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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.

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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 and Pertot, 2014; Thornton et al., 2009; Wetherald and Manabe, 2002). These effects of climate change are expected to increase poverty incidence in most developing countries and create new poverty pockets in countries with increasing inequality, in both developed and developing countries (IPCC, 2014).

A decrease in productivity of the already low-productivity agricultural systems in sub-Saharan Africa (SSA) is a serious threat to food security and livelihoods. While there are adaptation options that can create resilience in agricultural productivity, studies continue to show their low adoption rates across the region (Bradshaw et al., 2004; Di Falco et al., 2011; Mulwa et al., 2017; Singh et al., 2017; Smit and Wandel, 2006). In crop farming, such adaptation measures include using adaptive seeds (seed specifically bred to withstand climate related stress such as drought) and spreading risks across different crop types (crop diversification) (Howden et al., 2007). In livestock farming, farmers can adopt breeds of livestock that are tolerant to stress such as drought, or they can diversify into different breeds of the same livestock species, or they can keep different livestock species (Rojas-Downing et al., 2017).

Recent literature on diversification focuses on rural transformations from predominantly agriculture-related to rural non-farm sectors (Barrett et al., 2017). This is important in the poverty reduction literature, where low agricultural wages are replaced by relatively higher non-farm wages, which reduces the disguised unemployment predominant in rural agricultural sectors of developing countries. However, rural transformation starts with investments in agriculture for higher productivity, which in turn increases marketable surplus and enhances farmer participation in output markets, leading to value addition along the market value chain thus creating non-farm jobs. Productivity is still too low in most of SSA for meaningful transformation to happen, including in northern Namibia. Climate change threatens to depress this productivity further. Thus, it remains important to evaluate strategies that aim to create resilience in agricultural production and reduce vulnerability to climate change (Bradshaw et al., 2004).

Most studies assessing diversification at the farm level focus on either crop or livestock diversification (Megersa et al., 2014; Rojas-Downing et al., 2017; Tittonell, 2014). Others extending to non-farm diversification treat on-farm diversification as one activity that encompasses crop and livestock farming (Asfaw et al., 2015; Berhanu et al., 2007; Martin and Lorenzen, 2016). Yet others compare outcomes of farmers who are specialized in either of the enterprises with those of farmers who practice mixed farming (Tibesigwa, Visser and Turpie, 2015). Considering each farm enterprise (livestock or crop) diversification sep-
arately may underestimate joint effect on food security and does not allow for the identification of barriers to each diversification type, which is an important aspect for policy targeting. 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; rather, it is the extent of diversification that matters, including the use of different crop- and livestock-type mixes that mitigate the impact of climate shocks.

In northern Namibia, both crop and livestock farming are practiced extensively. It is therefore important to understand the barriers to diversification in each, as well as the contribution of each to food security. This study adds to the literature by assessing the joint determinants of diversification in both livestock and crop farming. Further, it evaluates how the extent of diversification in each activity contributes to food security. Finally, the study looks at how combinations of varying levels of diversification in both crop and livestock production affect food security. To our knowledge, this is the first study to look at the effect of the level of diversification on food security.

2 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 (see for example Barrett and Reardon, 2001). 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 and 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 (Musenwa 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 et al., 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 et al., 2001; Davis et al., 2010; Wuepper et al., 2018). Investigating how each of these is important for diversification in the study region is important for policy. Further, given the dearth of literature in the region on determinants of food security, establishing the link between farm diversification and food security is an important addition to the literature.

3 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 (Republic 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 et al., 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 and 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 Figure 1).

Crop cultivation remains the most practiced livelihood activity in the region while a high proportion also keep small ruminants. Cattle rearing is the third most practiced livelihood activity, signifying the importance of livestock keeping. Pearl millet is the preferred crop over other cereals (see Figure 2) because it is relatively drought resistant, is tolerant of high temperatures, and can grow in sandy soils (Uno, 2005).

4 Sampling and data

Data for this study come from the Adaptation at Scale in Semi-Arid Regions (ASSAR) project that was anchored at the African Climate and Development Initiative (ACDI) in the University of Cape Town. 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.

Two constituencies were each selected from Oshana and Oshikoto and three from Omusati to capture the diversity within the regions. Random sampling proportionate to size was then used to select villages and households to include in the survey. Data was collected by a team of trained enumerators using a structured questionnaire in the months of August and September 2017. The goal was to assess households’ vulnerability and/or resilience to climate variability by identifying the degree of diversity in their livelihoods, their exposure to socioeconomic and climate shocks, and existing local adaptation strategies. The survey also covered coping strategies to both idiosyncratic and covariate shocks, demographic and socioeconomic data, and key wellbeing outcomes including food security (see Table 1 for the descriptive statistics for these variables).

