World Development 125 (2020) 104686

Contents lists available at ScienceDirect

World Development

journal homepage: www.elsevier.com/locate/worlddev

Crop diversity, household welfare and consumption smoothing under risk: Evidence from rural Uganda

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ARTICLE INFO

Article history:
Accepted 10 September 2019
Available online 20 September 2019

Keywords:
Crop diversification
Household welfare
Risk coping
Consumption smoothing
Uganda

ABSTRACT

In the wake of climate change, there is now a resurgence of interest in the promotion of crop diversification as a climate smart agricultural practice in Sub-Saharan Africa. The development economics literature suggests that increasing crop diversity is an effective risk management and consumption smoothing strategy in a context characterized by repeated exposure to shocks but weak institutional innovations. Using panel survey data from rural Uganda merged with historical weather data, this paper sheds light on the household welfare and consumption smoothing effects of crop diversity. We employ instrumental variables methods to control for unobserved heterogeneity and potential reverse causality. Our study finds that crop diversification is a welfare enhancing strategy that increases consumption and aggregate household diets. Instrumental variables quantile regression results show that crop diversification generates higher consumption benefits for poorest households in the lower quantile of the consumption distribution than for relatively richer households. Crop diversification also improves consumption smoothing through reducing households' reliance on less effective strategies such as informal insurance and involuntary diet changes as risk coping mechanisms. Overall, the findings suggest that transforming agriculture towards a more diversified cropping system is a viable pathway for improving diets, welfare, risk management and the resilience of rural households.

1. Introduction

Unpredictable and aberrant weather exposes farm households in developing countries to pervasive production risks with significant repercussions on food production, income and consumption (Dercon, 2004; Di Falco & Chavas, 2009; Gao & Mills, 2018). Climate variability also poses an additional challenge to the food security and adaptive capacity of poor and marginalized households who lack natural and economic assets and are repeatedly exposed to market shocks (Asfaw, Pallante, & Palma, 2018). Households adopt various strategies to mitigate the negative effects of production and consumption risks arising from climate variability and extremes. The literature illustrates that diversifying economic activities (e.g., crops, income, assets or savings) is an important risk management and consumption smoothing strategy adopted by rural households in an environment characterized by incomplete markets and where social safety nets provide limited support (Barrett, Reardon, & Webb, 2001; Dercon, 1996; Ellis, 2000; Fafchamps, 1992; Kurosaki & Fafchamps, 2002; Morduch, 1995). Farm households adopt crop diversification as a self-insurance mechanism against multiple risks affecting their income and consumption especially when they face liquidity, asset and credit constraints and their access to off-farm income is very limited (Dercon, 2002; Khanal & Mishra, 2017).

In the current policy discourse, there is a resurgence of interest in the promotion of crop diversification as evidence from Sub-Saharan Africa (SSA) demonstrates that reliance on mono-cropping contributes to low agricultural productivity and exposes rural households to production and price risks (Benson, Mugarura, & Wanda, 2008; Chibwana, Fisher, & Shively, 2012; Saenz & Thompson, 2017; Teklewold, Kassie, Shiferaw, & Köhlin, 2013). Crop diversification is deemed as important for increasing agricultural production, enhancing food security, reducing poverty, building resilience against economic and climatic risks, while conserving the ecological biodiversity and aiding sustainable agricultural transformation (Donfouet, Barczak, Détang-Dessendre, & Maigné, 2017; FAO, 2012; Lin, 2011; Massawe, Mayes, & Cheng, 2016; Michler & Josephson, 2017). As a climatic risk hedging option, crop diversification can reduce the risk of crop failure, yield

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https://doi.org/10.1016/j.worlddev.2019.104686
0305-750X/

variability and can mitigate price risks for poor and marginal farming households operating in rain-fed areas (Bezabih & Sarr, 2012; Coromaldi, Pallante, & Savastano, 2015; Imbs & Wacziarg, 2003; Rosenzweig & Parry, 1994).

Since the work of Heady (1952) who propose diversification as an agricultural activity to manage uncertainty, there is growing evidence on the role of crop diversification as an effective farm-level response to climate variability (Arslan et al., 2018; Asfaw et al., 2018, Asfaw, Scognamillo, Di Caprera, Sitko, & Ignaciuk, 2019; Bradshaw, Dolan, & Smit, 2004; Di Falco & Chavas, 2009; Lin, 2011; Michler & Josephson, 2017; Seo & Mendelsohn, 2008). However, the contribution of crop diversification for household welfare receives interest only in contemporary work (Loison, 2015). Recent studies in India (Birthal, Roy, & Negi, 2015), Thailand (Kasem & Thapa, 2011), and Ethiopia (Michler & Josephson, 2017) show that crop diversification prevents and alleviates poverty, reduces poverty persistence and increases income. Other studies in Africa find that crop diversification increases income and energy intake in Niger (Asfaw et al., 2018), dietary diversity in Malawi (Jones, Shrinivas, & Bezner-Kerr, 2014; Snapp & Fisher, 2015) and nutrition for poor farm households in Nigeria (Rahman & Chima, 2016). A recent meta-analysis of existing studies that analyzed the associations between farm production diversity and dietary diversity in developing-country farm households reports that the evidence that identifies the impact of farm production diversity on diets and nutrition is mixed and inconclusive (Sibhatu et al., 2018). Thus, providing rigorous evidence on the welfare impacts of crop diversification is needed to provide insights into the role of diversification in poverty reduction, food security and development. Such evidence would also help to design policies that explicitly address diversification as possible determinants of future levels of welfare and foster institutions to support welfare-improving diversification.

Another strand of the literature on the economics of crop diversification encompasses numerous seminal studies that have focused on the relationship between diversity and risk (Alderman & Paxson, 1994; Dercon, 1996; Di Falco & Perrings, 2005; Little, Smith, Cellarius, Coppock, & Barrett, 2001; Rosenzweig & Wolpin, 1993). Crop diversification is cited among potential risk mitigating mechanisms that are used by households against unpredictable production and consumption risks (Morduch, 1995; Townsend, 1994). Previous studies document that agricultural households smooth consumption by employing informal insurance arrangements or involuntarily changing their consumption and diets, among others, after shocks occur (Morduch, 1995). However, evidence on the link between *ex-ante* risk management in the form of crop diversification and *ex-post* consumption smoothing or risk coping behaviour is thin (Dercon, 1996; Fafchamps, 1992; Rosenzweig & Wolpin, 1993). Di Falco, Adinolfi, Bozzola, and Capitanio (2014) is perhaps the only study that finds that crop diversification to be a substitute for financial insurance when households mitigate the impact of risk. To help fill to this knowledge gap in the literature, we examine whether a household's *ex-ante* risk management or income smoothing decisions in the form of crop diversification has impact on consumption smoothing behavior in the event of shocks.

The study makes important contributions to the literature by providing empirical evidence on the household welfare and risk coping effects of crop diversity in the small farm sector in a developing country context using panel data from Uganda. It differs from existing studies in many aspects. First, most of the existing studies are based on cross-sectional data and estimates are, therefore, plagued by endogeneity. Our study utilizes rich panel survey and historical rainfall data from Uganda which enables us capture the dynamics in crop diversification and its implications on household welfare and risk coping. Second, to address the econometric challenges of endogeneity and reverse causality and produce credible impact estimates, we employ estimation strategies that rely on panel data econometrics and instrumental variables methods. We exploit the exogenous variation in crop production decisions due to climate variability and neighborhood effects to instrument crop diversity. Third, the level of crop diversity is measured using a series of crop diversity indices (Count, Shannon-Weaver, Composite entropy and Berger-Parker) to capture the extent of the diversity of crops cultivated. Hence, we are able to study the different aspects of multi-cropping regimes and assess the sensitivity of results to different crop diversity measures. Fourth, in addition to assessing the average impacts of crop diversification on consumption, we also estimate the heterogeneous effects using quantile regressions.

We find that crop diversity increases household welfare (dietary diversity and consumption expenditure) and reduces households' reliance on informal insurance as a risk coping mechanism. Results from quantile based instrumental variables regression show that crop diversity generates higher consumption benefits for low consuming households positioned in the lower quantile of the consumption distribution. The findings suggest that crop diversity contributes to improved welfare, nutrition security and risk management among rural households. The evidence will help in the effective design of policies that will facilitate promotion of diversification. Overall, the findings of this study provide useful insights for the current and emerging policy focus on agricultural transformation and economic diversification in rural SSA.

The rest of this paper is structured as follows. Section 2 presents a brief overview of the study country context. Section 3 presents a brief theoretical framework. Section 4 demonstrates the empirical strategies. Section 5 discusses the data and variables used for the analysis. Section 6 presents the econometric results and the last section concludes.

2. Country context

Uganda is a small, landlocked country in Eastern Africa that has achieved significant poverty reduction in the last decade (Bank, 2016). Much of the national poverty reduction has occurred among households working in agriculture. Agricultural income growth appears to be the major driver for Uganda's progress in poverty reduction. Due to its immense potential in the country's economy, the agricultural sector has been given priority in the national development plan for poverty reduction and economic growth. Despite this political will and significant gains in poverty reduction, a third of Ugandans remain poor, food insecure and vulnerable to shocks. As in much of SSA, poverty and hunger in Uganda are intrinsically linked to agriculture, the sector dominated by smallholder families (estimated at 85%) that are engage in mixed crop-livestock farming and primarily grow crops for subsistence purposes.[1] The major food crops grown in Uganda include maize, rice, beans, soya beans, palms, and horticultural crops. Cash crops include coffee, cotton, tea, cocoa, tobacco, and sugarcane (Veljanoska, 2014).

The choice of Uganda as a case for this study is motivated by the following reasons. First, Uganda is a country facing a wide range of development challenges including low agricultural productivity, high food insecurity, and climate change. Increased weather (rainfall and temperature) variability negatively affect food production, consumption and make farm households net buyers in markets. In response to climatic variability, rural Ugandan households engage in ex-ante and *ex-post* consumption smoothing strategies. Second, Uganda has high farming diversity potential and rich agroecologi-

[1] See https://ccafs.cgiar.org/publications/climate-smart-agriculture-ethiopia#.XCzUKFxKjcs.

cal diversity hotspots that are essential for improving food security and reducing the adverse effects of current and future climate change on livelihoods and food systems (Coromaldi et al., 2015; Covarrubias, 2015; Smale, 2006; Waha et al., 2018). Third, there are few off-farm income diversification options in the country. This limits the capacity of diversifying income away from agriculture as a strategy for poverty reduction.

Given that Ugandan agriculture is mostly rain-fed, relying on few low-risk crops or specialization in few staple crops may exacerbate exposure to shocks and aggravate food insecurity and poverty. Therefore, the decision to engage in diversified crop production comes naturally. Increasing crop diversity appears to be the most promising solution to deal with irregular weather conditions, market shocks and for improving rural livelihoods (Veljanoska, 2014). Uganda is one of the few African countries that explicitly incorporated diversification as part of its national agricultural investment strategies for adaptation and building resilience (Arslan et al., 2018). Therefore, Uganda makes an interesting case to explore the household welfare and risk coping or consumption smoothing effects of crop diversity. The evidence generated from this study will feed into the current agricultural development policy of the country that seeks to achieve food and nutrition security and improve household welfare through enhancing sustainable agricultural productivity.

