for the identification of barriers to each diversification type. Similarly, comparing specialized systems with mixed ones hides information on how the extent of diversification in each enterprise affects welfare. Furthermore, it is difficult to encounter specialized systems among smallholder farmers, who more often practice a mix of crop and livestock activities (as exemplified in northern Namibia).

Our study adds to this literature by assessing the joint determinants of diversification in both livestock and crop farming, and how the extent of diversification in each activity contributes to food security. Further, in a novel attempt to assess which enterprise diversification contributes most to food security, the study compares food security outcomes for households with varying levels of crop and livestock diversification.

1.1. Climate change and farm diversification

Diversification literature identifies factors that "push" farmers to diversify as a hedge against risks, and factors that "pull" farmers to diversify in order to take advantage of other opportunities. In farm diversification, an example of a push factor may be the increasing climate shocks that make it risky to rely on a certain crop (e.g. maize) or livestock type (e.g. cattle) as the only enterprise, necessitating the adoption of a mix of crop and livestock types that may be more resilient to climate shocks. A "pull" factor on the other hand may be the advantage of planting crop mixes that are symbiotic, e.g., planting runner beans that use maize stalks as support, while fixing nitrogen fertilizer for the maize crop.

Climate change affects livestock production through impacts on pasture and water, as well as through diseases associated with climate shocks (Rojas-Downing et al., 2017). Choosing the optimal count of livestock and livestock types to keep is key to mitigating these impacts. Declining pastures and water availability may call for substitution of resource-demanding species like cattle for the more resilient small ruminants like goats and sheep (Gautam & Andersen, 2016). In Namibia, the importance of mixing small ruminants with cattle rearing is more pronounced; while cattle ownership is a symbol of prestige and the animals are used for festivities like weddings, funerals and bride price (Musemwa et al., 2008), the small ruminants are important for providing nutrients and dietary diversity, either through direct consumption or sale. In Ethiopia, Megersa et al. (2014) found that households that were more diversified in livestock production had higher average off-take in livestock sales, had fewer months of food insecurity, and scored higher on household food dietary diversity.

Crop diversification involves the use of different seed varieties of the same crop type, as well as planting of different crop types in a farming season. Agricultural intensification inputs like hybrid seeds have been the core of agricultural transformation since the green revolution. Within the context of a changing climate, improved seeds have to be not just output enhancing but also resilient to shocks like droughts and pests (Lin, 2011; Mulwa, Marenya, Rahut, & Kassie, 2017). Incorporating these types of seeds in a mix of crops and varieties planted can be an important adaptation strategy for resilience. Other benefits of diversified cropping systems include improving soil fertility and expanding household's dietary diversity for improved nutrition uptake.

Studies show that at the subsistence level, diversification into both crop and livestock production is complementary (Berhanu et al., 2007; Megersa et al., 2014). Farmers can use crop residues as livestock feed while animals provide draught power and manure (Megersa et al., 2014). This relationship may however have a threshold level above which competition for scarce resources leads to one crowding out the other. For example, with scarce labor, households may only practice crop farming, which has a higher marginal return to labour, while those with higher labour supply may be able to diversify into livestock (Berhanu et al., 2007).

The success factors for diversification as identified in the literature include social capital, asset ownership, government/NGO transfer programs, remittances and off-farm opportunities (Barrett, Bezuneh, & Aboud, 2001; Davis et al., 2010; Wuepper, Yesigat Ayenew, & Sauer, 2018). Investigating the importance of each of these for diversification in the study region is important for policy. The dearth of literature on agricultural production and food security in the study region further shows the importance of this study.

1.2. Study area

This study was conducted in three regions in northern Namibia: Omusati, Oshana and Oshakati. Climate in the region is semi-arid and rainfall is seasonal and highly variable both in quantity and timing. A changing climate has resulted in shorter rain seasons characterised by high temperatures, late onset of rains and higher incidences of droughts (Government of the Repulic of Namibia, 2011). This has exacerbated vulnerability of livelihoods in the region which are highly dependent on natural resources and comprise mostly rain-fed subsistence agriculture. There is low adaptive capacity in the region and Namibia is considered to be among the highly vulnerable African countries with regard to climate change (Reid, Sahlen, Stage, & MacGregor, 2007).

Land use in the region is characterised by combining livestock herding and small-scale cereal production, supplemented by timber and non-timber resources like wild fruits and *mopane* worms (Newsham & Thomas, 2009). A significant proportion of households (25%) participate in off-farm income ventures, while 23% participate in government transfer programs. This number is relatively small, though, compared to those who rely on farming and forest products (timber and non-timber) for livelihoods (see Fig. 1).

1.3. Sampling and data

Data for this study come from the Adaptation at Scale in Semi-Arid Regions (ASSAR) project. A multistage random sampling procedure was used to select 650 households from three regions in northern Namibia. First, the three regions (Oshana, Omusati and Oshikoto) were purposively selected based on agricultural productivity and exposure to climate change.

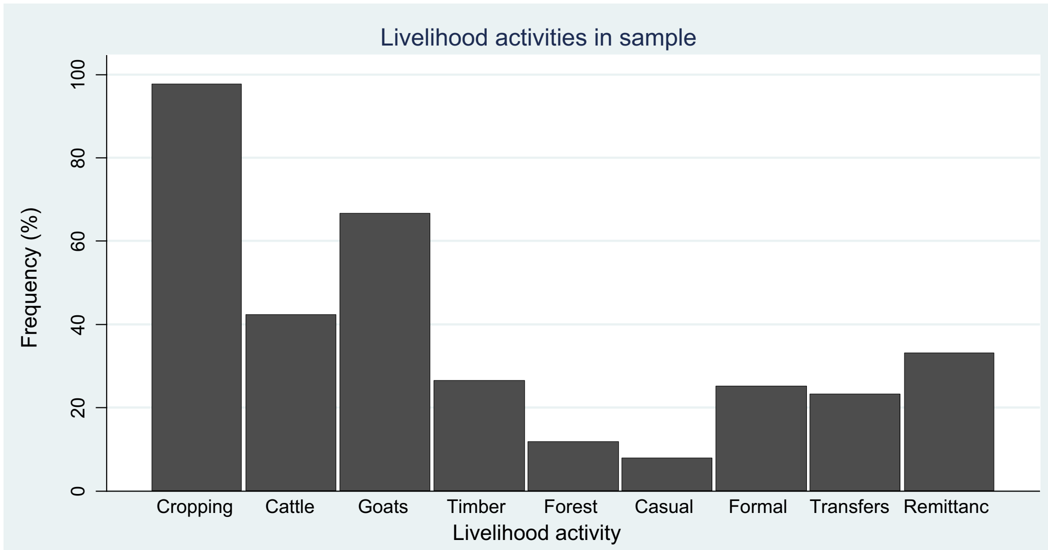

Fig. 1. Livelihood activities practiced Crop cultivation remains the most practiced livelihood activity in the region while a high proportion also rear livestock (cattle and small ruminants).

