Crop diversification, household nutrition and child growth: Empirical evidence from Ethiopia

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Abstract

Recently, there is a resurgence of interest in agricultural diversification as a strategy to deal with a variety of issues including improving nutrition in the context of a changing climate and missing or poorly developed markets. However, the empirical evidence base to justify this policy position is thin. This research seeks to contribute to the growing literature and the policy discourse by providing empirical evidence on the impact of crop diversity on household nutrition and child growth in Ethiopia using panel survey data from the Living Standards Measurement Study-Integrated Surveys on Agriculture (LSMS-ISA) combined with historical weather data. The study finds that crop diversification is associated with improvement in aggregate household diets and child health. Findings from the study also show that the effect of crop diversification on child health vary by market access, but not by child gender and exposure to drought shock.

Keywords: crop diversification; child growth; household diets; nutrient gap; Ethiopia

JEL Classification: I15, J13, Q16

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1 Introduction

Despite some progress to reduce the prevalence of malnutrition in Sub-Saharan Africa (SSA), recent evidence shows that high risks of nutrition insecurity and staggering levels of child malnutrition remain ubiquitous particularly in rural areas of the region (FAO et al., 2018; Gillespie and van den Bold, 2017; IFPRI, 2016). Rural households are plagued by undernutrition and chronic deficiency of micronutrients or essential vitamins and minerals ("hidden hunger") that often coexist in the same household or individuals (Gillespie and van den Bold, 2017; Koppmair et al., 2017; Sibhatu et al., 2015). Children pay the heaviest toll as malnutrition due to undernutrition or nutrient deficiency is the cause for about 45% of all deaths of children under 5 years of age (Gillespie and van den Bold, 2017; IFPRI, 2016). Childhood malnutrition has an adverse effect on the child's future potential during adulthood due to its negative impact on physical stature, educational and cognitive development and productivity (Gillespie and van den Bold, 2017; IFPRI, 2016; Lovo and Veronesi, 2019). Thus, malnutrition might take children and communities into a cycle of intergenerational poverty and entrench inequalities. Reducing the burden of malnutrition would, therefore, have crucial implications for economic development.

Due to its dual role as both the source of income and diverse foods for consumption, agriculture remains the most important sector to improve nutrition and break the generational cycle of malnutrition (Carletto et al., 2015; Ruel and Alderman, 2013). Despite this potential, for many years, nutrition policies have been aligned with the health sector with less or no equal push to align them with the agriculture sector (Hoddinott et al., 2015; Kumar et al., 2015). As a result, agriculture has been slow to respond to the persistent problem of malnutrition (Koppmair et al., 2017; Pingali, 2015). The capacity of agricultural policies to achieve better nutritional outcomes is also constrained due to a bias towards improving the productivity of few staple crops as a strategy to spur agricultural productivity and improve welfare (Khoury et al., 2014; Pingali, 2015). Although increased farm specialization has contributed to poverty reduction in developing countries, reliance on few staple crops has led to a decrease in agricultural and dietary diversity (Pellegrini and Tasciotti, 2014), low agricultural productivity (Teklewold et al., 2013) and exposes farmers to production and price shocks (Benson et al., 2008; Chibwana et al., 2012; Hooper et al., 2012; Saenz and Thompson, 2017). As the challenges of malnutrition and climate change come together as an opportunity in agriculture, there seems to be a growing consensus that the solution to tackle them lies on identifying climate-smart agricultural practices that could also improve nutrition (Global Panel, 2015).

In the current policy discourse, crop diversification is promoted and preferred over monocropping as it is deemed important to increase agricultural production, enhance nutrition security, and aid sustainable agricultural transformation (Asfaw et al., 2018; FAO, 2012; Massawe et al., 2016; Michler and Josephson, 2017). This is also echoed in recent agricultural development policies that aim to spur agricultural development and achieve health and nutrition outcomes through increasing investment on agriculture (Dillon et al., 2018). The United Nation's Sustainable Development Goals (SDGs) accentuate that increasing crop diversity is of paramount importance to simultaneously improve agricultural production and nutrition in a sustainable manner (Fiorella et al., 2016). Crop diversification is among the productive agricultural adaptation approaches available to farmers in SSA who face liquidity, asset, or other constraints (Covarrubias, 2015). As such, crop diversification is one of the several climate-smart agricultural practices that would help to improve nutrition among rural households (Donfouet et al., 2017; Global Panel, 2015; Joshi et al., 2004).