3. Theoretical framework

3.1. Economics of crop diversification

Economic theory asserts that households diversify their economic activities to improve their risk management capacity, smooth income streams *ex-ante* (Alderman & Paxson, 1994; Barrett et al., 2001), and smooth consumption *ex-post* shocks (Morduch, 1995). Consumption smoothing expresses household's desire to have a stable and predictable consumption path in their lifetime. Although diversification is a common practice across different sectors (e.g., finance), the peculiarities of agricultural production such as dependence on weather patterns, seasonality in the demand for inputs and heterogeneity in land quality distinguishes diversification in agricultural production from other sectors (Arslan et al., 2018). Incomplete credit and insurance markets or market failures, quasi-universal circumstances in developing countries, are among the primary conditions that lead to diversification in rural economies (Arslan et al., 2018; Kurosaki & Fafchamps, 2002).

Portfolio theory postulates that crop diversification is a production risk management strategy for risk-averse and subsistence farm households (Rosenzweig, 1988). In the absence of insurance and reliable food markets, for instance, poor households minimize their exposure to various risks by growing their own food and diversifying their activities (Fafchamps, 1992; Kurosaki & Fafchamps, 2002). By diversifying food crop production, a farm household gains some assurance that it can have something to eat even in the event of crop failure, food price shocks, or lack of food in local markets. When *ex-post* consumption smoothing mechanisms are absent, diversification can help households meet their risk-management needs left unmet due to missing insurance markets (Binswanger, 1983; Fafchamps, 1992; Reardon, 1997). Depending on their market-orientation, some farm households may also add new crops to their crop mix to increase their income. Crop diversification may also reduce income variability by allowing participation in multiple crop markets. However, the effectiveness depends on the level of correlation of prices in the markets.

The desire for income or profit maximization and risk minimization are not the only stimuli for diversification in agricultural production (e.g., Omamo, 1998; Pope & Prescott, 1980). Studies demonstrate that diversification in agricultural production can arise under conditions where specialization would be expected or even if we assume no risk (Just & Pope, 2001; Pope & Prescott, 1980). In rural economies where households face multiple market imperfections and markets are poorly developed and less integrated (De Janvry & Sadoulet, 2006), crop diversification decisions may also be motivated by food security and nutritional considerations (Bezabih & Di Falco, 2012; Hoddinott, Headey, & Dereje, 2015; Pellegrini & Tasciotti, 2014). While markets do not exist in some cases, if they do, accessing them might be prohibitive due to high transaction costs. In other circumstances, there could be a constraint on the quantities to be exchanged in the markets. In the presence of high transaction costs, households are forced to satisfy consumption from own production (Fafchamps, 1992; Van Dusen & Taylor, 2005).

3.2. Crop diversity, welfare and risk coping: hypotheses and Impact pathways

The interest in this study is to empirically show the effect of crop diversity on household consumption, nutrition, and risk coping behavior related to consumption smoothing. While lack of formal insurance and incomplete markets are the major factors driving the crop diversification decision, increased crop diversification is expected to affect consumption expenditure, nutrition and risk coping behavior. Based on the existing studies and the theoretical framework, we hypothesize that crop diversification will increase household welfare (household diets and consumption) in the context of missing or incomplete insurance and food markets. For the poorest households who have the least capacity to effectively cope with risk, diversification is one of the few viable options available to manage the challenges associated with climate risk (Asfaw et al., 2019). Thus, welfare will be more responsive to crop diversity for relatively poor households that lack formal risk management options. We also hypothesize that crop diversification would reduce households' use of negative risk coping strategies or risky consumption smoothing strategies.

In what follows, based on empirical evidence, we briefly discuss the potential pathways through which crop diversification will impact household welfare and risk coping (consumption smoothing) behaviour.

3.2.1. Productivity and income effects

Crop diversification would affect household welfare (consumption expenditure and diet diversity) through various channels. Primarily, it can improve household welfare through its productivity and income effects. Crop diversification boosts crop productivity at the household level by increasing yield (Chavas & Di Falco, 2012; Di Falco & Perrings, 2005; Di Falco, Bezabih, & Yesuf, 2010; Feder, Just, & Zilberman, 1985). For subsistence oriented households that primarily consume from own production, cultivating diverse crops guarantees consumption of diverse diets (Ecker & Qaim, 2011). It can also increase consumption and nutrition diversity through increasing crop income from high-value and cash crops in the production portfolio (Birthal et al., 2015; Fafchamps, 1992). The resulting income would enable a household purchase diverse and potentially micronutrient-rich foods, and ultimately improves household welfare (Dzanku & Sarpong, 2011). For households with poor access to markets, reliance on monocropping for consumption makes their diet poorly diversified that would lead to high risk of micronutrient deficiencies and malnutrition (Ecker & Qaim, 2011). In contrast, crop diversification would exert positive consumption and nutrition effects in areas where markets are less integrated with national or local food markets (Ecker & Qaim, 2011; Fafchamps, 1992; Lovo & Veronesi, 2019; Omamo, 1998). Besides its direct effect, crop diversity might affect household welfare indirectly by influencing the local availability of crops in relatively marginalized areas (Ecker & Qaim, 2011).

3.2.2. Downside risk mitigation and insurance effects

When environmental risks increase, crop diversification would increase production and food consumption through risk reducing mechanisms (Asfaw et al., 2019; Lovo & Veronesi, 2019) because it can be a natural insurance (as opposed to financial insurance) against downside risk or crop failure (Baumgärtner & Quaas, 2010). Ecologists have provided two explanations for the beneficial role of crop diversity in production risk management. The "sampling effect" hypothesis asserts that households manage production risks by increasing the number of crops with different climatic requirements and responses to biotic stressors (Tilman, Polasky, & Lehman, 2005). The second set of explanation, the "complementarity effect" hypothesis, emphasizes that growing different crops that have different traits and characteristics is a strategy to adapt to different environmental conditions due to complementarity effects (Loreau & Hector, 2001; Sala et al., 2000). Both effects would ultimately reduce the probability of crop failure (Chavas & Di Falco, 2012; Loreau & Hector, 2001). Crop diversification can also reduce exposure to weather shocks and increase crop yields through controlling crop diseases and pests. It could also reduce exposure to market risks (e.g., fluctuations of grain prices) and help households manage price risks by having crops in the portfolio that exhibit uncorrelated prices (Dercon, 1996; Di Falco & Perrings, 2005). Through its risk buffering benefits, crop diversification can help households improve their welfare and grow out of poverty (Michler & Josephson, 2017).

3.2.3. Consumption smoothing effects

Crop diversification can influence risk coping or consumption smoothing behavior of rural households in various ways. In rural areas where formal insurance or safety nets are lacking or not fully functioning, crop diversification can be an effective risk coping strategy (Barrett et al., 2001; Dercon, 2002; Loison, 2015). Acting as a substitute to formal insurance (Di Falco et al., 2014), crop diversity could reduce households' use of negative risk coping mechanisms. Through increasing food consumption and welfare and hence improved consumption smoothing, crop diversity can reduce the need for informal insurance and involuntary diet changes as risk-coping strategies. The effect of crop diversification on reducing the use of risky consumption smoothing strategies would be higher when households experience shocks vis-vis a scenario where the households face no shocks (Asfaw et al., 2018).

4. Empirical strategy

4.1. Drivers of crop diversification

Crop choice or diversification decisions will be determined by households' willingness to bear risk or risk attitude, the availability of consumption smoothing measures, and households' preferences (Alderman & Paxson, 1994; Arslan et al., 2018; Asfaw et al., 2018; Fafchamps, 1992; Rosenzweig & Wolpin, 1993). A wide range of variables are introduced in the crop diversity model to capture the degree of risk aversion, transaction costs, and household preferences. The variables include household asset endowments that could determine the degree to which farmers diversify their production portfolio (Arslan et al., 2018; Asfaw et al., 2018, 2019). Asset endowments of the household are represented as livelihood assets or capitals and include natural capital (rainfall, temperature, elevation, cultivated land, agroecology), physical capital (livestock holding, asset value), human capital (education, gender, age of the head, household size), financial capital (remittances and transfers, distance to road, distance to markets), and social capital.

Physical and human capital assets would affect households' ability to bear risk (Barrett et al., 2001; Dercon, 1996; Feder et al., 1985; Rosenzweig & Wolpin, 1993). Consumption preferences are affected by variables such as the demographic composition of the household that shift the taste for consumption goods (Dercon, 1996). Household demographic composition (e.g., household size) and wealth would also affect risk and time preferences as well as liquidity and credit constraints. Proximity to markets and major roads, that would capture the effect of the economic and geographic environment and transaction costs, are important pull factors that would influence diversification behavior, risk coping and household welfare (Barrett et al., 2001). Climate factors are the major exogenous factors that could influence households' production decisions through altering risk profile (Angrist & Krueger, 2001; Adger et al., 2009; Arslan et al., 2018). They are captured by rainfall, elevation and temperature that are major source of covariate shocks and reflect exposure to weather shocks and the short and long-term temporal and spatial climate variations (Asfaw et al., 2018; Gao & Mills, 2018).

The estimates for drivers of crop diversification are obtained using the following correlated random effects (CRE) model

$$D_{it} = \delta X_{it} + \gamma Z_{it} + \lambda \bar{M}_i + \varepsilon_{it} \quad (1)$$

where D_{it} is crop diversity (measured using different crop diversity indices discussed in Section 5.2), X_{it} is a vector of the asset endowment or capital variables discussed above; Z_{it} is a set of instrumental variables (mean temperature and elevation, rainfall shock, and average village level crop diversification). We also include region, time and region-time interactions to control for temporal and spatial differences in biophysical conditions, access to infrastructure, policy changes, etc. not possibly captured by the other covariates.[2] In Eq. (1), we assume that time-invariant unobserved effect or household-specific heterogeneity (say c_i) can be replaced with its projection onto the time averages of the exogenous variables ($\bar{M}_i$) as: $c_i = \lambda \bar{M}_i + a_i$. ε_{it} is the idiosyncratic error term that captures time-varying unobserved factors. δ and γ are the parameters of interest to be estimated.

The CRE is an alternative approach to the fixed effects (Mundlak, 1978; Chamberlain, 1982). It is preferred over the traditional random effects (RE) model as it relaxes the stringent exogeneity assumption of the RE approach by allowing an arbitrary correlation between the unobserved effect (c_i) and the explanatory variables (X_{it} and Z_{it}). It also avoids the incidental parameters problems associated with the fixed effects. The estimation procedure in CRE amounts to including the mean of all time-varying variables as an additional set of explanatory variables in the crop diversification equation to control for time-invariant unobserved heterogeneity (Wooldridge, 2002, 2010). We run separate regressions for the different crop diversity metrics.[3]

4.2. Strategies for estimating the impact of crop diversification

Estimating the impact of crop diversity on the outcomes faces numerous econometric issues that could result in endogeneity.