Two constituencies were each selected from Oshana and Oshikoto and three from Omusati to capture the diversity within the regions. Random proportionate to size sampling was then used to select villages and households to include in the survey. Data was collected by a team of trained enumerators using as structured questionnaire in the months of August and September 2017.

2. Construction and description of variables

2.1. Farm enterprise diversification indices

Different types of indices have been used in the literature to measure livelihood diversification (Davis et al., 2010; Lay, Mahmoud, & M'Mukaria, 2008; Wuepper et al., 2018). Our study aimed to investigate not only the number of farming activities a household is engaged in, but also the intensity of engagement in each. To this end, we chose the Herfindahl–Hirschman index (hereafter HHI) which is mostly used in finance to measure market concentration, and has been applied previously in studies similar to ours (see Chen et al., 2018; Wuepper et al., 2018).

Information on crops and seed types grown by a household and area allocated to each was used to construct the crop diversification index, while the livestock diversification index was constructed using information on livestock types and numbers kept by a household. Following Rhoades (1993), we calculate the HH indices as;

$$HHI_{kj} = \sum_{i=1}^{n} (ES_i)^2$$

where *HHI* is the index for household *k* for *j* diversification (crop/livestock), *ES* is the enterprise share (i.e. area share for crop *i or Tropical Livestock Units (TLU)* share for livestock type *i)* and *n* is the number of crops cultivated/livestock types kept per household.

A highly diversified household has an HHI close to 0, while a fully specialized one has an HHI of 1. A look at the distribution of the HHI index for both crop and livestock diversification reveals a spike around 1, indicating a high proportion with complete specialization in either of the two enterprises (Fig. 2).

2.2. Exposure to climatic shocks

To establish people's exposure to climatic shocks, some studies use respondents' perceptions on long term changes in climate variables like rainfall and temperature (for example Megersa et al., 2014), while others use geo-referenced climate infpormation (for example Asfaw, Pallante, & Palma, 2018). The former is more subjective and may be confounded by a number of factors, for example the respondent's existing knowledge about climate change. With the latter, the covariate nature of climate shocks implies that households in similar geographic locations will experience similar climatic events, hence limiting heterogeneity in the climatic shocks exposure variable.

To establish exposure to climatic shocks, our study utilizes information collected from the survey regarding whether a household was exposed to climatic shocks in the past. To construct the variable, incidences of exposure were restricted to those occurring three or more years prior to the survey year, such that the variable would be correlated with current diversification strategies as hypothesized to be, but not current food security outcomes. This allows for the validity of the variable as an instrument in estimating effect of diversification on food security, as discussed later under the section on the estimation strategy.

2.3. Food security measures

The study uses household food per capita expenditure and household dietary diversity score (HDDS) as indicators of food security. Household food expenditure measures the food access dimension of food security since it captures other sources of food besides own production, while HDDS measures the food utilization dimension. The use of the two indicators in this study ensures a comprehensive measure of food security while also acting as a check on the robustness on the results.

2.4. Socio-economic variables

Access to capital and income is an important prerequisite in the adoption of relatively expensive technology. We hypothesize a positive correlation between level of diversification and variables like access to off-farm income, credit, remittances, govern-

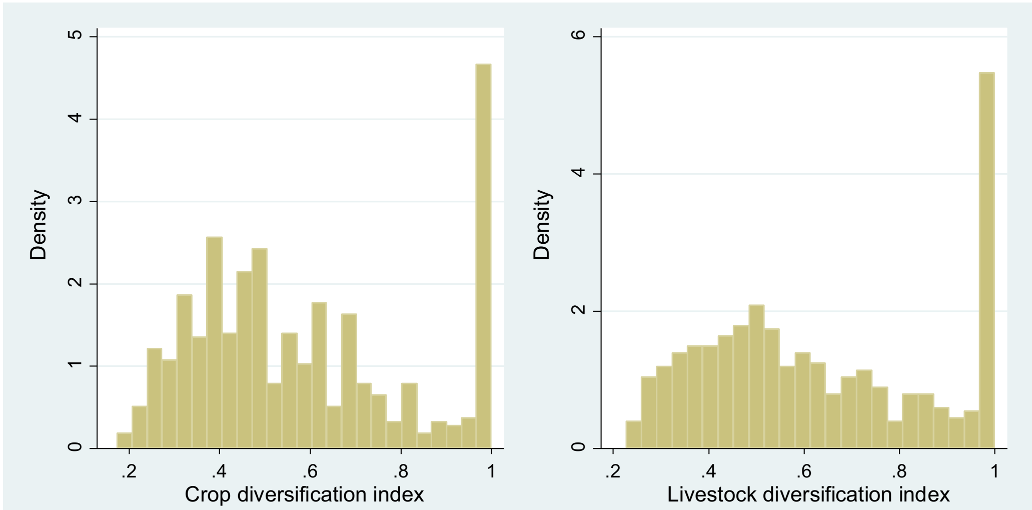

Fig. 2. Farm enterprise diversification indices.

ment safety nets and physical assets. These variables are also included in the outcome equation to control for their effect on food security outcomes, given the level of diversification. For the asset ownership and social capital variables included in the analysis, principal component analysis was used to construct the former and factor analysis for the latter, following Wuepper et al. (2018). Other usual household demographic variables included in the analysis include household head's age, gender and education level, and the size of the household in adult equivalence (see Table 1).

Access to climate information has also been shown to affect climate change adaptation, including farm diversification decisions (Chen et al., 2018; Mulwa et al., 2017). The study uses data on whether households received climate-related information for both livestock and crop management to construct a climate information access variable for inclusion in the analysis.

3. Estimation strategy and model specification

3.1. Estimation strategy

The analytical framework presents some challenges. First, the decisions to diversify in both crop and livestock enterprises are interdependent; diversifying into different livestock types can be informed by the crop types a household farms, and vice versa. We also hypothesize that the two decisions are jointly determined by similar factors. Secondly, crop and livestock farming simultaneously affect food security either as complements or substitutes when practiced together. Analysing the effect of one without considering the other might over- or under- estimate their contribution to the food security status of a household. Similarly, different levels of diversification in each would also have different implications for food security.

Table 1
Descriptive statistics.