While assessment of the economics of crop diversification has a long story in the development and agricultural economics literature, its impact on diets and nutrition receives interest only in contemporary work. The literature on crop diversification and nutrition can be divided into two strands: (i) those that examine the link between production diversity and dietary diversity (Dillon et al., 2015; Hirvonen and Hoddinott, 2017; Jones et al., 2014; Sibhatu et al., 2015; Snapp and Fisher, 2015) and, (ii) studies that link production diversity with child growth outcomes (Kumar et al., 2015; Lovo and Veronesi, 2019). A recent comprehensive review of existing studies that analyzed the associations between farm production diversity, dietary diversity and/or nutrition in developing-country farm households reports that the evidence that identifies the impact of farm production diversity on diets and nutrition is mixed, hence inconclusive (Sibhatu et al., 2018). While the existing few studies are informative of the agriculture-nutrition linkage, empirical work on this topic is still sparse to assist policy making.

This study makes important contributions to the literature by illuminating the link between agriculture and nutrition in the small farm sector in a developing country context with a focus on Ethiopia. First, most studies rely on cross-sectional data which limit the opportunity to study the dynamics of production diversity and nutrition outcomes (Lovo and Veronesi, 2019; Sibhatu et al., 2018). I utilize rich panel survey data merged with historical weather data that allows me to control for the effects of a variety of household and individual characteristics, climatic and agro-ecological conditions and institutional characteristics on crop choice and nutrition. The panel nature of the data enable me capture the dynamics in crop diversification and its implications on nutrition. Second, unlike previous studies that focus on the link between production diversity and nutrition either at the household or individual level, I study the link at both levels. Third, existing studies rely on a single or few measures of crop diversity and nutrition. To address this gap, I measure the level of crop diversity using various crop diversity indices that also allows me to study the different aspects of multi-cropping regimes and to test the sensitivity of results to different crop diversity measures. The nutrition outcome indicators include household nutrient production and consumption gaps, diet quality, food intake, diet diversity and child growth.

The other contribution of the study stems from the estimation of the heterogeneous effect of crop diversity on nutrition across different groups. In relation to this, I also explore if drought shocks have negative effect on child growth and it crop diversification has a role to mitigate the effect of drought shocks. As an add on to few studies that employed instrumental variables (IV) methods beyond simple statistical methods (Sibhatu et al., 2018), I used panel data instrumental variables that enable producing credible and robust causal inference by addressing the econometric challenges of potential endogeneity and reverse causality. I exploit the exogenous variation in crop diversification decisions due to network externality or neighbourhood effects to instrument crop diversity. The rich nature of the data and the selected empirical strategy help me resolve disagreements in the literature by addressing fundamental issues regarding the exogeneity and measurement of crop diversity and its impact on nutrition.

In addition to contributions to the literature, the findings of the study will provide relevant insights to the policy discourse. The results will help policy making that aims to improve nutrition in agriculture-based economies characterized by repeated exposure to shocks and limited access to markets. The findings will also provide evidence that could be used for the design of policies and strategies to improve nutrition in areas plagued by the challenges of micronutrient deficiencies and increased prevalence of diet-related disease (Romeo et al., 2016). The results from the impact heterogeneity analysis provide policy-relevant evidence to target nutrition improving policies and interventions.

The rest of this paper is structured as follows. Section 2 presents a brief of the study country context. Section 3 presents a theoretical framework that motivates the choice of the empirical strategy discussed in section 4. Section 5 discusses the data and provides descriptive statistics for the variables of interest. Section 6 discusses the findings of the study. The last section concludes with some policy implications of the findings.

2 Country context

Ethiopia is largely an agricultural country. The agriculture sector employs about 70% of the labor force. The sector is predominantly rain-fed and vulnerable to climate variability and extremes. As a result, climate change is a challenge for food security and food consumption in the country. Like other SSA countries, climatic variability and extremes have serious implications for a significant proportion (85%) of the population that resides in rural Ethiopia.[1]

The country faces a wide range of development challenges including low agricultural productivity, poverty, and high food insecurity (Beyero et al., 2015). Malnutrition is also a long-standing pressing issue in Ethiopia despite improvements in the last two decades. This is evident from the unacceptably high rates of stunted growth among children under 5 years of age and micronutrient deficiencies (Christiaensen and Alderman, 2004; Hirvonen and Hoddinott, 2017; Porter and Goyal, 2016). The cost associated with child undernutrition only is estimated to be more than 16% of the country's annual Gross Domestic Product (GDP) (Gillespie and van den Bold, 2017). The Government of Ethiopia has made a firm commitment to combat malnutrition.

While the food and agriculture sector has fueled economic growth in the country, there is now an increasing interest to leverage agriculture to improve nutrition. This is emphasized in the National Nutrition Plan (NNP) that engages agriculture for improving nutrition and the Growth and Transformation Plan II (GTP) that emphasizes addressing malnutrition (Beyero et al., 2015). The country has also established various strategies and programs to mainstream nutrition into agriculture (Beyero et al., 2015).