[2] In Uganda in particular, there is regional heterogeneity in cropping seasons (rainy) and land quality. While the majority of the country is exposed to two cropping and rainy seasons, the North part benefits from only one rainy season. The central-southern region is the most productive in terms of crop production (Veljanoska, 2014).

[3] The crop count index is a count variable that takes a limited number of values. This suggests the use of Poisson regression or other count outcome data models. The other crop diversity indices could also be left-censored. They can be estimated using Tobit or fractional logit as applied to panel data. However, in our sample, the number of left-censored observations is less than 2%. We, therefore, apply linear models.

The first potential source of endogeneity is the presence of unobserved heterogeneity due to time-invariant factors that would affect both cropping decisions and the outcomes. Crop diversification is a voluntary decision that might be affected by unobserved household characteristics such as preferences, innate ability, openness to innovation and entrepreneurial motives that could lead to selection bias in the choice to diversify or not and also correlated with the outcomes. The second source of endogeneity are time-varying unobserved factors and idiosyncratic shocks that would simultaneously influence crop diversity as well as household welfare and risk coping. Such type of unobserved endogeneity may arise due to omission of relevant time-varying factors, simultaneous responses to idiosyncratic or covariate shocks, or measurement errors (Terza, Basu, & Rathouz, 2008; Verkaart, Munyua, Mausch, & Michler, 2017). The third source of endogeneity is reverse causality or simultaneity problem in that household welfare may affect crop diversity and vice versa (Asfaw et al., 2018; Michler & Josephson, 2017). While diversification affects household income through risk reducing mechanisms, the reverse might also be true because households' initial level of welfare is likely to affect their probability of overcoming entry barriers and liquidity constraints to the implementation of diversification strategies (Asfaw et al., 2019). Availability of risk coping mechanisms may also determine the need for *ex-ante* risk management strategies such as crop diversification (Dercon, 1996; Rosenzweig & Wolpin, 1993). Failure to control for these econometric issues will either overestimate or underestimate the supposed true effect of crop diversification. In what follows, we discuss the empirical strategies used to estimate the impact of crop diversity on the outcomes while endogeneity.

4.2.1. Crop diversity and household welfare

The relationship between household welfare and crop diversity is represented using the following model

$$y_{it} = \phi D_{it} + \beta X_{it} + \alpha_i + \upsilon_{it} \tag{2}$$

where y_{it} is a measure of household welfare (dietary diversity, per adult equivalent consumption expenditure) or risk coping (informal insurance, involuntary change in diets), D_{it} is crop diversification as defined above and X_{it} is a vector of additional control variables defined above. α_i is the household-specific unobserved effect and υ_{it} is the idiosyncratic error term. ϕ is the parameter of interest that denotes the impact of crop diversification on welfare. We utilize fixed effects instrumental variables (FE-IV) approach to estimate the impact of crop diversification on household dietary diversity and per adult equivalent consumption expenditure while addressing endogeneity.

Two sets of instruments are used for household level crop diversification. The first is the average village level crop diversification excluding the household under consideration. The choice of this instrument is inspired by insights from research on the importance of social networks and neighborhood effects in agricultural technology adoption and production decisions (Conley & Udry, 2010; Krishnan & Patnam, 2013; Magnan, Spielman, Lybbert, & Gulati, 2015). Farming decisions of households (including their crop choice) are very likely to be influenced by the decision of neighboring households due to peer effects or potential learning externality. Farms that operate in the same agro-environmental conditions, and face similar demographic, institutional and economic characteristics, are likely to adopt similar production systems (Lovo & Veronesi, 2019). A farm household located in a village where farmers diversify their crop production is more likely to adopt a diversified production system than a household located in a less diversified village (Ahmadzai, 2017; Asfaw et al., 2019; Lovo & Veronesi, 2019). The leave-out mean crop diversity at household level is expected not to be correlated with the household unobserved heterogeneity and the household outcome variables (Asfaw et al., 2019; Townsend, 1994).

The second set of instruments for crop production diversity includes climate variables. Climate variability is a major source of risk that alters farmers' risk profile that in turn affects their crop portfolio selection decisions (Dercon, 1996; Dercon & Christiaensen, 2011; Rosenzweig & Wolpin, 1993). Households' exposure to weather shocks would affect crop diversity (Asfaw et al., 2018, 2019). Based on a historical rainfall data which spans about 30 years (1981–2010), we generate a rainfall shock variable as rainfall deviation from the long-term historical average following Michler, Baylis, Arends-Kuenning, and Mazvimavi (2018). The variable could be a proxy for village level climatic conditions and used as instrument to crop production diversity. Variation in temperature also determines farmers' crop choice as different crops respond differently to change in temperature (Dillon, McGee, & Oseni, 2015; Hirvonen & Hoddinott, 2017). The impact of temperature on production choices varies with elevation. Thus, we exploit the interaction of elevation with temperature as an additional instrument for crop diversity.

The use of the FE-IV is with an assumption that the data generating process for crop diversification and the welfare outcomes is linear. The empirical strategy accounts for endogeneity of crop diversification as well as unobserved heterogeneity. The inclusion of household fixed effects will enable controlling for potential omitted variable bias related to time-invariant unobservables that will affect both crop diversification and the outcomes. The estimator removes the time-invariant unobserved effects by deviating the variables from their time averages, and then applies IV. We report cluster robust standard errors to deal with heteroscedasticity and serial dependence of idiosyncratic shocks. To assess whether our results are robust to the way in which crop diversity is measured, we run separate regressions for each crop diversity index. The outcome equations are also estimated separately for the different outcome measures.

As robustness check, we employ two-stage residual inclusion (2SRI) approach (Terza et al., 2008; Wooldridge, 2014).[4] The 2SRI approach addresses potential endogeneity and reverse causality between crop diversity and household welfare outcomes. In an application similar to ours, Bezu, Kassie, Shiferaw, and Ricker-Gilbert (2014), Michler and Josephson (2017), and Verkaart et al. (2017) utilize a two-stage predictor substitution (2SPS) method where the unconditional expected values of the endogenous regressor are used as instrument for observed values. The 2SPS is argued to be inconsistent for both the structural parameters and average partial (or marginal) effects while the 2SRI is consistent (Terza et al., 2008). In the 2SRI framework, the first stage involves regressing crop diversification on the instrumental variables and additional covariates. In our case, this first stage is obtained by means of a panel correlated random effects approach discussed above (Eq. (1)). From the first stage regressions, we retrieve the residuals that are used in the second stage regression.

The second stage estimation is also implemented using the CRE approach. In the second stage, the endogenous term (D_{it}) is maintained in the main outcome equation and the residuals from the first-stage regression are introduced as substitutes for the unobserved confounders. The resulting 2SRI specification is

$$y_{it} = \phi D_{it} + \psi \check{D}_{it} + \beta X_{it} + \omega \bar{V}_i + \epsilon_{it}^{2SRI} \tag{3}$$

where y_{it} is a measure of household welfare and D_{it} is crop diversity as discussed above. $\check{D}_{it}$ includes the residuals of the crop diversification equations which corrects for potential endogeneity between

[4] Additional robustness check is also performed using alternative specifications treating crop diversity as exogenous.

the outcomes and the diversification variable. X_{it} is as defined above and $\bar{V}_i$ is the time-average of all time-varying variables included in the outcome equation. Since the second stage regressions include residuals from the first stage reduced form equations, standard errors are bootstrapped. Due to the short nature of our panel and to correct for serial correlation and heteroscedasticity, we estimate panel-robust standard errors with cluster correction at the household level (White, 1980; Cameron & Trivedi, 2010). Results from the FE-IV are also contrasted with various specifications for the two welfare metrics.

4.2.2. Heterogeneous effects of crop diversity on welfare

Crop diversification can produce impacts that are heterogeneous across the different classes of the consumption distribution and hence can generate non-linear and distributional effects on household welfare (Asfaw et al., 2018, 2019). Estimating the heterogeneous effects is important for policy targeting purposes as low-consuming households may be especially responsive to crop diversity relative to high-consuming households. To explore the relationship between crop diversity and consumption at different points in the conditional distribution of consumption expenditure, we model the quantile of the conditional distribution of aggregate consumption expenditure as a function of crop diversification and other covariates using a quantile-IV regression.[5]

We specify the quantile regression model as follows:

$$y_{it,\tau} = \beta_\tau d_{it} + \rho_\tau x_{it} + e_{\tau it} \tag{4}$$

with

$$Q_\tau(y_{it}|d_{it}, x_{it}) = \beta_\tau d_{it} + \rho_\tau x_{it} \tag{5}$$

where y is consumption expenditure, d is crop diversity, x are the other covariates as defined earlier and e is a vector of idiosyncratic errors. $Q_\tau(y_{it}|d_{it}, x_{it})$ identifies the τ^{th} conditional quantile of y given d and x. β and ρ are vectors of parameters to be estimated.

Estimating the distribution impact of crop diversity on consumption expenditure is also complicated by potential endogeneity due to reverse causality between the welfare outcome and the crop diversification variables. To deal with this issue, we utilize the two-stage residual inclusion (2SRI) approach discussed above and employed in related studies (Asfaw et al., 2018; Michler et al., 2018). In the first stage, we regress crop diversification on the set of instrumental variables and additional covariates by a means of a panel correlated random effects model discussed earlier. In the second stage, we estimate a pooled quantile regression model (separately for each quantile) augmented with the Mundlak (1978) approach to purge unobserved heterogeneity. The reduced form second stage equation is

$$y_{\tau,it} = \phi_\tau D_{\tau,it} + \psi_\tau \check{D}_{\tau,it} + \beta_\tau X_{\tau,it} + \omega_\tau \bar{V}_i + \epsilon^{2SRI}_{\tau,it} \tag{6}$$

$\widehat{D}_{it}$ includes the residuals from the first stage crop diversification equations to correct for potential endogeneity between the welfare outcome and diversification. $\bar{V}_i$ are the mean of the time-varying covariates used in the outcome equation. Since the second-stage regressions include estimates from the first stage, the variance-covariance matrix of the estimators (standard errors) is computed through bootstrapping. To check robustness of our results, we also produce estimates using pooled quantile regression with the Mundlak approach without additional correction for endogeneity of crop diversity.

[5] We utilize the Stata command *bsqreg* to estimate the model that allows us produce QR estimates for several values of τ (0.2, 0.4, 0.6 and 0.8). The choice of the quantile bandwidths is arbitrary. To allow comparison of estimates from our model with previous findings, we chose same bandwidths as Asfaw et al. (2018).