Variable	Variable description	Mean	Std. Dev.
Dependent variables			
Improved seed	Household has adopted drought tolerant/early maturing millet varieties (1 = yes; 0 = no)	0.18	–
Crop diversification	Herfindahl–Hirschman index (HHI) for crop diversification	0.58	0.24
Livestock diversification	Herfindahl–Hirschman index (HHI) for livestock diversification	0.63	0.24
Food expenditure	Per capita food expenditure (N$)	112.5	141.9
Dietary diversity	Household Dietary diversity score	6.92	1.98
Explanatory variables			
Climate shocks-crop	Past exposure to climate shocks with severe effect on cropping (1 = yes; 0 = no)	0.48	–
Climate shocks-livestock	Past exposure to climate shocks with severe effect on livestock (1 = yes; 0 = no)	0.35	–
Age	Age of household head	61.57	17.03
Education	Education of household head (years of schooling)	5.66	4.05
Gender	Gender of household head (1 = male; 0 = female)	0.43	–
Household size	Total household size (number)	5.63	3.06
Asset index	Assets owned (pca[1] factors)	1.62e-08	1.00
Social capital	Factors of relatives and friends one can go to for help in and outside village if in need	−2.03e-09	0.67
Information access-crop	If household received climate information specific to crop management (1 = yes; 0 = no)	0.52	–
Information access-livestock	If household received climate information specific to livestock management (1 = yes; 0 = no)	0.45	–
Credit access	If household received crop/livestock input credit (1 = yes; 0 = no)	0.20	–
Formal employment	If household had access to formal employment opportunities (1 = yes; 0 = no)	0.25	–
Government transfers	If household received safety nets from the government (1 = yes; 0 = no)	0.23	–
Remittances	If household had access to remittance income (1 = yes; 0 = no)	0.33	–
Location characteristics			
Omusati (ref. region)	Omusati region (1 = yes; 0 = no)	43.93	–
Oshana	Oshana region (1 = yes; 0 = no)	29.19	–
Oshikoto	Oshikoto region (1 = yes; 0 = no)	26.88	–

Our analysis involves two decision equations with continuous dependent variables (indices with an upper limit censored at 1). The seemingly unrelated regression (SUREG) model has been used in similar studies to estimate equations with continuous dependent variables and correlated error terms (Kassie, Kim, & Fellizar, 2017; Wilde, McNamara, & Ranney, 1999). However, given that the dependent variables are continuous only up to an upper limit censoring, each of the two equations are re-estimated using a Tobit model and the results compared with those from the SUREG model.

In impact evaluation, the major challenge of attributing impact using observational data is establishing a true counterfactual free of bias. Observed and unobserved heterogeneity among the treatment and control groups may confound the effect of treatment, leading to wrong interpretations and policy recommendations. When observations are observed repeatedly over time intervals, panel data methods can easily be applied to control for unobserved heterogeneity, while conventional methods are used to control for the observed heterogeneity (for example observing the before and after treatment scenarios). This is not so straightforward for cross-sectional studies as in this study.

Based on the preceding discussion, our main challenge in impact estimation emanates from the non-random process of assigning treatment. Farmers in our sample may have self-selected into different levels of crop and livestock diversification, based on observable (e.g. income, extension access, etc.) and unobservable (e.g. personal ambition, managerial ability, etc.) conditions. For a genuine claim to the effect of diversification, we need to correct for this non-randomness in the diversification decisions. Existing methods that correct for this endogeneity either use instrumental variables or matching techniques like propensity score matching. In our case, the instrumental variable approach would require an instrument that is correlated with diversification decisions, but not directly correlated with food security outcomes.

Given the continuous nature of our treatments (indices of crop and livestock diversification), we rule out step-wise correction methods that assume the treatment is binary or categorical. Generalized Propensity Score (GPS) method could be used to estimate dose-response functions (for example Kassie, Jaleta, & Mattei, 2014) in this case on the effect of extent of farm diversification on stated food security outcomes. However, our study has two treatment variables (crop and livestock diversification indices) and estimation of the combined effect of multiple treatment variables using the GPS method is still nascent (Egger & von Ehrlich, 2013). Thus, following other similar studies (Asfaw et al., 2018; Kassie, Teklewold, Marenya, Jaleta, & Erenstein, 2015), we adopt the control function approach, also called the two stage residual inclusion (2SRI) method (Terza, Basu, & Rathouz, 2008), to correct for endogeneity and estimate the true effect of crop and livestock diversification on household food security outcomes.

To achieve this, we first estimate joint determinants of crop and livestock diversification using the SUREG model, and obtain the crop and livestock diversification residuals. We then plug these into a second stage Ordinary Least Squares (OLS) regression of the effect of diversification on food security, controlling for other observable covariates. The instruments used in the first stage and excluded in the second stage are access to livestock/crop management information and past exposure to climatic shocks. As stated earlier, for these variables to meet the exclusion restrictions and hence be valid instruments, they must be correlated with the diversification decisions but not food security outcomes, i.e., they should affect food security outcomes only through their effect on diversification decisions. It's intuitive to see how access to information meets this criterion. For the climatic shock exposure variable, the restriction of these shocks to those that occurred more than two years ago makes it unlikely that they are directly correlated with current food security outcomes, while being correlated with current diversification decisions. Including household income and asset ownership in the outcome equation also controls for the possible long term effects of past exposure to climate shocks, given the literature on climatic shocks and poverty traps among vulnerable households (Leichenko & Silva, 2014).

3.2. Empirical model

The SUREG model is specified as:

$$HHI_i = \beta_i climshock_i + \alpha_i climinfor_i + \varphi_i \boldsymbol{X} + \varepsilon_i \quad (1)$$

where *HHI* is the Herfindahl–Hirschman index for enterprise*i (i = crop/livestock)*; *climshock* is the variable for climate shocks on enterprise*i; climinfor* is the variable for climate information on enterprise *i* management; $\boldsymbol{X}$ is a vector of all other explanatory variables that are similar in both equations; ε_i are the error terms for the two equations and $COV(\varepsilon_1, \varepsilon_2) \neq 0$ (i.e., error terms for Eqs. (1) and (2) are correlated).

The two equations do not need to have exactly the same set of explanatory variables (Cappellari & Jenkins, 2010). We thus include the indicator variable for climate information specific to crop management on the crop diversification equation, and that for climate information specific to livestock management on the livestock diversification equation. Climate shocks usually affect both crop and livestock enterprises within a farm, where shocks in one enterprise (e.g. livestock) may reinforce diversification in the other (e.g. crop) as a resilience-boosting strategy. To capture these dynamics, we include both shocks to crop and livestock enterprises in each of the diversification equations, including an interaction term between the two shocks. The two equations are balanced in the number of observations and are therefore estimated using the normal *SUREG* STATA command, without any loss in efficiency (McDowell, 2004).