With the challenges of climate change and malnutrition come together in agriculture, there is an increasing interest to adopt agricultural practices such as production of diverse crops that is both climate- and nutrition-smart. Ethiopia is home of rich plant genetic diversity which would contribute to world biodiversity resources and play a crucial role in improving human nutrition (Michler and Josephson, 2017). The country has also diverse agro-climatic conditions that enable growing variety of foods across the country (Hirvonen and Hoddinott, 2017). Therefore, Ethiopia makes a good case to test whether and how increased crop diversity affects household nutrition and child growth. This study will provide evidence about the opportunities and challenges related to scaling up the impact on nutrition through the food and agriculture sector.

3 Theoretical framework

3.1 Conceptual framework and impact pathways

In the literature, there has been a long-held debate over whether it is better to specialize or diversify. The Ricardian theory of comparative advantage asserts that specializing in cash crops could increase income and consumption (Govereh and Jayne, 2003; Masanjala, 2006). In the absence of insurance markets and reliable (cash) crop markets, high transaction costs may limit the attractiveness of crop specialization to enable households to earn more income and maximize profit (Goetz, 1993). Orr (2000) also emphasizes that the benefits of specializing in cash crops might be limited by geographic and agroecological conditions. Even though conventional wisdom associates farm specialization with higher income, farm specialization in the form of reliance on a single crop could also be an indicator of an extreme food insecure scenario.

Economic theory asserts that the main driving forces that lead to diversification are the desire to increase risk management capacity (risk aversion), to smooth income streams *ex-ante* (Barrett et al., 2001), and to smooth consumption *ex-post* shocks (Morduch, 1995). Portfolio theory

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

postulates that crop diversification is a production risk management strategy for risk-averse households (Rosenzweig, 1988). Farmers can reduce the risk of the return of crop production portfolio by including additional crops to the production portfolio (Benin et al., 2004; Just, 1975). Subsistence farmers often diversify their production to protect themselves from food price risks, downside risk or lack of food availability in local markets. Even in the presence of food markets, small farmers are very likely to remain self-sufficient in staple production as a strategy against food price risk Fafchamps (1992). Others may diversify for income purposes depending on their market-orientation. However, the desire for profit maximization and risk minimization are not the only stimuli for diversification in agricultural production (Omamo, 1998; Pope and Prescott, 1980). In rural economies burdened by market imperfections, particularly in areas where markets are poorly developed and less integrated, crop diversification decisions may also be motivated by food security and nutritional considerations (Bezabih and Di Falco, 2012; Hoddinott et al., 2015; Pellegrini and Tasciotti, 2014).

There are several channels through which crop diversification would impact nutrition and reduce the risk of micronutrient deficiencies (Ecker and Qaim, 2011; Gómez et al., 2013; Lovo and Veronesi, 2019; Sibhatu et al., 2015). First, crop diversification could contribute to nutrition through increasing total production, diet diversity and diet quality from own production (Dillon et al., 2015, 2018; Lovo and Veronesi, 2019). Such pathway works most when households are isolated from insurance, credit and output markets and exposed to climate variability and extremes (Ecker and Qaim, 2011; Lovo and Veronesi, 2019). Incomplete markets means households cannot easily insure themselves from exogenous shocks and they cannot depend on markets for fully satisfying their food demand. In these contexts, crop diversification will emerge as a natural decision to meet nutritional demands. Under the circumstances of market failures or imperfections, the production decisions of farm households are non-separable from their consumption preferences because a household simultaneously behaves both as a producing (profit maximizing) and a consuming (utility maximizing) unit (de Janvry et al., 1991; Singh et al., 1986; Taylor and Adelman, 2003). This is an indication of the means by which increased agricultural diversification can directly influence nutrition in addition to any indirect effects via income (Carletto et al., 2017; Hoddinott et al., 2015).

The other channel through which crop diversification may affect nutrition is through its income effect (Michler and Josephson, 2017; Pellegrini and Tasciotti, 2014). It could increase income that will allow households purchase food and nutrients from markets, that would ultimately improve the quality of diets and reduce household micronutrient consumption gaps. Crop diversification might affect household nutrition and child growth outcomes through its natural insurance effect (Di Falco and Perrings, 2005). It would improve the capacity of local food systems to produce diverse crops in the face of environmental shocks due to climate change (Global Panel, 2015).