4.2.3. Crop diversity and risk coping

In this study, we also assess the impact of crop diversification on two risk coping measures which are binary outcome variables. Following Michler and Josephson (2017), for our binary response function, we assume that there is an underlying latent variable model:

$$y^*_{it} = \phi D_{it} + \beta X_{it} + \alpha_i + \upsilon_{it} \tag{7}$$

where $y_{it} = 1[y^*_{it} \geqslant 0]$ for $t = 1, \ldots, T$ and the other variables are as defined earlier. To recapitulate, we model crop diversification as in Eq. (1) as a linear function of the instruments and other covariates as follows:

$$D_{it} = \delta X_{it} + \gamma Z_{it} + c_i + \varepsilon_{it} \tag{8}$$

The impact of crop diversification (D_{it}) on risk coping (y_{it}) is estimated using alternative econometric methods that address the endogeneity of crop diversity. The primary estimation method is the 2SRI or two-step control function method discussed above. The 2SRI is one of the instrumental variables (IV)-based approaches to correct for endogeneity bias due to the presence of unobservable confounders in nonlinear models (Terza et al., 2008; Wooldridge, 2014). Following Michler and Balagtas (2017) and Papke and Wooldridge (2008), we implement the 2SRI in two steps. First, we estimate the crop diversification model using pooled OLS with correlated random effects and clustered standard errors at the household. We save the generalized residuals from the first stage regressions. The second stage is implemented with correlated random effects probit (pooled maximum likelihood estimation) model of risk coping on crop diversification and other control variables. In this stage, the residuals saved from the first stage are included as additional regressors to control for endogeneity.

As a robustness check, we utilize the FE-IV method discussed above earlier and deploy the method using linear probability models (Dercon, Gilligan, Hoddinott, & Woldehanna, 2009; Michler & Josephson, 2017; Verkaart et al., 2017). Use of the linear probability model (LPM) is assuming the data generating process for the risk coping outcomes is linear. Estimation using LPM also provides coefficient estimates that are easy to interpret. As additional test for robustness of our results, we estimate our model using correlated random effects probit (pooled MLE) and fixed effects logit where we treat crop diversity as exogenous.

5. Data and descriptive statistics

5.1. Household survey and rainfall data

The data for the chapter come from the 2009 to 2012 waves of the Ugandan National Panel Survey (UNPS), a rich and nationally representative data administered by the Living Standards Measurement Study – Integrated Surveys on Agriculture (LSMS-ISA) program of the World Bank in collaboration with the Uganda Bureau of Statistics (UBoS). The survey collects detailed information on household characteristics, income sources, household assets, consumption expenditure, shocks and coping strategies, food security, land holdings, crop production and livestock ownership. The sample used in this study is a panel of rural households that is representative of rural Uganda.[6] Details of the description and summary of the main variables (covariates) used in the empirical models are presented in Table 9 (Appendix).

[6] Details of the survey including sample size, sampling methods, data and other supporting materials can be accessed from the website:www.worldbank.org/lsms-isa. The UNPS has five waves of data including the 2005/06. The latest round (2013/14) is not used since it replaces about a third of the original households by new samples. According to the UNPS report in 2011/12, the attrition rate for the whole sample across the three waves used in this study is less than 5%.

Georeferencing of the households enables merging the survey data with climatic or agroecological characteristics. We extract historical rainfall data (1981–2010) from the Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) data (Funk et al., 2015; Michler et al., 2018). CHRIPS generates satellite imagery with in situ station gridded time series rainfall data. While the dataset provides daily rainfall measurements, we generate spatial rainfall data by scaling the data into monthly and seasonal rainfall measures. We use rainfall of the growing season in Uganda that lasts from October until April the following year to compute a measure of rainfall shock.

5.2. Crop diversification measures and patterns

Crop diversification is measured using four interspecific crop diversity indices that capture both the number of crops in the crop production portfolio and their evenness: Count (richness), Shannon-Weaver, Composite entropy and Berger-Parker. The count index measures richness of cultivated crops and assumes that different crops contribute equally to the household crop portfolio, although this is not always the case (Benin, Smale, Pender, Gebremedhin, & and Ehui, 2004; Di Falco et al., 2010; Jones et al., 2014; Saenz & Thompson, 2017). The Berger Parker Index measures relative abundance computed as the inverse weight of the most abundant crop (Benin et al., 2004). The Shannon-Weaver index measures the proportional abundance and evenness, an improvement over the two indices. Because its upper limit depends on the number of crops grown, it cannot be used to compare the degree of diversification in different locations where different numbers of crops are grown (Saenz & Thompson, 2017). The Composite entropy index, a modified version of the Shannon-Weaver index, measures both richness and evenness and enables the comparison of crop diversity across different locations, and thus overcomes the limitations of the Shannon-Weaver index (Arndt, Pauw, & Thurlow, 2015; Ghosh, Sarkar, & Roy, & editors, 2015). Table 8 (Appendix) presents the definition and computation of the four crop diversity indices.

Table 1 summarizes the crop diversification pattern of the sample households. The count index shows that the average number of crops cultivated by the households is about 6 with a slight variation during the course of the panel. There appears to be no clear trend in crop diversification, particularly for the Count and Shannon-Weaver indices. The averages of the Shannon-Weaver and Berger-Parker indices are less than the count index. This indicates that land is not equally distributed to different crops cultivated by the households.

5.3. Household welfare and risk coping

We use real per adult-equivalent consumption expenditure (a flow measure) and household dietary diversity score (a stock measure) as indicators of household welfare (Upton, Cissé, & Barrett, 2016). Current consumption is often considered to be a preferred measure of welfare over income since consumption is smoother than income and risk-averse households prefer less variable consumption (Bezu et al., 2014; Dercon, 2002). Consumption expenditure is computed as the sum of the value of food and non-food consumption, either from own production, from the market or gift or in-kind in the previous 30 days. The aggregate value is scaled to adult equivalent bases to account for intra-household inequalities

Table 1
Summary statistics for crop diversity pattern (2009–2012).

Crop diversity indices	2009/10	2010/11	2011/12	Pooled
Count Index	5.78	5.98	5.31	5.67
	(2.20)	(2.12)	(1.98)	(2.12)
Shannon-Weaver Index	1.41	1.46	1.41	1.43
	(0.42)	(0.40)	(0.40)	(0.41)
Composite Entropy Index	0.67	0.68	0.69	0.60
	(0.15)	(0.14)	(0.14)	(0.14)
Berger-Parker Index	2.74	2.80	2.83	2.79
	(1.02)	(1.02)	(0.99)	(1.01)
Observations	1479	1367	1677	4523

Note: Mean values reported; Standard deviations in parentheses.

Table 2
Summary statistics of the outcome variables.

	2009/10	2010/11	2011/12	Pooled
Household welfare				
Per adult equiv. consumption (X 1000 USh)	53.55	46.13	45.01	48.14
	(67.33)	(46.25)	(56.95)	(57.83)
Log per adult equiv. consumption (USh)	10.66	10.48	10.47	10.53
	(0.62)	(0.68)	(0.68)	(0.67)
Household dietary diversity score (HDDS)	7.43	7.37	7.29	7.36
	(2.03)	(2.28)	(2.18)	(2.16)
Risk coping/consumption smoothing				
Informal insurance (1 = Yes)	0.141	0.179	0.176	0.165
	(0.348)	(0.383)	(0.381)	(0.372)
Involuntary dietary change (1 = Yes)	0.381	0.238	0.128	0.244
	(0.486)	(0.426)	(0.334)	(0.430)
Observations	1479	1367	1677	4523

Note: Mean values reported and standard deviations in parentheses. Reported per adult equivalent consumption expenditure values are after winsorizing top 1%. Log per adult equivalent consumption expenditure is based on log transformation of the original values.

and needs, and expressed in Ugandan Shillings (USh) using constant base prices. Table 2 shows that real per adult equivalent consumption expenditure falls over the years 2009 and 2010. However, it remains nearly the same between 2010 and 2011. The household dietary diversity score (HDDS) is computed as the number of food groups (among 12 food groups) consumed by the household in a week before the survey.[7] HDDs slightly decreased between 2009 and 2012.

To investigate the impact of crop diversification on risk coping or consumption smoothing, two risk coping strategies are considered: informal insurance and involuntary change in diets. These risk coping strategies are among the *ex-post* shock coping mechanisms that would help agricultural households smooth consumption (Alderman & Paxson, 1994; Morduch, 1995; Townsend, 1994). These strategies are usually considered in the absence of formal risk coping mechanisms (Deaton, 1991, 2002; Dercon & Christiaensen, 2011; Gao & Mills, 2018). Informal insurance includes cash or in-kind support provided by community or family members. It is not an effective strategy for maintaining consumption or welfare in times of covariate shocks (Barrett et al., 2001; Dercon, 2002; Townsend, 1994). Involuntary diet change is a negative post-shock response that involves reliance on less preferred food items, food rationing or cutting the size and number of daily consumptions. Thus, the two risk coping strategies are unproductive and provide limited support (Dercon, 2002). Table 2 shows that about 17% of the sample households (pooled sample) rely on informal insurance as a shock coping mechanism. There has been an increase in use of informal insurance as a consumption smoothing strategy over the study period. About 24% of the sample households practice involuntarily change in diets or consumption as a risk coping strategy. The proportion, however, significantly decreased from 38% in 2009 to 13% in 2012.

6. Results

6.1. Drivers of crop diversification

Table 3 provides the results for drivers of crop diversification obtained from a correlated random effects (CRE) model. The model diagnostic results show that the mean of the time-varying variables is jointly significant in the crop diversification model, which suggests the presence of unobserved heterogeneity and justifies the use of the CRE model.

Rainfall shock is found to be significant determinant of crop diversification. This finding suggests that households have an incentive to use crop diversification as an adaptation strategy against climate-related shocks (Arslan et al., 2018; Asfaw et al., 2018, 2019; Bezabih & Di Falco, 2012). The degree of crop diversification also increases with elevation. The positive and significant coefficient on elevation suggests that households located in the higher altitude zones are more likely to grow diversified crops. This could be due to different climatic conditions and agronomic possibilities (Van Dusen & Taylor, 2005). Although average temperature of the planting season has no significant effect on crop diversification, the interaction of temperature with elevation has negative effect on crop diversification. The significant effect of the interaction of temperature with elevation provides evidence that environmental heterogeneity plays a key role in determining crop diversity. We also find that village level crop diversity is a strong predictor of crop diversity which suggests that households' production choices are influenced by neighbourhood or locational peer effects. The finding is in agreement with a recent study in Malawi and Zambia that finds the level of crop diversification to be positively associated with the percentage of farmers in the village that adopt crop diversification (Asfaw et al. 2019). The instruments are also jointly significant in all of the crop diversity regressions.

Household demographic characteristics play an important role in determining the scope and degree of crop diversity. Age of the household head has a positive correlation with all crop diversity metrics except the composite entropy index. This suggests that older farmers cultivate more crops and diversify than younger farmers. This finding also raises the prospect for an intergenerational decline in crop diversity. The positive correlation between age and crop diversity could be due two reasons. First, farming experience is highly associated with age and experienced farmers are very likely to adopt crop diversification since they will have knowledge about its benefits. Second, technology mistrust increases with farmers' age (Bezu et al., 2014) and older farmers would prefer to rely on crop diversification (a lower risk activity) as a risk management strategy than other potentially risky options (Bezabih & Sarr, 2012). Crop diversity is also found to be correlated with gender of the household head, education of the head, household size and livestock holdings. However, the effects are marginal and significant only for few of the crop diversity indices.