5 Construction and description of variables

5.1 Farm enterprise diversification indices

Different types of indices have been used in the literature to measure livelihoods diversification. Several studies construct vector shares of total income from different sources to measure diversification (Barrett et al., 2001; Davis et al., 2010; Lay et al., 2008). Wuepper et al. (2018) use the Ogive index, which captures the number of activities in which a household is involved and their contribution to the household total income. Asfaw et al. (2015) on the other hand use the Margalef index, a concept borrowed from ecological studies and used to measure the number of different species in a given area. 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, but has been applied previously in studies similar to ours (Chen et al., 2018; Wuepper et al., 2018).

In the survey, farmers were asked information on the crops they had grown, types of seeds used and area allocated to each. In the case of intercropping, information on the proportion of the area allocated to each crop type and/or seed type was also elicited. This information is used to construct the crop diversification index. Farmers were also asked for information on the types of livestock they kept, and the number for each type. This is the information used to construct the livestock diversification index. 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 households have an HHI is close to 0, while those specialized in one enterprise have 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 complete specialization (Figure 3). Conventional normalization techniques like square root or log transformations fail to achieve true normality due to the spike around complete specialization. However, tests for the inclusion of these observations in the analysis show that the results remain robust even when they are included.

5.2 Climatic shocks

To establish people’s exposure to climatic shocks, some studies use respondents’ perceptions of changes in climate variables (e.g. rainfall and temperature) over a long period of time (for example, Megersa et al., 2014) while others use weather data of similar climate variables observed over long time periods (for example, Asfaw et al., 2015). 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. Thus, the observed weather data may be more suitable for comparing adaptation strategies across regions that are exposed differently to climatic shocks. Also, we hypothesize that a household’s experience of climate shocks in the past is more likely to induce future adaptation strategies compared to mere perception on whether the climate has changed. Our study thus elicits information on whether a household was exposed to climatic shocks in the past, and assesses how this might explain its current adaptation decisions, including (extent of) farm diversification.

As an indicator of exposure to climate-related shocks, respondents indicated whether they had suffered crop failure/low yields and/or livestock deaths over
the last 10 years due to drought/dry spells or pests and diseases. We also elicited the frequency of exposure to these shocks over the same time period including the most recent exposure, as well as the severity of exposure. To construct the climate shock variable, exposure was restricted to that occurring three or more years prior to the survey year. Excluding the two most recent year allows the variable to be used as an instrument that is hypothesized to be correlated with current diversification strategies but not with current food security outcomes, as discussed later under the section on the estimation strategy.

5.3 **Food security measures**

The study touches on three dimensions of food security: food availability, food access and food utilization (FAO, 2006). Productivity of improved millet seed is used to indicate the food availability dimension, given the importance of the crop in Namibia; household expenditure on food is used to indicate food access; and, lastly, household dietary diversity score (HDDS) is used to indicate food utilization. To evaluate the effect of improved seed use (a component of crop diversification) on food security, the study compares yields from improved millet seed varieties against those from traditional seed varieties. However, this comparison on productivity is not easy to achieve for livestock; while data on specific breeds of cattle and small ruminants are missing in our study, quantifying outputs from each breed (milk and meat) may also not be easy for smallholder farmers. The effect of productivity-improving technology, as a component of diversification, on food security is thus limited to crop diversification in this study.

As an indication of food access, we use household food expenditure, which captures other sources of food besides own production and thus includes any food that is bought with off-farm income or through selling off livestock and/or crop outputs. For a robustness check, household dietary diversity score (HDDS) is used to check on the food utilization dimension. The HDDS incorporates food consumed out of own production, as well as that bought with incomes from non-farm and off-farm activities, and is therefore a more comprehensive food security measure.

5.4 **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, remittances, government safety nets and physical assets. We also include these variables in the outcome equation to control for their effect on food security outcomes, given the level of diversification. Principal component analysis was used to construct the asset ownership variable included in the regression. Other usual household demographic variables included in the analysis include household head’s age, gender and education level, and the size of the household, converted into adult equivalence.
We hypothesize that social capital is an important determinant of diversification in the study area. Following Wuepper et al. (2018), we performed factor analysis to construct a social capital index using four variables: the number of relatives a household has in the village; number of close friends in the village; number of households in the village that can help financially in times of need; and number of households in the village that can give in-kind help if needed by the household. The choice of the variables to include in the social capital index is informed by two motivating factors: one, peer to peer learning is an important means of technology diffusion, which is also a way to view diversification in terms of different enterprises, and two, informal credit from friends and family is a crucial safety net that also aids in investments in rural areas that are characterised by missing credit markets (Collier, 1998).