In the step-wise error correction procedure and following Wooldridge (2002), we predict the residuals from Eq. (1) for both livestock and crop diversification, then include them in the regression equation below:

$$FS_j = \sigma HHI_c + \pi HHI_l + \theta_i \boldsymbol{X}_i + \lambda_c + \lambda_l + \mu_i \quad (2)$$

where *FS* is food security measure *j* (*j* = per capita food expenditure/household dietary diversity score), $HHI_c$and $HHI_l$are the crop and livestock diversification indices, respectively; $\boldsymbol{X}$ is the vector of variables from Eq. (1); λ_c and λ_l are the residuals (self-selection correction terms) for crop and livestock diversification obtained from Eq. (1); and μ is the error term.

4. Results and discussion

In this section, key results from the study are discussed. The section begins with describing results on the factors affecting diversification decisions, followed by results from the empirical model, and a non-parametric analysis of the effect of diversification on food security. The non-parametric analysis compares different combinations of crop and livestock diversification levels to understand how combining the two enterprises at different levels of diversification affects food security.

4.1. Determinants of diversification

The results from Table 2 (columns 3 and 4) show that key drivers of adaptation are: past exposure to climatic shocks, access to information and credit, wealth (asset index and formal employment) and socio-demographic variables like household size, gender and education.

Table 2
Determinants of climate change adaptation strategies.

Variable	Tobit		SUREG	
	Crop diversification	Livestock Diversification	Crop diversification	Livestock Diversification
	[1]	[2]	[3]	[4]
Climate shocks-crops	0.0173	0.0520*	0.00726	0.0338
	(0.0266)	(0.0273)	(0.0244)	(0.0227)
Climate shocks-livestock	0.000868	−0.0690**	0.00604	−0.0623**
	(0.0354)	(0.0349)	(0.0317)	(0.0296)
Climate shock-crops #	−0.120***	−0.0163	−0.102**	0.00195
climate shocks-livestock	(0.0460)	(0.0458)	(0.0415)	(0.0387)
Information access	−0.0895***	−0.0368*	−0.0748***	−0.0293
	(0.0214)	(0.0215)	(0.0195)	(0.0181)
HH head age	−0.000778	−7.79e-05	−0.000576	−8.90e-05
	(0.000748)	(0.000753)	(0.000675)	(0.000629)
HH head education	−0.00396	−0.00307	−0.00354	−0.00260
	(0.00317)	(0.00317)	(0.00285)	(0.00266)
HH head gender	−0.0185	−0.0591***	−0.00637	−0.0516***
	(0.0209)	(0.0210)	(0.0190)	(0.0177)
HH size	−0.00508	−0.0187***	−0.00390	−0.0154***
	(0.00352)	(0.00357)	(0.00322)	(0.00301)
Formal employment	0.0251	−0.0396	0.0256	−0.0333
	(0.0242)	(0.0240)	(0.0218)	(0.0203)
Asset index	0.00611	−0.0614***	0.00670	−0.0527***
	(0.0113)	(0.0112)	(0.0102)	(0.00951)
Social capital	0.0104	−0.0297*	0.00621	−0.0231*
	(0.0154)	(0.0156)	(0.0142)	(0.0132)
Credit access	0.106***	–	0.0898***	–
	(0.0265)		(0.0239)	
Government transfers	0.0239	−0.0185	0.0236	−0.0137
	(0.0248)	(0.0248)	(0.0225)	(0.0209)
Remittances	0.0198	−0.0295	0.0208	−0.0196
	(0.0222)	(0.0225)	(0.0203)	(0.0189)
Oshana region	0.0225	0.0877***	0.0231	0.0751***
	(0.0267)	(0.0272)	(0.0245)	(0.0228)
Oshikoto region	0.0599**	0.119***	0.0498**	0.0981***
	(0.0251)	(0.0254)	(0.0228)	(0.0213)
N	639	639	639	639

Standard errors in parentheses.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Consistent with other studies (Megersa, Markemann, Angassa, & Valle Zárate, 2014; Melissa Rojas-Downing, Pouyan Nejadhashemi, Harrigan, & Woznicki, 2017; Wuepper, Yesigat Ayenew, & Sauer, 2018) we find that past exposure to climate shocks significantly affects both crop and livestock diversification. Farmers who experienced both crop and livestock shocks within the past ten years were found to have diversified more in both enterprises. The crop diversification variable includes area share allocated to drought tolerant millet varieties and traditional ones, in addition to other crops like legumes and nuts. As such, shocks experienced in the past could drive households to hedge against future exposure by diversifying their crop and/or variety mix. Likewise, past exposure to livestock shocks also discourages specialization in one livestock type, perhaps as a hedge against diseases and pests occasioned by climate shocks or livestock deaths due to dwindling resources like pasture and water.

Similar to other study findings (Chen et al., 2018; Mulwa et al., 2017; Shiferaw, Kassie, Jaleta, & Yirga, 2014), availability of climate information was found to play a significant role in explaining both crop and livestock diversification. There is a negative correlation between diversification indices and information access, implying that access to information led to higher diversification (index tends to zero).

In terms of demographics, higher educated household heads diversify more in crop farming, while male-headed households are more diversified in livestock keeping. It's established in the literature that males tend to keep big ruminants like cattle, while women tend to keep small ruminants and poultry (Ellis, 1998; Gautam & Andersen, 2016). Male-headed households also tend to have both spouses present, and thus more likely to own a diversified portfolio of livestock assets. On the other hand, households that had heads who were formally employed were found to have diversified more in livestock keeping. This could indicate the importance of livestock as sources of prestige, and the ability to purchase these with access to employment wages. This is confirmed by the positive correlation between asset ownership and livestock diversification.

Consistent with other studies (e.g. Wuepper et al., 2018), the social capital variable is positively and significantly correlated with livestock diversification. Given the information used to construct this variable i.e. number of relatives and non-relatives a household has, and can rely on, in times of need for financial help, this could be viewed as a source of informal credit for acquisition of culturally important livestock assets. Some projects in the region also enhance livestock ownership by giving seed cattle to a community, which are then distributed to households within the community as the cattle multiply (Musemwa et al., 2008). Social capital within the community is expected to play a big role in livestock ownership in such cases. Surprisingly, access to credit for crop farming is found to decrease crop diversification, perhaps due to the specificity of dispensed inputs (e.g. improved millet seeds) as credit in kind.

4.2. Effect of diversification on food security

4.2.1. Empirical model results

We estimated the effect of diversification on monthly per capita food expenditure and household dietary diversity score (HDDS), conditional on other covariates controlled for in the analysis. This second stage of the 2SRI estimations followed either a Tobit or SUREG estimation of the determinants of crop and/or livestock diversification in the first stage (see Table 2). Columns 1–2 and 3–4 in Table 3 present estimations of the effect of crop and livestock diversification, respectively, on food security, following Tobit estimations in the first stage. Columns 5–6, on the other hand, are estimations of the effect of both livestock and crop diversification, among other control variables, on food security following SUREG estimation in the first stage. In this section, we report results from the latter estimation (columns 5–6).