Consistent with economic theory and empirical studies (Dercon, 1996; Rosenzweig & Wolpin, 1993), we find evidence that crop portfolio choice varies with household wealth. Crop diversification (Count and Shannon indices) is positively associated with asset wealth. The results also show that the scope and degree of crop diversification is positively correlated with the size of land cultivated regardless of the crop diversity metrics. This indicates the important role of the size of landholding as enabling factor for crop diversification. The finding is in agreement with Asfaw et al. (2019) that find positive correlation between size of cultivated land and crop diversification in Malawi, Niger and Zambia. Benin et al. (2004) also show that Ethiopian households with larger farms grow more diverse cereal crops. We find the degree of crop diversification to increase with distance to the nearest market. The significant relationship holds for all crop diversity indices except the Berger-Parker index. The finding is consistent with the assertion that greater diversification could be a strategy to insure consumption from own production for households with limited market access (Ecker & Qaim, 2011; Lovo & Veronesi, 2019). Arslan et al. (2018) also show that crop diversification increases with increase in the distance to markets in Zambia.

6.2. Welfare effects of crop diversification

6.2.1. Crop diversification and aggregate household diets

Table 4 presents the main results from the fixed-effects instrumental variables (FE-IV) regressions. The full set of results including the diagnostics tests related to the instruments for crop diversification are given in Table 10 (Appendix). The Kleibergen-Paap F statistic (test for weak identification) is significant and above 10 in all specifications which justifies the strength and relevance of the selected instruments. The results show that, with a 95% confidence, our IV estimates have less than 5% of OLS bias (Dercon et al., 2009). The Hansen J (Sargan-Hansen) Statistic, a test of overidentification, is not statistically significant. This shows that we do not have enough evidence to reject the null hypothesis that our instruments can be excluded from the second stage regressions. The results from the tests confirm the strength and validity of the instruments.

The results from the FE-IV regressions show that crop diversification has a positive impact on household dietary diversity (Table 4). On average, adding 1 more crop to the portfolio (Count

[7] The 12 food groups include: (i) cereals, (ii) roots & tubers, (iii) vegetables, (iv) fruits, (v) meat and poultry, (vi) eggs, (vii) fish and seafood, (viii) pulses, (ix) milk and milk products, (x) oil/fats, (xi) sugar/honey, and (xii) miscellaneous food items.

Table 3
Drivers of crop diversity: Estimates from Panel Correlated Random Effects.

	Count Index	Shannon-Weaver	Composite Entropy	Berger-Parker
Age of head	0.025***	0.005**	0.001	0.009*
	(0.009)	(0.002)	(0.001)	(0.005)
Male headed	−0.381*	−0.021	0.004	0.001
	(0.207)	(0.044)	(0.018)	(0.122)
Household size	0.058	0.012*	0.004	0.027
	(0.041)	(0.007)	(0.002)	(0.018)
Head education	0.124	0.037*	0.013	0.055
	(0.106)	(0.021)	(0.008)	(0.059)
Asset value (log)	0.057**	0.010**	0.003	0.006
	(0.023)	(0.005)	(0.002)	(0.012)
Land size	0.262***	0.040***	0.008**	0.067***
	(0.042)	(0.009)	(0.003)	(0.024)
Livestock holding	−0.001	0.005	0.002*	0.010
	(0.015)	(0.003)	(0.001)	(0.008)
Remittances	−0.066	−0.004	0.001	−0.009
	(0.082)	(0.017)	(0.007)	(0.046)
Distance to road	0.010	0.001	−0.000	0.008
	(0.058)	(0.009)	(0.003)	(0.025)
Distance to market	0.037**	0.013***	0.005**	0.014
	(0.016)	(0.004)	(0.002)	(0.010)
Rainfall shock	0.245***	0.047**	0.014*	0.086*
	(0.083)	(0.020)	(0.008)	(0.050)
Temperature	1.892	0.383	0.123	1.197
	(1.426)	(0.280)	(0.099)	(0.741)
Elevation	20.764	5.681*	2.063*	14.683*
	(16.168)	(3.078)	(1.086)	(8.370)
Temperature X Elevation	−0.739	−0.218*	−0.081*	−0.561
	(0.739)	(0.132)	(0.048)	(0.374)
Village crop diversity	0.335***	0.299***	0.231***	0.255***
	(0.043)	(0.042)	(0.046)	(0.049)
Mundlak variables	78.01***	91.57***	62.73***	48.06***
Joint significance of instruments	76.51***	63.38***	39.20***	34.53***
Region	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Region X Year	Yes	Yes	Yes	Yes
Constant	4.108	0.630	0.229	0.950
	(3.027)	(0.657)	(0.242)	(1.516)
Observations	4523	4523	4523	4521

Note: The Mundlak variables report the joint significance of the average of time-varying variables. Clustered standard errors in parentheses;* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 4
Effects of crop diversity on aggregate household dietary diversity.

	Count index	Shannon-Weaver	Composite Entropy	Berger-Parker
(1) FE-IV	0.158**	1.317***	4.682***	0.648***
	(0.049)	(0.262)	(0.935)	(0.127)
(2) 2SRI	0.104*	0.976***	2.538***	0.352***
	(0.060)	(0.305)	(0.978)	(0.118)
(3) FE-Poisson	1.008***	1.051***	1.135***	1.012**
	(0.003)	(0.013)	(0.004)	(0.005)
(4) Pooled OLS	0.153***	0.619***	1.195***	0.162***
	(0.017)	(0.083)	(0.230)	(0.031)

Note: Dependent variable is household dietary diversity score. (1) Reports, for the purpose of comparison, the results found in Table 10 (Appendix). (2) reports results of an alternative specification of the dietary diversity equation using a 2SRI method with bootstrap cluster standard errors; (3) reports incidence-rate ratios (IRR) from Fixed Effects-Poisson regressions and (4) reports estimates from the pooled OLS regressions. Clustered standard errors in all regressions; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

index) is associated with an increase in the dietary diversity score by 0.16. The result is fairly comparable with that of Koppmair, Kassie, and Qaim (2017). The small magnitude of the effect indicates that increasing crop diversity may not be sufficient to ensure improved diet diversity (Dillon et al., 2015). A 1 unit increase in the evenness of the area allocated across crops in the portfolio (Shannon-Weaver index) increases diet diversity by 1.32 on average. Even a 1 unit increase in the equitable allocation of land among crops (Composite entropy index) leads to an increase in household diet diversity by more than 4. The findings suggest that crop diversification through increased equitable allocation of land across crops generates better diet diversity benefits than crop diversification through the mere addition of crops.

Results from the FE-IV regressions are comparable with estimates obtained using the 2SRI model. The coefficients of the crop diversity indices appear to be fairly consistent across the two specifications. This is expected since two-stage least squares (2SLS) methods such as FE-IV and 2SRI methods are supposed to give equivalent results in linear models. The discrepancy in the results is perhaps because we use different approaches in the second-stage estimations. We further check robustness of our results using Fixed Effects-Poisson and pooled OLS regressions where we assume crop diversity to be exogenous. Estimates using the pooled OLS also help us to test if results are different if we assume crop diversity and household diet diversity do not significantly change over time. While both the FE-Poisson and the pooled OLS models show a positive and significant effect of crop diversification on dietary diversity, the estimates from pooled OLS are conservative compared to results from the FE-IV method.

Our findings are in compliance with findings of recent studies that demonstrate a positive association between crop diversification and diet diversity at the household level (Dillon et al., 2015; Jones et al., 2014; Makate, Wang, Makate, & Mango, 2016; Sibhatu, Krishna, & Qaim, 2015). The results underscore that crop diversity can be a useful strategy to improve nutrition and food security in areas where the triple challenges of malnutrition and micronutrient deficiencies are ubiquitous (Romeo, Meerman, Demeke, Scognamillo, & Asfaw, 2016; Sibhatu et al., 2015).

6.2.2. Crop diversification and consumption

Table 5 provides the coefficient estimates of the consumption expenditure equations obtained using the FE-IV model. The diagnostic test results (Table 12 in Appendix) confirm the validity and relevance of the instruments for crop diversity. The coefficients on crop diversity are positive and statistically significant for all crop diversity indices. This indicates that crop diversification is a welfare enhancing strategy. Increase in the number of crops grown in the household by 1 leads to about a 4.5% increase in per adult equivalent consumption expenditure. On average, a 1 unit increase in the equitable allocation of land across crops (Shannon-Weaver index) leads to an increase in the per adult equivalent consumption expenditure of 25.6%. Comparing the point coefficient estimates of the Count and Shannon-Weaver indices, we conclude that increase in equitable allocation of land among cultivated crops generates higher consumption benefits than the increase in the number of crops.

The estimates from the FE-IV are contrasted with those obtained from the two-stage residual inclusion (2SRI) method. The coefficients of the generalized residuals are significant in almost all the consumption expenditure equations whenever crop diversity exerts a significant effect. This compels us to reject the exogeneity of crop diversity in the household welfare equations. The results from the 2SRI method also show that crop diversity has a positive and significant effect on per adult equivalent consumption expenditure. Both increase in the number of crops in the production portfolio (Count index) and increase in the equitable allocation of land across the crops cultivated (Shannon-Weaver index) have a positive and significant effect on per adult equivalent consumption expenditure. The results from the FE-IV model are also contrasted with results obtained from CRE and pooled OLS where we treat crop diversification as exogenous. The results are positive and significant only for the Count index.

6.2.3. Heterogeneous effects of crop diversity on consumption

We assess the effect of crop diversity on four different quantiles of household consumption using quantile-IV regression to test if crop diversification has heterogeneous effects on consumption among low consuming (poor) and high consuming (richer) households. Table 6 summarizes the coefficient estimates from the quantile regression (full results in Tables 14–17, Appendix) for the four

Table 5
Effects of crop diversity on consumption expenditure.

	Count index	Shannon-Weaver	Composite Entropy	Berger-Parker
(1) FE-IV	0.045**	0.256**	0.763*	0.132**
	(0.020)	(0.108)	(0.403)	(0.055)
(2) 2SRI	0.039**	0.215***	0.426	0.055
	(0.015)	(0.081)	(0.267)	(0.035)
(3) CRE	0.010*	0.025	0.037	0.008
	(0.005)	(0.024)	(0.066)	(0.009)
(4) Pooled OLS	0.020***	0.023	-0.069	-0.004
	(0.005)	(0.023)	(0.064)	(0.008)

Note: Dependent variable is the log of per adult equivalent consumption expenditure. (1) reports, for the purpose of comparison, the results found in Table 10 (Appendix). (2) reports results of an alternative specification of the consumption expenditure equation using a 2SRI method; (3) reports results from CRE regression, and (4) reports estimates from pooled OLS regression. Clustered standard errors in all regressions; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 6
Welfare effects of crop diversity: quantile regression estimates.