To establish the extent to which people have access to credit markets, we asked respondents about the different sources of credit for purchasing various inputs like improved seed, fertilizer, pesticides and livestock products. We differentiate formal from informal credit by eliciting the different types of credit sources.

Access to climate information has been shown to affect climate change adaptation, including farm diversification decisions (Mulwa et al., 2017; Chen 2018). We used data on whether respondents received climate-related information for both livestock and crop management, and whether this information was timely and adequate, to construct a climate information access variable for inclusion in the analysis.

6 Estimation strategy and model specification

6.1 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, implying path dependency. We also hypothesize that the two decisions are jointly determined by similar factors. Secondly, crop and livestock farming both 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.

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 et al., 2017; Wilde et al., 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. Methods that correct for this endogeneity use instrumental variables in or matching techniques like propensity score matching. In the instrumental variable approach, the correct instrument would be one which is correlated to diversification decisions, but not directly correlated with food security outcomes. One could then use two-step instrumental variable regressions or the control function approach.

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 et al., 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 and von Ehrlich, 2013). Thus, following other similar studies (Asfaw et al., 2018; Kassie et al., 2015), we adopt the control function approach, also called the two stage residual inclusion (2SRI) method (Terza, Basu, and 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 OLS estimation 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. 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 and Silva, 2014).

6.2 Empirical model

The SUREG model is specified as:

\[ HHI_i = \beta_i \text{climshock}_i + \alpha_i \text{climinfor}_i + \delta_i \mathbf{X}_i + \varepsilon_i \]  

(1)

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

The two equations do not need to have exactly the same set of explanatory variables (Cappellari and 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 equations 1 for both livestock and crop diversification, then include them in the OLS equation below:

\[ FS_j = \sigma HHI_c + \pi HHI_l + \theta_i \mathbf{X}_i + \lambda_c + \lambda_l + \mu \]  

(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; \( \mathbf{X} \) is the vector of variables from equation 1; \( \lambda_c \) and \( \lambda_l \) are the residuals (self-selection correction terms) for crop and livestock diversification obtained from equation 1; and \( \mu \) is the error term.

7 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.

7.1 Determinants of diversification

The first objective of the study was to evaluate the drivers to diversification (see Table 2). The coefficients from the Tobit models (columns 1 and 2) and the SUREG model (columns 3 and 4) are similar in direction but smaller under the latter; the standard errors are also smaller under the SUREG model, indicating efficiency and consistency of the SUREG estimates. The interpreted results in this section are therefore from the SUREG estimation of the joint determinants of crop and livestock diversification (columns 3 and 4). The results from this section also forms the first step of the two-stage residual inclusion (2SRI) approach to study effects of diversification on food security, discussed in the next section.

To reiterate, our indices for diversification, as shown in Figure 2, are constructed such that households that are highly diversified in an enterprise (crop or livestock), have an index of close to zero for that particular enterprise. Conversely, the more a household is specialized in an enterprise, the higher the value of the index; households that are completely specialized in an enterprise have an index of 1 for that particular enterprise.

The results 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).

Consistent with other studies (Asfaw et al., 2015; Megersa et al., 2014; Rojas-Downing et al., 2017; Wuepper et al., 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 (excluding the previous two 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.

Availability of climate information plays a significant role in explaining both crop and livestock diversification. This result has also been shown elsewhere (Chen et al., 2018; Mulwa et al., 2017; Shiferaw et al., 2014). There is a negative correlation between diversification indices and information access, implying that access to information led to higher diversification (index tends to zero). It
thus seems that farmers with access to information on how to manage crops and livestock in the context of a changing climate found diversification as an important adaptation strategy and adopted it.

In terms of demographics, household head’s years of education is positively correlated with crop diversification (or negatively correlated with crop specialization), while male-headed households are more likely to be diversified in livestock production. 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 and Andersen, 2016). In male-headed households, it is more likely that both spouses are present, and thus they are also likely to own a diversified portfolio of livestock assets.

Participating in formal employment increased the extent of livestock diversification. 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 (or negative correlation between asset ownership and livestock specialization).

Consistent with other studies (e.g. Wuepper et al. 2018), our social capital variable is positively and significantly correlated with livestock diversification. Given the information used to construct this variable (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 (Musenwa 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.