The results show that both crop and livestock diversification have significant effects on food security outcomes; crop diversification significantly affects both per capita food expenditure and HDDS while livestock diversification affects only HDDS. Specifically, a unit increase in crop diversification increases household monthly per capita expenditure by about N$78 and HDDS by about 0.7 points. A unit increase in livestock diversification on the other hand increases HDDS by about 0.8 points. The results point to an income effect of crop production where greater diversification leads to higher incomes, hence ability to spend more on food, perhaps due to using resilient crops and seed varieties. Livestock in northern Namibia is mostly kept for household consumption and festivities, which could explain why diversifying in this enterprise leads to a significant effect on dietary diversity, but not in food expenditure.

Although the aim of the study was to evaluate the effect of diversification on food security, we report briefly on other significant variables explaining food security outcomes in our model. Socio-demographic variables that affect food security outcomes include age, education and gender of the household head. An additional year of age of the household head is associated with an increase in household monthly per capita food expenditure by about 1 Namibian dollar (N$1) and household dietary diversity score (HDDS) by about 0.01 points. Similarly, an extra year of education of the household head increases the household's monthly per capita food expenditure by about N$11 and the HDDS by about 0.11 points. Consistent with other studies (for example Tibesigwa & Visser, 2016), we find that male-headed households have higher food security status in terms of per capita food expenditure; they out-spent female-headed households by N$50 per capita on food every month.

Socio-economic variables affecting household food security include asset ownership, social capital, access to formal employment, and government transfers. Households owning more assets spend more on food, with an extra unit in the asset ownership index associated with an increase in monthly per capita food expenditure by N$42. Similarly, a unit increase in a household's

Table 3
Determinants of food security.

	Crop divers. equations		Livestock divers. equations		Combined	
	Per capita food expenditure (N$)	Dietary diversity score	Per capita food expenditure (N$)	Dietary diversity score	Per capita food expenditure (N$)	Dietary diversity score
	[1]	[2]	[3]	[4]	[5]	[6]
Crop diversification index	−55.83**	−0.714**	–	–	−77.62***	−0.666**
	(23.43)	(0.330)			(23.28)	(0.327)
Livestock diversification index	–	–	3.852	−0.884**	0.682	−0.836**
			(25.36)	(0.366)	(25.22)	(0.352)
HH head age	1.020**	0.0142**	1.456***	0.0148**	1.437***	0.0136**
	(0.407)	(0.00573)	(0.398)	(0.00576)	(0.397)	(0.00555)
HH head education	9.583***	0.135***	11.01***	0.117***	10.71***	0.106***
	(1.770)	(0.0250)	(1.703)	(0.0265)	(1.734)	(0.0259)
HH head gender	12.88	0.229	43.16***	0.0104	50.27***	0.0155
	(11.35)	(0.160)	(12.00)	(0.211)	(12.14)	(0.218)
HH size	–	−0.001	–	−0.088	–	−0.0837
		(0.0281)		(0.0545)		(0.0553)
Asset index	−2.807	0.173**	33.68***	−0.170	41.83***	−0.157
	(5.950)	(0.0842)	(8.466)	(0.183)	(9.010)	(0.198)
Social capital index	3.413	0.148	15.55*	−0.0922	18.13**	−0.0780
	(8.213)	(0.115)	(8.824)	(0.146)	(8.816)	(0.144)
Formal employment	27.34**	0.933***	56.72***	0.639***	64.47***	0.613***
	(12.79)	(0.182)	(13.17)	(0.209)	(13.75)	(0.216)
Government transfer	−36.59***	−0.182	−10.64	−0.387**	−4.893	−0.335*
	(13.09)	(0.191)	(13.49)	(0.196)	(13.90)	(0.196)
Remittances	−12.56	0.371**	3.771	0.194	5.795	0.245
	(11.97)	(0.169)	(12.02)	(0.179)	(12.14)	(0.174)
Error correction term- crop	−207.3**	1.254	–	–	43.39	0.291
	(89.34)	(1.332)			(112.1)	(1.570)
Error correction term- livestock	–	–	−486.5***	4.204*	−709.9***	4.584
			(82.77)	(2.356)	(112.0)	(3.097)
Oshana region	−14.79	−0.320	−44.50***	0.0467	−49.42***	0.0586
	(14.44)	(0.208)	(15.02)	(0.294)	(15.04)	(0.300)
Oshikoto region	14.96	−0.368*	−31.93*	0.128	−37.14**	0.145
	(14.55)	(0.208)	(16.32)	(0.346)	(16.34)	(0.350)
N	639	639	614	614	613	613

Standard errors in parentheses.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

social capital index increases monthly per capita food expenditure by about N$18, implying the importance of kinship ties as important safety nets in rural areas. Households in which the head is formally employed are shown to spend about N$64 on food more per household member, and have about 0.6 points more in HDDS, compared to their counterparts. This underscores the importance of diversification beyond the farm into off-farm income sources, for household food security in the face of climate change.

4.2.2. A non-parametric analysis

This subsection is a continuation of the analysis above where we attempt to see how varying combinations of crop-livestock diversification levels affect food security. To achieve this, the crop and livestock diversification indices are each divided into three categories, i.e., High, Middle and Low diversification levels, based on the distribution of each index (note that given different distributions of each index, cut-off points delineating start and end of each category may be different). The different categories from both indices are then combined to form a 3 × 3 matrix of crop-livestock diversification levels (Table 4). Next, food security outcomes for these different combinations are compared using kernel densities.

Table 4
Combinations of different levels of crop and livestock diversification.

Livestock diversification		Crop diversification		
		$0.7 < x$ Low	$0.4 < x \leq 0.7$ Medium	$x \leq 0.4$ High
$0.75 < x$	Low	***LL***	LM	***LH***
$0.45 < x \leq 0.75$	Medium	ML	MM	MH
$x \leq 0.45$	High	***HL***	HM	***HH***

The aim is to see whether high diversification in either crop or livestock farming is more important for household food security. Of the nine categories, our interest is thus on the food security outcomes for the low and high combinations (i.e. LL, HL, LH and HH) and results for these are reported in this section.