	Endogenous crop diversity				*Exogenous crop diversity*			
	20%	40%	60%	80%	20%	40%	60%	80%
Count index	0.112***	0.094***	0.082***	0.080***	0.017*	0.022***	0.015*	0.015*
	(0.026)	(0.022)	(0.021)	(0.020)	(0.009)	(0.008)	(0.008)	(0.009)
Shannon-Weaver	0.423***	0.382***	0.247**	0.231**	0.094**	0.077**	0.062*	0.049
	(0.085)	(0.109)	(0.111)	(0.111)	(0.041)	(0.037)	(0.037)	(0.042)
Composite entropy	0.396	0.198	−0.231	−0.026	0.210**	0.150	0.134	0.007
	(0.388)	(0.426)	(0.296)	(0.333)	(0.106)	(0.099)	(0.099)	(0.116)
Berger-Parker	0.051	0.040	0.042	0.041	0.031**	0.017	0.021	0.018
	(0.064)	(0.049)	(0.049)	(0.056)	(0.015)	(0.014)	(0.014)	(0.016)

Note: Dependent variable is real consumption expenditure per adult equivalent. Bootstrapped standard errors with 500 replications in parentheses. All regressions include control variables, time averages of time varying variables and year dummy; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 7
Impact of crop diversity on risk coping.

	Count index	Shannon-Weaver	Composite Entropy	Berger-Parker
A: Informal insurance				
(1) 2SRI	-0.018**	-0.074**	-0.091	-0.036*
	(0.009)	(0.036)	(0.145)	(0.022)
(2) FE-IV	−0.008	-0.151*	-0.719**	-0.093**
	(0.016)	(0.082)	(0.300)	(0.042)
(3) CRE probit	−0.007**	−0.057***	-0.146***	-0.023***
	(0.004)	(0.017)	(0.042)	(0.006)
(4) Fixed effects logit	−0.085*	−0.664***	-1.788***	−0.287***
	(0.047)	(0.230)	(0.639)	(0.088)
B: Change in diets				
(1) 2SRI	-0.024**	−0.049	0.182	-0.001
	(0.011)	(0.051)	(0.158)	(0.024)
(2) FE-IV	−0.032*	-0.198*	−0.676*	−0.083
	(0.019)	(0.101)	(0.371)	(0.052)
(3) CRE probit	−0.007*	-0.008	0.005	0.006
	(0.004)	(0.018)	(0.049)	(0.007)
(4) Fixed effects logit	−0.016	0.083	0.337	0.074
	(0.041)	(0.199)	(0.537)	(0.073)

Note: (1) reports average partial effects (APEs) from the 2SRI or control function method; (2) reports fixed effects-IV regression results; (3) reports APEs from CRE probit (pooled maximum likelihood estimations), and (4) reports fixed effects logit coefficients; All regressions include control variables; (1) and (3) include time averages of all explanatory variables, year and region dummies. Standard errors in parentheses are clustered at the household level; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

crop diversity indices. In the 2SRI model that addresses endogeneity, only the Count and Shannon-Weaver indices have significant effects. The effects are unambiguously higher for low consuming households and decreases as we move toward the top of the consumption distribution. The coefficient estimates for the Shannon-Weaver index shows that the size of the impact on the poorest group or those at the lowest quantile band (0.423) is about double the impact on the richest group (0.231). This suggests that low consuming households that increase their level of crop diversity will reap greater returns to their production portfolio in terms of increased consumption. This could be because low consuming (relatively poor) households are very likely to be risk-averse due to low initial wealth conditions and could adopt crop diversification as a livelihood strategy. In contrast, high consuming households are wealthier and thus could have alternative risk management options. Our findings agree with recent studies that reach at similar conclusion (Asfaw et al., 2018, 2019).

To test the robustness of the results, we estimate the model using a pooled quantile regression with the Mundlak device to deal with unobserved heterogeneity but crop diversity is considered to be exogenous. Even when we do not allow for endogeneity of crop diversity, we conclude that crop diversity generates higher consumption effects for low consuming (poor) households. While the Count and Shannon-Weaver indices appear to be significant in most of the consumption quantile equations, the Composite entropy and Berge-Parker indices are positive and statistically significant only for the lowest consumption expenditure quantile. The results from the quantile regressions also confirm that increase in equitable allocation of land among crops produces higher consumption benefits for low-consuming households.

6.3. Crop diversification and risk coping

We assess the effect of crop diversification on two commonly employed risk coping strategies by rural Ugandan households: informal insurance and involuntary diet change (Table 7). First, we estimate the impacts using the 2SRI method. The results show that crop diversification has a negative effect on risk coping through informal insurance arrangements in the form of reliance on relatives or friends. The coefficients of crop diversity are statistically significant for all indices except the Composite entropy index. The estimated effect is statistically significant for involuntary change in diets only for the Count index.

We also estimate the impacts of crop diversification on risk coping using the FE-IV LPM model. The various tests for the instruments for crop diversification justify the validity of the selected instruments (Tables 18 and 19, Appendix). Results from the FE-IV regression show that crop diversification (with the exception of the Count index) has a negative and significant effect on informal insurance (Table 7, panel A, row (1)). The findings from the 2SRI and FE-IV, although the magnitudes are somehow different, indicate that *ex-ante* crop diversification reduces the need for informal insurance as a risk coping strategy. Results from the FE-IV regressions also show that crop diversification reduces the likelihood of involuntary change of diets or consumption reductions as a risk coping or consumption smoothing strategy. With the exception of the Berger-Parker index, all crop diversity measures are negatively associated with risk coping through involuntary diet change (at 10% significance level).

Table 7 also provides estimates of the risk coping (consumption smoothing) equations obtained using various estimation methods for robustness checks. In row (3), we report estimates obtained using the pooled correlated random effects probit model, an alternative specification where crop diversity is treated as exogenous. The marginal effects of crop diversity are statistically significant for informal insurance. In row (4), we report results from fixed effects (conditional) logit regressions. The results show that risk coping through informal insurance is negatively associated with crop diversity. However, the correlations are insignificant for involuntary change in diets. The results from the CRE probit (pooled maximum likelihood estimation) and fixed effects logit models are comparable with the estimates from our preferred model for informal insurance. Overall, results from the FE-IV, 2SRI and the alternative specifications show that crop diversity reduces households' reliance on the solidarity of their social networks *ex-post* shocks as a risk coping or consumption smoothing strategy.

7. Conclusion

Rural households face a plethora of shocks that have substantial repercussions on their well-being and adaptive capacity. In an environment characterized by absent or poorly functioning insurance and credit markets, agricultural households adopt crop diversity as a self-insurance mechanism for improving welfare and risk management. This study contributes to the growing literature and the policy discourse by empirically investigating the effect of crop diversification on household welfare and risk coping using panel survey data from Uganda combined with historical rainfall data. We explore how increasing crop diversity through expanding crop portfolio and increasing the equitable allocation of land across cultivated crops balances the goals of welfare maximizing and hedging climate-induced risks. We utilize panel data estimators and instrumental variables methods to estimate causal relations between crop diversification and household welfare and risk coping after addressing for potential endogeneity. A series of crop diversity indices are used to capture the different facets of crop diversity and to test the robustness of results across various crop diversity metrics.

The results of the study show that climatic factors, village level crop diversity, farm size and market access are important predictors of households' crop diversification decisions. The findings suggests that policies to promote crop diversification might need to focus in areas with limited access to markets and with high agroecological heterogeneity. Most important, the results of the study show that crop diversification improves household welfare as indicated by the positive and significant effects on diet diversity and consumption expenditure. Furthermore, the impact of crop diversification on consumption is more pronounced among households positioned at lowest quantile of the consumption distribution than relatively richer and high-consuming households. This highlights that crop diversification could be a pro-poor strategy and diversification interventions could be more effective if tailored toward poor segments of the rural population. Although both the cultivation of more crops and the equitable distribution of land across crops improve household welfare, crop diversification through an increase in the equitable allocation of land across crops generates higher welfare benefits. We also find evidence that crop diversification reduces households' reliance on informal insurance as a risk-coping or consumption smoothing mechanism.

The findings suggest that crop diversification is a strategy to enhance household welfare and improve risk management behavior in the context of climatic shocks and incomplete markets. The study contributes evidence to the burgeoning literature and the findings provide inputs for recent development policy agenda aims at poverty reduction and accelerating Africa's growth. Importantly, the results of this study are in favor of the current policy focus that promotes crop diversification. If crop diversification is to contribute to economic diversification and agricultural transformation in rural Africa, alleviating the structural and technical impediments needs to be a policy priority. Although we may safely conclude that increasing crop diversity through expanding crop portfolio and equitable allocation of land across crops would boost household welfare and consumption smoothing, it may also affect the use of agricultural inputs (e.g., chemical fertilizer and improved seeds) if land is reallocated away from crops that use these inputs intensively. Exploring this effect by linking input use and the productivity effects of crop diversity could be of interest in the literature. Further research is also needed to explore how the scope and benefits of crop diversity in SSA would be affected by a small farm holding or land size, resource endowment constraints, and the availability of infrastructure.

Acknowledgement

We would like to confirm that the authors do not receive any financial support for this research. The paper is written when the first author was at UNU-MERIT as a PhD fellow.

Appendix A

See Tables 8–19.

Table 8
Calculation of crop diversification indices.

Index	Interpretation	Formula	Range
Count	Richness	D = J	D $\geqslant 0$
Shannon-Weaver	Evenness; proportional abundance	$D = -\sum_i^{\alpha} \alpha_i ln(\alpha_i)$	D $\geqslant 0$
Composite Entropy Index	Evenness; proportional abundance	$D = -\sum_i^{\alpha} \alpha_i ln_J(\alpha_i)(1 - 1/J)$	$0 \leqslant D \leqslant 1$
Berger-Parker	Relative abundance	$D = 1/max(\alpha_i)$	D $\geqslant 1$

Note: α_i is the share of land allocated to the i^{th} crop; J is the number of crops cultivated by the household. Source: Own elaboration based on Asfaw et al. (2018).

Table 9
Summary statistics for variables used in the analysis.

	2009/10	2010/11	2011/12	Pooled
Age of head (years)	47.28	48.22	48.54	48.03
	(14.92)	(15.03)	(15.24)	(15.08)
Male headed	0.744	0.729	0.713	0.728
	(0.437)	(0.445)	(0.452)	(0.445)
Household size	4.667	4.391	4.312	4.452
	(2.066)	(1.902)	(1.979)	(1.990)
Head education	0.193	0.328	0.304	0.275
	(0.395)	(0.470)	(0.460)	(0.446)
Asset value (X1000)	13362.5	14552.3	14490.0	14140.2
	(39676.3)	(44866.6)	(39295.0)	(41172.8)
Land cultivated (acres)	4.746	5.257	3.545	4.455
	(22.84)	(27.65)	(6.530)	(20.44)
Livestock holding (TLU)	2.262	1.908	1.868	2.009
	(3.994)	(3.436)	(3.710)	(3.730)
Remittances (1 = Yes)	0.283	0.277	0.279	0.280
	(0.450)	(0.448)	(0.449)	(0.449)
Distance to road (km)	8.798	8.853	8.745	8.795
	(7.175)	(7.246)	(7.189)	(7.200)
Distance to market (km)	33.64	33.36	33.58	33.53
	(17.94)	(17.62)	(18.60)	(18.09)
Production shock(1 = Yes)	0.596	0.390	0.315	0.429
	(0.491)	(0.488)	(0.465)	(0.495)
Health shock (1 = Yes)	0.165	0.133	0.067	0.119
	(0.371)	(0.340)	(0.250)	(0.324)
High cost of inputs (1 = Yes)	0.026	0.013	0.014	0.017
	(0.158)	(0.111)	(0.116)	(0.130)
Rainfall shock	1.271	0.106	0.0003	0.448
	(0.877)	(0.240)	(0.004)	(0.775)
Temperature (°C)	21.66	21.69	21.64	21.66
	(1.588)	(1.577)	(1.649)	(1.607)
Elevation (km)	1.234	1.232	1.236	1.234
	(0.247)	(0.247)	(0.260)	(0.252)
Observations	1479	1367	1677	4523

Note: Mean values reported, standard deviations in parentheses.