7.2 Effect of diversification on food security

7.2.1 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). In Table 3, columns 1-2 and 3-4 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 signifi-
cant 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 NAM $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 can 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 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 NAM $11 and the HDDS by about 0.11 points. Male-headed households out-spent female-headed ones by NAM $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. Rich households spend more on food, with an extra unit in the asset ownership index (from principal component analysis as explained earlier) associated with an increase in monthly per capita food expenditure by NAM $42. Similarly, a unit increase in a household’s social capital index increases monthly per capita food expenditure by about NAM $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 NAM $64 in per capita monthly food expenditure more than those who don’t have access. They also 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.

7.2.2 A non-parametric analysis

This subsection is a continuation of the parametric 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 3X3 matrix of crop-livestock diversification levels (Table 4). Next,
food security outcomes for these different combinations are compared using kernel densities. 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) (Figure 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) (Figure 3b); highly diversified in both crop and livestock (HH) versus little or no diversification in both (LL) (Figure 3c); highly diversified in both crop and livestock (HH) versus highly diversified in livestock and little or no diversification in crops (HL) (Figure 3d); little or no diversification in livestock and highly diversified in crops (LH) versus little or no diversification in either (LL) (Figure 3e); highly diversified in livestock and little or no diversification in crops (HL) versus little or no diversification in either (LL) (Figure 3f).

As the shapes of the distribution imply, significant differences in mean expenditures are observed between HH and LL combinations (figure 3a), LH and LL combinations (figure 3e), and HL and LL combination (figure 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 significantly 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.

8 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. Focusing on farm diversification, this paper finds diversifying in either crop or livestock farm enterprises to have an impact on per capita food spending and dietary diversity, two indicators used as proxies for food security in this study. Diversifying in both enterprises had even higher
impact. Access to climate information relevant for management of both crops and livestock was a key determinant of farm diversification. Gender was the other key determinant of diversification and food security; although over half of the households in our sample were headed by females, male-headed households were more diversified in both crop and livestock, and were more food secure. Our finding suggests female-headed households are more vulnerable to negative impacts of climate change than households headed by males.

Another key policy variable explaining diversification is access to credit, implying a need for deepening credit accessibility and availability for the rural population in Namibia. The importance of social capital in explaining adaptation as a source of informal credit further amplifies this result. 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.

References


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## Table 1. Descriptive statistics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Variable description</th>
<th>Mean</th>
<th>Std. Dev.</th>
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<tr>
<td><strong>Dependent variables</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Improved seed</td>
<td>Household has adopted drought tolerant/early maturing millet varieties (1=yes; 0=no)</td>
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<td>Crop diversification</td>
<td>Herfindahl–Hirschman index (HHI) for crop diversification</td>
<td>0.58</td>
<td>0.24</td>
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<tr>
<td>Livestock diversification</td>
<td>Herfindahl–Hirschman index (HHI) for livestock diversification</td>
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<td>0.24</td>
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<td>Food expenditure</td>
<td>Per capita food expenditure (NAM $)</td>
<td>112.5</td>
<td>141.9</td>
</tr>
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<td>Household Dietary diversity score</td>
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<td>1.98</td>
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<tr>
<td><strong>Explanatory variables</strong></td>
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<td>Age of household head</td>
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<tr>
<td>Education</td>
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<tr>
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<td>If household received crop/livestock input credit (1=yes; 0=no)</td>
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<tr>
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<td><strong>Location characteristics</strong></td>
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<td>Tobit Livestock Diversification</td>
<td>SUREG Crop diversification</td>
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<td>--------------------------------</td>
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<td>-0.0748*** (0.0195)</td>
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N 639 639 639 639

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Table 3. Food security determinants: OLS regressions with selection error correction terms

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<th>Combined equations</th>
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<td>Per capita food expenditure (NAM $)</td>
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Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1
Table 4. Combinations of different levels of crop and livestock diversification

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<th>Livestock diversification</th>
<th>Crop diversification</th>
<th>0.7 &lt; x</th>
<th>0.4 &lt; x ≤ 0.7</th>
<th>x ≤ 0.4</th>
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<td>Low</td>
<td>Low</td>
<td>LL</td>
<td>LM</td>
<td>LH</td>
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<td>Medium</td>
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<tr>
<td>High</td>
<td>High</td>
<td>HL</td>
<td>HM</td>
<td>HH</td>
</tr>
</tbody>
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Figure 1: Livelihood activities practiced
Figure 2: Farm enterprise diversification indices

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