Six combinations are compared: Highly diversified in both crops and livestock (HH) *versus* little or no diversification in both (LL) (Fig. 3a); little or no diversification in livestock and highly diversified in crops (LH) *versus* highly diversified in livestock and little or no diversification in crops (HL) (Fig. 3b); highly diversified in both crop and livestock (HH) *versus* little or no diversification in livestock and highly diversified in crops (LH) (Fig. 3c); highly diversified in both crop and livestock (HH) *versus* highly diversified in livestock and little or no diversifications in crops (HL) (Fig. 3d); little or no diversification in livestock and highly diversified in crops (LH) *versus* little or no diversification in either (LL) (Fig. 3e); highly diversified in livestock and little or no diversification in crops (HL) *versus* little or no diversification in either (LL) (Fig. 3f).

As the shapes of the distribution imply, significant differences in mean expenditures are observed between HH and LL combinations (Fig. 3a), LH and LL combinations (Fig. 3e), and HL and LL combination (Fig. 3f). Households that are highly diversified in both crop and livestock farming (HH) on average spend more on food in a month compared to those with low diversification in both enterprises (LL). High monthly food expenditure was also noted in the low livestock-high crop (LH) and high livestock-low crop diversification (HL) categories, each compared to the low livestock-low crop (LL) diversification category.

No significant difference in food expenditure was observed between the low livestock-high crop (LH) and high livestock-low crop (HL) diversification categories. Similarly, the outcome for high livestock-high crop (HH) diversification category was not signifi-

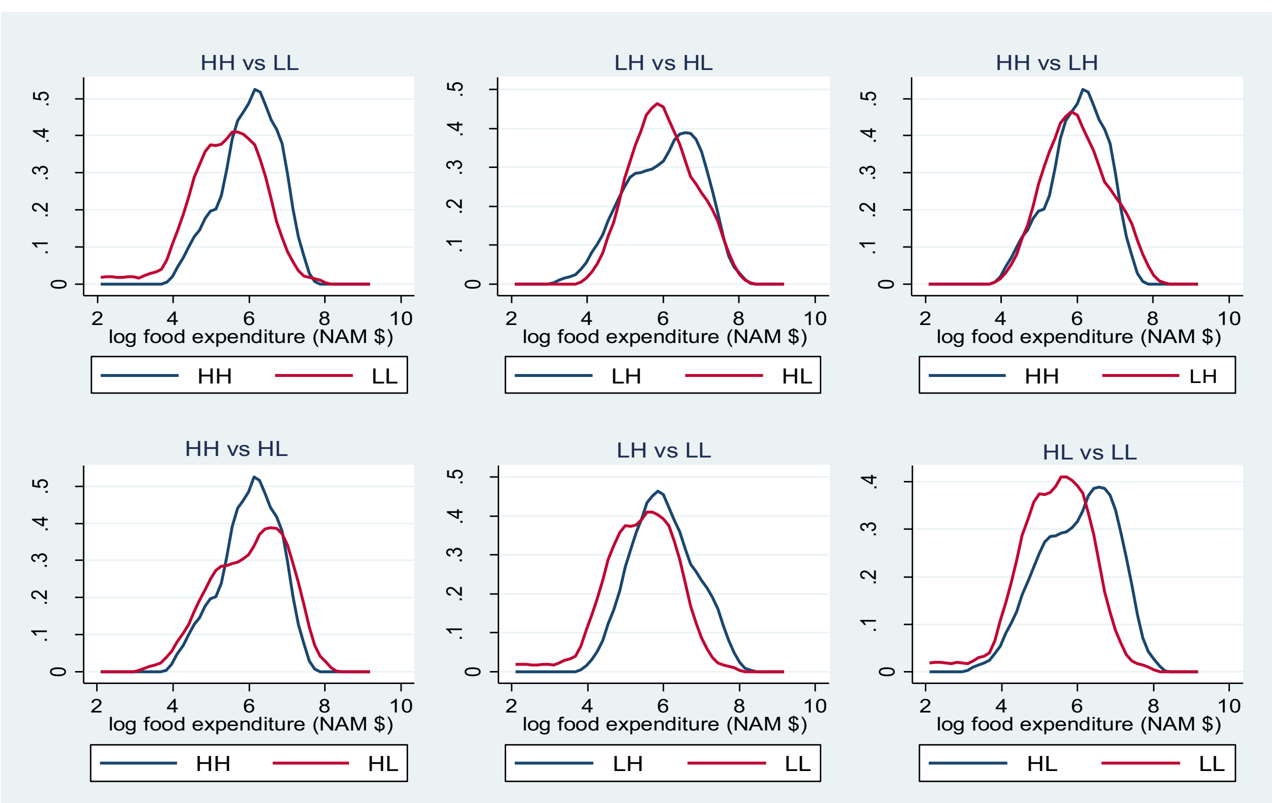

Fig. 3. a-f (clockwise): Distributions of food expenditure for combinations of different levels of crop and livestock diversification.

cantly different from that of the low livestock-high crop (LH) category or that of the high livestock-low crop (HL) categories. These results thus seem to indicate that high diversification in either crop or livestock enterprise leads to high food security outcomes, irrespective of which enterprise a household is more diversified in.

5. Conclusion and policy implications

Adapting to the changing climate is critical for rural communities residing in semi-arid regions, where livelihoods are already fragile. Diversification of livelihoods is a key strategy of strengthening the adaptive capacity and resilience of vulnerable communities. This paper finds that farm diversification has a positive impact on per capita food expenditure and dietary diversity, two indicators used as proxies for food security in this study. Further, the non-parametric analyses shows that there is no difference in food security outcomes for households that are highly diversified in either crop or livestock enterprises, and lowly diversified in the other. However, households that are highly diversified in crop and livestock enterprises achieve the highest food security outcomes.

Note that the non-parametric analysis does not control for other important factors that may also explain food security outcomes, thus the estimated effect of crop or livestock diversification on food security is not conditional on other covariates. However, combining results from this estimation with those from the parametric regression provides for robustness check. The study region is semi-arid, characterized by a mix of pastoralism and subsistence crop farming, thus external validity of results obtained in this study may not be guaranteed for areas characterized by farming systems.

Regardless of these limitations, results from the study offer important policy-relevant insights. Improving accessibility to markets is crucial for the attainment of food security, in an environment of increasing climatic shocks. Different areas may differ in the comparative advantage in terms of the agro-ecology for the production of crops or livestock. In such a case, households may thus be better off specializing in a particular enterprise, with adequate diversification within that enterprise for resilience, then accessing other food products from the markets.

Another policy variable identified in the study as a key determinant to diversification decisions is that of access to climate information related to management of both crops and livestock. Extension advice should therefore be targeted towards improving knowledge on climate change in the region, and dissemination of information on the available strategies households can utilize to mitigate against weather variability and climatic shocks like droughts. Improvement in the number of extension providers in the rural areas will also ensure many farmers have access to information on the suite of technologies and practices that constitute climate smart agriculture, for sustainable production.