Table 10
Effect of crop diversity on dietary diversity: FE-IV estimates.

	Count index	Shannon-Weaver	Composite Entropy	Berger-Parker
Crop diversity	0.158**	1.317***	4.682***	0.648***
	(0.075)	(0.418)	(1.624)	(0.210)
Age of head	−0.019*	−0.021**	−0.021**	−0.021**
	(0.011)	(0.010)	(0.010)	(0.011)
Male headed	−0.070	−0.105	−0.147	−0.142
	(0.246)	(0.246)	(0.250)	(0.262)
Household size	0.100***	0.096**	0.094**	0.096**
	(0.038)	(0.038)	(0.038)	(0.039)
Head education	0.303**	0.268**	0.256**	0.280**
	(0.122)	(0.122)	(0.124)	(0.124)
Asset value (log)	0.048**	0.044**	0.044*	0.057**
	(0.021)	(0.022)	(0.023)	(0.023)
Land size (log)	0.063	0.043	0.056	0.051
	(0.049)	(0.049)	(0.049)	(0.050)
Livestock holding	0.017	0.011	0.007	0.011
	(0.018)	(0.018)	(0.018)	(0.018)
Remittances	0.066	0.063	0.053	0.068
	(0.089)	(0.091)	(0.093)	(0.092)
Distance to road	−0.042	−0.043	−0.041	−0.056
	(0.046)	(0.049)	(0.054)	(0.052)
Distance to market	−0.014	−0.023	−0.030	−0.011
	(0.027)	(0.029)	(0.032)	(0.030)
Constant	6.929***	6.540***	5.531***	6.141***
	(0.996)	(1.026)	(1.218)	(1.139)
Year	Yes	Yes	Yes	Yes
F test of excluded instruments	33.29***	24.06***	10.89 ***	11.31***
Kleibergen-Paap Wald F statistic	33.29**	24.06**	10.89**	11.31**
Sargan-Hansen (Hansen J) statistic	7.306	7.028	4.791	7.258
Observations	4523	4523	4523	4521

Note: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; clustered standard errors in parentheses. In all models crop diversity is treated as endogenous and instrumented with the rainfall shock, elevation-temperature interaction and village level crop diversity. Kleibergen-Paap Wald F statistic is for weak identification test. Sargan-Hansen (Hansen J) is for overidentification test of all instruments.

Table 11
Effects of crop diversity on dietary diversity: 2SRI estimates.

	Count Index	Shannon-Weaver	Composite Entropy	Berger-Parker
Crop diversity	0.104*	0.976***	2.538***	0.352***
	(0.060)	(0.305)	(0.978)	(0.118)
Generalized residual	−0.051	-0.674**	−1.781*	-0.285**
	(0.064)	(0.319)	(0.998)	(0.121)
Age of head	−0.015*	−0.016*	−0.015	−0.015
	(0.009)	(0.009)	(0.009)	(0.009)
Male headed	−0.147	−0.163	−0.216	−0.201
	(0.219)	(0.217)	(0.217)	(0.219)
Household size	0.100***	0.096***	0.098***	0.096***
	(0.036)	(0.035)	(0.035)	(0.035)
Head education	0.328***	0.304***	0.310***	0.324***
	(0.115)	(0.115)	(0.116)	(0.114)
Asset value (log)	0.064***	0.064***	0.068***	0.073***
	(0.022)	(0.022)	(0.023)	(0.023)
Land size (log)	0.095**	0.079*	0.098**	0.096**
	(0.047)	(0.047)	(0.046)	(0.046)
Livestock holding	0.017	0.013	0.010	0.013
	(0.018)	(0.018)	(0.019)	(0.019)
Remittances	0.034	0.033	0.029	0.030
	(0.086)	(0.086)	(0.087)	(0.087)
Distance to road	−0.061	−0.060	−0.056	−0.061
	(0.047)	(0.048)	(0.049)	(0.049)
Distance to market	−0.006	−0.016	−0.017	−0.011
	(0.020)	(0.020)	(0.020)	(0.020)
Constant	2.846***	2.746***	2.572***	2.905***
	(0.581)	(0.603)	(0.723)	(0.656)
Mundlak variables	Yes	Yes	Yes	Yes
Region	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Constant	2.846***	2.746***	2.572***	2.905***
	(0.561)	(0.584)	(0.695)	(0.640)
χ^2	867.99***	780.51***	737.64***	733.80***
Observations	4520	4520	4520	4518

Note: Bootstrapped (500 replications) and clustered standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; All regressions include time averages of time varying variables.

Table 12
Effects of crop diversity on consumption expenditure: FE-IV estimates.

	Count index	Shannon-Weaver	Composite Entropy	Berger-Parker
Crop diversity	0.045**	0.256**	0.763*	0.132**
	(0.020)	(0.108)	(0.403)	(0.055)
Age of head	0.007**	0.007**	0.007**	0.007*
	(0.003)	(0.003)	(0.003)	(0.003)
Male headed	−0.022	−0.033	−0.040	−0.041
	(0.072)	(0.071)	(0.071)	(0.072)
Household size	−0.141***	−0.142***	−0.142***	−0.141***
	(0.010)	(0.010)	(0.010)	(0.011)
Head education	0.009	0.004	0.004	0.006
	(0.029)	(0.029)	(0.029)	(0.029)
Asset value (log)	0.033***	0.033***	0.033***	0.035***
	(0.007)	(0.007)	(0.007)	(0.007)
Land size (log)	0.038***	0.038***	0.042***	0.039***
	(0.013)	(0.014)	(0.013)	(0.014)
Livestock holding	0.003	0.002	0.001	0.002
	(0.005)	(0.005)	(0.005)	(0.005)
Remittances	0.007	0.006	0.005	0.008
	(0.025)	(0.025)	(0.025)	(0.026)
Distance to road	−0.010	−0.010	−0.010	−0.013
	(0.009)	(0.009)	(0.010)	(0.010)
Distance to market	0.003	0.002	0.002	0.005
	(0.006)	(0.006)	(0.006)	(0.006)
Constant	10.183***	10.143***	10.004***	10.056***
	(0.270)	(0.270)	(0.302)	(0.285)
Year	Yes	Yes	Yes	Yes
F test of excluded instruments	33.29***	24.06***	10.89 ***	11.31***
Kleibergen-Paap Wald F statistic	33.29**	24.06**	10.89*	11.31*
Sargan-Hansen statistic	3.22	3.22	3.49	3.33
Observations	4523	4523	4523	4521

Note: Clustered standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 13
Consumption expenditure effects of crop diversity: 2SRI estimates.

	Count index	Shannon-Weaver	Composite Entropy	Berger-Parker
Crop diversity	0.039**	0.215***	0.426	0.055
	(0.015)	(0.081)	(0.267)	(0.035)
Generalized residual	−0.027*	−0.183**	−0.379	−0.046
	(0.015)	(0.083)	(0.276)	(0.035)
Age of head	0.006**	0.007**	0.007**	0.007**
	(0.003)	(0.003)	(0.003)	(0.003)
Male headed	−0.022	−0.036	−0.047	−0.044
	(0.066)	(0.065)	(0.065)	(0.065)
Household size	−0.145***	−0.145***	−0.145***	−0.145***
	(0.010)	(0.010)	(0.010)	(0.010)
Head education	0.018	0.014	0.017	0.020
	(0.029)	(0.029)	(0.029)	(0.029)
Asset value (log)	0.050***	0.051***	0.052***	0.052***
	(0.009)	(0.009)	(0.009)	(0.009)
Land size (log)	0.037***	0.038***	0.043***	0.043***
	(0.013)	(0.013)	(0.012)	(0.012)
Livestock holding	0.002	0.001	0.001	0.001
	(0.005)	(0.005)	(0.005)	(0.005)
Remittances	0.002	0.002	0.001	0.001
	(0.024)	(0.024)	(0.024)	(0.024)
Distance to road	−0.008	−0.007	−0.007	−0.008
	(0.014)	(0.014)	(0.014)	(0.014)
Distance to market	−0.001	−0.003	−0.002	−0.000
	(0.005)	(0.005)	(0.006)	(0.005)
Mundlak variables	Yes	Yes	Yes	Yes
Region	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Constant	9.091***	9.158***	9.282***	9.246***
	(0.190)	(0.194)	(0.217)	(0.202)
χ^2	1673.53***	1643.92***	1667.61***	1666.18***
Observations	4520	4520	4520	4518

Note: Bootstrapped standard errors (500 replications) in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; All regressions include time averages of time varying variables.

Table 14
Welfare effects of crop diversity (Count index): Quantile regression estimates.

	Q = 20%	Q = 40%	Q = 60%	Q = 80%
Count index	0.112***	0.094***	0.082***	0.080***
	(0.026)	(0.022)	(0.021)	(0.020)
Generalized residual	−0.104***	−0.086***	−0.075***	−0.074***
	(0.026)	(0.024)	(0.023)	(0.022)
Age of head	0.002	0.004	0.003	0.007*
	(0.005)	(0.005)	(0.004)	(0.004)
Male headed	−0.058	0.075	−0.007	0.046
	(0.130)	(0.108)	(0.097)	(0.112)
Household size	−0.143***	−0.145***	−0.144***	−0.157***
	(0.018)	(0.014)	(0.015)	(0.017)
Head education	−0.009	0.049	0.008	0.002
	(0.057)	(0.054)	(0.050)	(0.052)
Asset value (log)	0.089***	0.090***	0.080***	0.073***
	(0.017)	(0.014)	(0.014)	(0.018)
Land size (log)	0.014	0.023	0.034*	0.014
	(0.018)	(0.017)	(0.018)	(0.021)
Livestock holding	0.011	0.005	0.007	0.007
	(0.010)	(0.008)	(0.008)	(0.008)
Remittances	0.040	0.024	−0.003	−0.040
	(0.043)	(0.033)	(0.031)	(0.038)
Distance to road	−0.014	−0.020	−0.008	−0.002
	(0.018)	(0.012)	(0.010)	(0.018)
Distance to market	−0.015	0.001	−0.001	0.007
	(0.012)	(0.006)	(0.004)	(0.010)
Mundlak variables	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Constant	7.399***	7.866***	8.403***	8.994***
	(0.256)	(0.182)	(0.178)	(0.225)
Observations	4520	4520	4520	4520

Note: Dependent variable is real consumption expenditure per adult equivalent. The variable is log transformed and valued in Ugandan Shillings. Bootstrapped standard errors in parentheses with 500 replications; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; All regressions include time averages of time varying variables.