The study also identifies gender as another key determinant of diversification decisions, and food security; male-headed households were more diversified in both crop and livestock enterprises, and were more food secure. Our finding suggests that female-headed households are more vulnerable, and policies that aim to empower women in the study region would therefore be beneficial. Such policies could be in the form of special financial products specifically meant for women in order to enable them access credit easier. Intervention programs by development partners that target women have also been shown to be highly effective elsewhere in improving household welfare, and should be advocated for in the study region.

Finally, the huge contribution of off-farm incomes to food security in our study further points to the already established concept of rural transformation as a vehicle for the development of rural areas in the developing world, through availing of non-farm opportunities. There is a consensus that climate change impacts will continue to be felt in the next few decades, despite the global efforts to mitigate emissions that cause the global warming problem. Policy makers in SSA thus need to urgently think of ways to fast-track access to non-farm opportunities in the rural areas of these regions, for diversified portfolio of activities that guarantee resilient livelihoods in the face of these challenges.

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References

Adjimoti, G. O., & Kwadzo, G. T. M. (2018). Crop diversification and household food security status: Evidence from rural Benin. *Agriculture and Food Security, 7*(1), 1–12. https://doi.org/10.1186/s40066-018-0233-x.

Asfaw, S., Pallante, G., & Palma, A. (2018). Diversification strategies and adaptation deficit: Evidence from rural communities in Niger. *World Development, 101*, 219–234. https://doi.org/10.1016/j.worlddev.2017.09.004.

Barrett, C., Bezuneh, M., & Aboud, A. (2001). Income diversification, poverty traps and policy traps and shocks in Cote d' Ivoire and Kenya shocks. *Food Policy, 26*, 367–384. https://doi.org/10.1016/S0306-9192(01)00017-3.

Barrett, C. B., Christiaensen, L., Sheahan, M., & Shimeles, A. (2017). On the structural transformation of rural Africa. *Journal of African Economies, 26*, i11–i35. https://doi.org/10.1093/jae/ejx009.

Berhanu, W., Colman, D., & Fayissa, B. (2007). Diversification and livelihood sustainability in a semi-arid environment: A case study from southern Ethiopia. *Journal of Development Studies, 43*(5), 871–889. https://doi.org/10.1080/00220380701384554.

Bradshaw, B. E. N., Dolan, H., & Smit, B. (2004). Farm-level adaptation to climatic variability and change: Crop diversification in the Canadian Prairies. *Climatic Change*, 119–141.

Cappellari, L., Jenkins, S. (2010). The Stata Journal. Stata Journal, 10(3), 288–308. https://doi.org/The Stata Journal

Chen, M., Wichmann, B., Luckert, M., Winowiecki, L., Förch, W., & Läderach, P. (2018). Diversification and intensification of agricultural adaptation from global to local scales. *PLoS One, 13*(5), 1–27. https://doi.org/10.1371/journal.pone.0196392.

Davis, B., Winters, P., Carletto, G., Covarrubias, K., Quiñones, E. J., Zezza, A., ... DiGiuseppe, S. (2010). A cross-country comparison of rural income generating activities. *World Development, 38*(1), 48–63. https://doi.org/10.1016/j.worlddev.2009.01.003.

Di Falco, S., Veronesi, M., & Yesuf, M. (2011). Does adaptation to climate change provide food security? A micro-perspective from Ethiopia. *American Journal of Agricultural Economics, 93*(3), 829–846. https://doi.org/10.1093/ajae/aar006.

Egger, P. H., & von Ehrlich, M. (2013). Generalized propensity scores for multiple continuous treatment variables. *Economics Letters, 119*(1), 32–34. https://doi.org/10.1016/j.econlet.2013.01.006.

Elad, Y., & Pertot, I. (2014). Climate change impacts on plant pathogens and plant diseases. *Journal of Crop Improvement, 28*(1), 99–139. https://doi.org/10.1080/15427528.2014.865412.

Ellis, F. (1998). Household strategies and rural livelihood diversification. *Journal of Development Studies, 35*(1), 1–38. https://doi.org/10.1080/00220389808422553.

Gautam, Y., & Andersen, P. (2016). Rural livelihood diversification and household well-being: Insights from Humla, Nepal. *Journal of Rural Studies, 44*, 239–249. https://doi.org/10.1016/j.jrurstud.2016.02.001.

Government of the Repulic of Namibia. (2011). National climate policy for namibia-2011.

Howden, S. M., Soussana, J.-F., Tubiello, F. N., Chhetri, N., Dunlop, M., & Meinke, H. (2007). Adapting agriculture to climate change. *Proceedings of the National Academy of Sciences of the United States of America, 104*(50), 19691–19696. https://doi.org/10.1073/pnas.0701890104.

IPCC, Pachauri, R. K. (2014). Climate Change 2014 Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. DOI:10.1017/CBO9781107415324.

Kassie, M., Jaleta, M., & Mattei, A. (2014). Evaluating the impact of improved maize varieties on food security in Rural Tanzania: Evidence from a continuous treatment approach. *Food Security, 2012*, 1–14. https://doi.org/10.1007/s12571-014-0332-x.

Jayne, T. S., Chamberlin, J., & Headey, D. D. (2014). Land pressures, the evolution of farming systems, and development strategies in Africa: A synthesis. *Food Policy, 48*, 1–17. https://doi.org/10.1016/j.foodpol.2014.05.014.

Kassie, G. W., Kim, S., & Fellizar, F. P. (2017). Determinant factors of livelihood diversification: Evidence from Ethiopia. *Cogent Social Sciences, 3*(1), 1–16. https://doi.org/10.1080/23311886.2017.1369490.

Kassie, M., Teklewold, H., Marenya, P., Jaleta, M., & Erenstein, O. (2015). Production risks and food security under alternative technology choices in Malawi: Application of a multinomial endogenous switching regression. *Journal of Agricultural Economics, 66*(3), 640–659. https://doi.org/10.1111/1477-9552.12099.

Kyalo Willy, D., Muyanga, M., & Jayne, T. (2019). Can economic and environmental benefits associated with agricultural intensification be sustained at high population densities? A farm level empirical analysis. *Land Use Policy, 81*(May 2018), 100–110. https://doi.org/10.1016/j.landusepol.2018.10.046.

Lay, J., Mahmoud, T. O., & M'Mukaria, G. M. (2008). Few opportunities, much desperation: The dichotomy of non-agricultural activities and inequality in Western Kenya. *World Development, 36*(12), 2713–2732. https://doi.org/10.1016/j.worlddev.2007.12.003.