Table 15
Welfare effects of crop diversity (Shannon-Weaver): Quantile regression estimates.

	Q = 20%	Q = 40%	Q = 60%	Q = 80%
Shannon-Weaver	0.423***	0.382***	0.247**	0.231**
	(0.140)	(0.123)	(0.107)	(0.113)
Generalized residual	−0.377**	−0.355**	−0.221*	−0.238**
	(0.151)	(0.139)	(0.115)	(0.122)
Age of head	0.003	0.002	0.006	0.011**
	(0.005)	(0.004)	(0.004)	(0.004)
Male headed	−0.070	0.018	−0.087	0.021
	(0.121)	(0.107)	(0.093)	(0.111)
Household size	−0.129***	−0.146***	−0.151***	−0.167***
	(0.017)	(0.014)	(0.014)	(0.018)
Head education	−0.009	0.022	0.025	0.003
	(0.064)	(0.053)	(0.048)	(0.050)
Asset value (log)	0.088***	0.093***	0.089***	0.075***
	(0.018)	(0.013)	(0.015)	(0.018)
Land size (log)	0.023	0.039**	0.056***	0.036*
	(0.019)	(0.017)	(0.020)	(0.020)
Livestock holding	0.007	−0.001	0.006	0.006
	(0.010)	(0.008)	(0.006)	(0.009)
Remittances	0.048	0.033	−0.004	−0.055
	(0.044)	(0.036)	(0.032)	(0.042)
Distance to road	−0.010	−0.010	−0.013	−0.001
	(0.016)	(0.014)	(0.012)	(0.022)
Distance to market	−0.015	−0.008	0.001	0.009
	(0.010)	(0.005)	(0.005)	(0.012)
Mundlak variables	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Constant	7.035***	7.814***	8.326***	9.045***
	(0.234)	(0.202)	(0.209)	(0.244)
Observations	4520	4520	4520	4520

Note: Dependent variable is real consumption expenditure per adult equivalent. The variable is log transformed and valued in Ugandan Shillings. Bootstrapped standard errors in parentheses with 500 replications; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; All regressions include time averages of time varying variables.

Table 16
Welfare effects of crop diversity (Composite entropy): Quantile regression estimates.

	Q = 20%	Q = 40%	Q = 60%	Q = 80%
Composite entropy	0.396	0.198	−0.231	−0.026
	(0.388)	(0.426)	(0.296)	(0.333)
Generalized residual	−0.252	−0.139	0.236	−0.069
	(0.414)	(0.451)	(0.315)	(0.364)
Age of head	0.005	0.004	0.008**	0.011***
	(0.005)	(0.004)	(0.003)	(0.004)
Male headed	−0.070	−0.038	−0.094	−0.061
	(0.136)	(0.101)	(0.101)	(0.101)
Household size	−0.133***	−0.147***	−0.149***	−0.162***
	(0.018)	(0.014)	(0.015)	(0.018)
Head education	−0.008	0.012	0.047	0.021
	(0.058)	(0.053)	(0.048)	(0.053)
Asset value (log)	0.102***	0.094***	0.090***	0.077***
	(0.019)	(0.013)	(0.015)	(0.018)
Land size (log)	0.025	0.056***	0.069***	0.044*
	(0.019)	(0.018)	(0.018)	(0.023)
Livestock holding	0.006	−0.002	0.008	0.009
	(0.009)	(0.008)	(0.006)	(0.008)
Remittances	0.051	0.023	−0.017	−0.065
	(0.042)	(0.036)	(0.031)	(0.045)
Distance to road	−0.012	−0.010	−0.015	−0.004
	(0.017)	(0.013)	(0.012)	(0.022)
Distance to market	−0.011	−0.000	0.008	0.016
	(0.008)	(0.007)	(0.006)	(0.013)
Mundlak variables	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Constant	7.344***	8.276***	8.899***	9.429***
	(0.283)	(0.271)	(0.224)	(0.280)
Observations	4520	4520	4520	4520

Note: Dependent variable is real consumption expenditure per adult equivalent. The variable is log transformed and valued in Ugandan Shillings. Bootstrapped standard errors in parentheses with 500 replications; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; All regressions include time averages of time varying variables.

Table 17
Welfare effects of crop diversity (Berger-Parker): Quantile regression estimates.

	Q = 20%	Q = 40%	Q = 60%	Q = 80%
Berger-Parker	0.051	0.040	0.042	0.041
	(0.064)	(0.049)	(0.049)	(0.056)
Generalized residual	−0.030	−0.037	−0.038	−0.040
	(0.068)	(0.053)	(0.050)	(0.058)
Age of head	0.006	0.005	0.007**	0.011***
	(0.006)	(0.003)	(0.003)	(0.004)
Male headed	−0.072	−0.027	−0.069	−0.042
	(0.134)	(0.101)	(0.097)	(0.108)
Household size	−0.128***	−0.148***	−0.152***	−0.162***
	(0.019)	(0.014)	(0.014)	(0.019)
Head education	0.004	0.024	0.044	0.022
	(0.057)	(0.053)	(0.048)	(0.050)
Asset value (log)	0.102***	0.094***	0.091***	0.079***
	(0.019)	(0.012)	(0.015)	(0.018)
Land size (log)	0.028	0.049***	0.059***	0.046**
	(0.018)	(0.018)	(0.017)	(0.021)
Livestock holding	0.005	−0.000	0.006	0.007
	(0.009)	(0.007)	(0.006)	(0.008)
Remittances	0.048	0.032	−0.016	−0.053
	(0.045)	(0.037)	(0.033)	(0.043)
Distance to road	−0.009	−0.007	−0.016	−0.001
	(0.015)	(0.013)	(0.011)	(0.020)
Distance to market	−0.013	−0.004	0.004	0.013
	(0.009)	(0.006)	(0.005)	(0.012)
Mundlak variables	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Constant	7.319***	8.190***	8.694***	9.376***
	(0.277)	(0.213)	(0.214)	(0.256)
Observations	4518	4518	4518	4518

Note: Dependent variable is real consumption expenditure per adult equivalent. The variable is log transformed and valued in Ugandan Shillings. Bootstrapped standard errors in parentheses with 500 replications; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; All regressions include time averages of time varying variables.

Table 18
Effects of crop diversity on informal insurance: FE-IV estimates.

	Count Index	Shannon-Weaver	Composite Entropy	Berger-Parker
Crop diversity	−0.008	-0.151*	-0.719**	-0.093**
	(0.016)	(0.082)	(0.300)	(0.042)
Age of head	−0.002	−0.001	−0.001	−0.001
	(0.003)	(0.003)	(0.003)	(0.003)
Male headed	0.001	0.003	0.009	0.009
	(0.052)	(0.051)	(0.051)	(0.051)
Household size	−0.000	0.001	0.001	0.001
	(0.008)	(0.008)	(0.008)	(0.008)
Head education	0.025	0.031	0.035	0.031
	(0.023)	(0.023)	(0.023)	(0.023)
Asset value (log)	−0.007	−0.006	−0.006	−0.008
	(0.006)	(0.006)	(0.006)	(0.005)
Land size	−0.000**	−0.000**	−0.000**	−0.000**
	(0.000)	(0.000)	(0.000)	(0.000)
Livestock holding	−0.001	0.000	0.001	0.000
	(0.004)	(0.004)	(0.004)	(0.004)
Remittances	0.059***	0.059***	0.060***	0.058***
	(0.019)	(0.019)	(0.019)	(0.019)
Distance to road	−0.013	−0.012	−0.013	−0.011
	(0.010)	(0.010)	(0.010)	(0.010)
Distance to market	0.012	0.014*	0.015**	0.012
	(0.009)	(0.008)	(0.007)	(0.008)
Production shock	0.169***	0.168***	0.167***	0.169***
	(0.015)	(0.015)	(0.015)	(0.015)
Health shock	0.428***	0.429***	0.431***	0.436***
	(0.027)	(0.027)	(0.027)	(0.027)
High cost of inputs	−0.087	−0.079	−0.073	−0.074
	(0.064)	(0.064)	(0.066)	(0.066)
Year	Yes	Yes	Yes	Yes
Constant	−0.119	−0.045	0.143	0.035
	(0.261)	(0.251)	(0.249)	(0.257)
F test of excluded instruments	32.95***	24.47***	11.21***	11.42***
Kleibergen-Paap Wald F statistic	32.95**	24.47**	11.21*	11.42*
Sargan-Hansen statistic	3.26	3.95	4.33	4.34
χ^2	478.8***	486.2***	473.6***	480.1***
Observations	4520	4520	4520	4518

Note: Standard errors in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 19
Effects of crop diversity on involuntary diet change: FE-IV estimates.

	Count Index	Shannon-Weaver	Composite Entropy	Berger-Parker
Crop diversity	−0.032*	-0.198*	−0.676*	−0.083
	(0.019)	(0.101)	(0.371)	(0.052)
Age of head	−0.000	0.000	0.000	0.000
	(0.003)	(0.004)	(0.004)	(0.004)
Male headed	−0.025	−0.017	−0.011	−0.012
	(0.062)	(0.063)	(0.064)	(0.062)
Household size	0.008	0.008	0.009	0.008
	(0.007)	(0.008)	(0.008)	(0.008)
Head education	0.007	0.011	0.012	0.008
	(0.028)	(0.028)	(0.029)	(0.028)
Asset value (log)	−0.007	−0.007	−0.007	−0.009
	(0.006)	(0.006)	(0.006)	(0.006)
Land size	−0.000*	−0.000*	−0.000*	−0.001**
	(0.000)	(0.000)	(0.000)	(0.000)
Livestock holding	−0.005	−0.004	−0.003	−0.004
	(0.004)	(0.004)	(0.004)	(0.004)
Remittances	0.004	0.005	0.006	0.004
	(0.020)	(0.020)	(0.021)	(0.020)
Distance to road	0.005	0.006	0.005	0.007
	(0.009)	(0.009)	(0.008)	(0.009)
Distance to market	−0.005	−0.004	−0.003	−0.006
	(0.006)	(0.006)	(0.006)	(0.006)
Production shock	0.463***	0.460***	0.459***	0.460***
	(0.017)	(0.017)	(0.017)	(0.017)

Table 19 (*continued*)

	Count Index	Shannon-Weaver	Composite Entropy	Berger-Parker
Health shock	0.070***	0.072***	0.074***	0.080***
	(0.026)	(0.026)	(0.027)	(0.027)
High cost of inputs	0.018	0.029	0.032	0.031
	(0.070)	(0.070)	(0.069)	(0.068)
Year	Yes	Yes	Yes	Yes
Constant	0.485**	0.527**	0.670**	0.561**
	(0.243)	(0.247)	(0.276)	(0.253)
F test of excluded instruments	32.95***	24.47***	11.21***	11.42***
Kleibergen-Paap Wald F statistic	32.95**	24.47**	11.21*	11.42*
Sargan-Hansen (Hansen J) statistic	6.80	6.47	5.78	5.64
χ^2	1176.0***	1147.4***	1118.2***	1115.4***
Observations	4520	4520	4520	4518

Note: Standard errors in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

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