Leichenko, R., & Silva, J. A. (2014). Climate change and poverty: Vulnerability, impacts, and alleviation strategies. *Wiley Interdisciplinary Reviews: Climate Change, 5*(4), 539–556. https://doi.org/10.1002/wcc.287.

Lin, B. (2011). Resilience in agriculture through crop diversification: adaptive management for environmental change. *BioScience, 61*(3), 183–193. https://doi.org/10.1525/bio.2011.61.3.4.

Makate, C., Wang, R., Makate, M., & Mango, N. (2016). Crop diversification and livelihoods of smallholder farmers in Zimbabwe: Adaptive management for environmental change. *SpringerPlus, 5*(1). https://doi.org/10.1186/s40064-016-2802-4.

Mango, N., Makate, C., Mapemba, L., & Sopo, M. (2018). The role of crop diversification in improving household food security in central Malawi. *Agriculture and Food Security, 7*(1), 1–10. https://doi.org/10.1186/s40066-018-0160-x.

Martin, S. M., & Lorenzen, K. (2016). Livelihood diversification in rural Laos. *World Development, 83*, 231–243. https://doi.org/10.1016/j.worlddev.2016.01.018.

McDowell, A. (2004). From the help desk: Seemingly unrelated regression with unbalanced equations. Stata Journal, 4(4), 442–448. https://doi.org/The Stata Journal.

Megersa, B., Markemann, A., Angassa, A., & Valle Zárate, A. (2014). The role of livestock diversification in ensuring household food security under a changing climate in Borana, Ethiopia. *Food Security, 6*(1), 15–28. https://doi.org/10.1007/s12571-013-0314-4.

Melissa Rojas-Downing, M., Pouyan Nejadhashemi, A., Harrigan, T., & Woznicki, S. A. (2017). Climate change and livestock: Impacts, adaptation, and mitigation. *Climate Risk Management, 1–19*. https://doi.org/10.1016/j.crm.2017.02.001.

Mulwa, C., Marenya, P., Rahut, D. B., & Kassie, M. (2017). Response to climate risks among smallholder farmers in Malawi: A multivariate probit assessment of the role of information, household demographics, and farm characteristics. *Climate Risk Management, 16*, 208–221. https://doi.org/10.1016/j.crm.2017.01.002.

Musemwa, L., Mushunje, A., Chimonyo, M., Fraser, G., Mapiye, C., & Muchenje, V. (2008). Nguni cattle marketing constraints and opportunities in the communal areas of South Africa: Review. *Aftican Journal of Agricultural Research, 3*(4), 239–245.

Newsham, A., & Thomas, D. (2009). Agricultural adaptation, local knowledge and livelihoods diversification in North-Central Namibia Retrieved from. *Tyndall Centre for Climate Change Research*, 1–48 http://www.tyndall.ac.uk/sites/default/files/twp140_0.pdf.

Onyutha, C. (2018). African crop production trends are insufficient to guarantee food security in the sub-Saharan region by 2050 owing to persistent poverty. *Food Security, 10*(5), 1203–1219. https://doi.org/10.1007/s12571-018-0839-7.

Reid, H., Sahlen, L., Stage, J., MacGregor, J. (2007). The Economic Impact of climate change in Namibia. Environmental Economics Programme Discussion Paper 07-02, (November), 1–54.

Rhoades, S. A. (1993). The Herfindahl-Hirschman index. *Federal Reserve Bulletin, 79*, 188.

Rojas-Downing, M. M., Nejadhashemi, A. P., Harrigan, T., & Woznicki, S. A. (2017). Climate change and livestock: Impacts, adaptation, and mitigation. *Climate Risk Management, 16*, 145–163. https://doi.org/10.1016/j.crm.2017.02.001.

Shiferaw, B., Kassie, M., Jaleta, M., & Yirga, C. (2014). Adoption of improved wheat varieties and impacts on household food security in Ethiopia. *Food Policy, 44* (October 2015), 272–284. https://doi.org/10.1016/j.foodpol.2013.09.012.

Singh, C., Daron, J., Bazaz, A., Ziervogel, G., Spear, D., Krishnaswamy, J., ... Kituyi, E. (2017). The utility of weather and climate information for adaptation decision-making: Current uses and future prospects in Africa and India. *Climate and Development*, 1–17. https://doi.org/10.1080/17565529.2017.1318744.

Smit, B., & Wandel, J. (2006). Adaptation, adaptive capacity and vulnerability. *Global Environmental Change, 16*(3), 282–292. https://doi.org/10.1016/j.gloenvcha.2006.03.008.

Terza, J. V., Basu, A., & Rathouz, P. J. (2008). Two-stage residual inclusion estimation: Addressing endogeneity in health econometric modeling. *Journal of Health Economics, 27*(3), 531–543. https://doi.org/10.1016/j.jhealeco.2007.09.009.

Thornton, P. K., van de Steeg, J., Notenbaert, A., & Herrero, M. (2009). The impacts of climate change on livestock and livestock systems in developing countries: A review of what we know and what we need to know. *Agricultural Systems, 101* (3), 113–127. https://doi.org/10.1016/j.agsy.2009.05.002.

Tibesigwa, B., & Visser, M. (2016). Assessing gender inequality in food security among small-holder farm households in urban and rural South Africa. *World Development, 88*, 33–49. https://doi.org/10.1016/j.worlddev.2016.07.008.

Tibesigwa, B., Visser, M., & Turpie, J. (2015). The impact of climate change on net revenue and food adequacy of subsistence farming households in South Africa. *Environment and Development Economics, 20*(3), 327–353. https://doi.org/10.1017/S1355770X14000540.

Tittonell, P. (2014). Livelihood strategies, resilience and transformability in African agroecosystems. *Agricultural Systems, 126*, 3–14. https://doi.org/10.1016/j.agsy.2013.10.010.

Wetherald, R. T., & Manabe, S. (2002). Simulation of hydrologic changes associated with global warming. *Journal of Geophysical Research Atmospheres, 107*(19). https://doi.org/10.1029/2001JD001195.

Wilde, P. E., McNamara, P. E., & Ranney, C. K. (1999). The effect of income and food programs on dietary quality: A seemingly unrelated regression analysis with error components. *American Journal of Agricultural Economics, 81*(4), 959. https://doi.org/10.2307/1244338.

Wooldridge, J. M. (2002). Econometric Analysis of Cross Section and Panel Data. MIT Press: Cambridge, MA, USA. DOI:10.1515/humr.2003.021.

Wuepper, D., Yesigat Ayenew, H., & Sauer, J. (2018). Social capital, income diversification and climate change adaptation: Panel data evidence from Rural Ethiopia. *Journal of Agricultural Economics, 69*(2), 458–475. https://doi.org/10.1111/1477-9552.12237.