3.2 Theoretical model

The theoretical model underpinning this study follows the works of Dillon et al. (2015), Hoddinott et al. (2015) and Dillon et al. (2018). As in these studies, the theoretical model extends the agricultural household model (Singh et al., 1986) to link crop production diversity with household nutrition and child growth outcomes in a single framework. Agricultural households are assumed to maximize expected utility from consumption of a vector of home-produced goods ($x^a_{t;c,h}$), market-purchased goods ($x^m_{t;c,h}$) and leisure (ℓ_t), with a primary concern about the nutritional status of children and household nutrient intake ($N_{t;c,h}$), where c and h denote children and household, respectively (Hoddinott et al., 2015).

The household utility maximization problem is specified using the following dynamic intertemporal utility function

$$\max \quad \mathrm{E}\Big[\sum_{t=0}^{\infty}\beta^t \mathrm{u}(N_{t;c,h}, x^a_{t;c,h}, x^m_{t;c,h}, \ell_t; \Phi_{c,h}, \xi_{c,h})\Big] \tag{1}$$

where $\beta = (1/1+\delta)$ with $\delta \in (0,1)$ is the rate of household time preference, $u(.)$ is an instantaneous utility function that satisfies $u'(.) > 0$, $u''(.) < 0$ and $u'''(.) \geq 0$. $\Phi_{c,h}$ and $\xi_{c,h}$ represent observed and unobserved characteristics, respectively, that would capture household preferences that parameterize the utility function (de Janvry and Sadoulet, 2006). The household maximizes utility subject to various constraints including agricultural production, time endowment, health and budget constraints (Dillon et al., 2018; Hoddinott et al., 2015; LaFave et al., 2013).

The agricultural production function (equation 2) transforms farm inputs including labor (L^f_t) and other inputs (v_t) into agricultural goods (Q_t). Production also depends on farm characteristics (Φ_f) and climate shocks (S_c). The production constraint is specified as

$$Q_t = Q_t(L^f_t, v_t; \Phi_f, S_c) \tag{2}$$

The household's time endowments or time constraint (equation 3) comprises of labor used on the farm (L^f_t), off-farm/non-farm labor (L^n_t) and leisure (ℓ_t).

$$T_t = L^f_t + L^n_t + \ell_t \tag{3}$$

The biological health or nutrition production (equation 4) is a function of consumption of nutrients from own production ($N_{c,h}(x^a_{t;c,h})$) and purchased market goods ($N_{t;c,h}(x^m_{t;c,h})$). It could be a function of knowledge of good care practices and nutrition (K^n), leisure(ℓ_t), health shocks (S_h), and other observable ($\Upsilon_{c,h}$) and unobservable household and child characteristics ($\kappa_{c,h}$) (Dillon et al., 2018; Hoddinott et al., 2015).

$$H_{t;c,h} = H_t(N_{t;c,h}x^a_t, N_{t;c,h}x^m_t, K^n, \ell_t, S_h, \Upsilon_{c,h}, \kappa_{c,h}) \tag{4}$$

Equation 5 presents the intertemporal household budget constraint. Households finance their expenditure from total income that is composed of farm profit (π_t), exogenous income ($\tilde{Y}_t$), and an endowment of family time (T_t) valued at the market wage (ω) net of all costs. They in turn spend their income on the purchase of farm inputs and market purchased food.

$$W_{t+1} = (1 + r_{t+1})[W_t + \pi_t + \omega(T - \ell_t) + \tilde{Y}_t] - [p^v v_t + p^m_t x^m_{t;c,h}] \tag{5}$$

where v_t and p^v are vectors of farm inputs such as agricultural labour, fertiliser, pesticides or herbicides, and prices for these inputs, respectively; p^m_t is a vector of prices for marketed food.

To recap, the household's problem is to choose own produced agricultural goods, purchased market goods, agricultural inputs and leisure to maximize expected utility subject to the various constraints discussed above. Under the assumption of complete input and output markets, constrained maximization of the utility function subject to the constraints leads to consumption demand of the following functional form (Hoddinott et al., 2015)

$$V_t = v_t(p^x, p^m, \omega, r_{t+1}, \tilde{Y}_t, \pi_t(p^v, p^x; \Phi_f, S_c), \lambda_u, \Phi_{c,h}, \xi_{c,h}) \tag{6}$$

where $V_t = (N_{t;c,h}, x^a_{t;c,h}, x^m_{t;c,h}, \ell_t)$.

The demand for consumption good (including nutrients) depends on prices of agricultural commodities (p^x), price of market purchased goods (p^m), wage (ω), interest rate (r_{t+1}), farm profit (π_t), exogenous income ($\tilde{Y}_t$) and future prices via marginal utility of wealth (λ_u). Consumption demand also depends on observed ($\Phi_{c,h}$) and unobserved characteristics ($\xi_{c,h}$) that would affect food preferences.

Under the strong assumptions of complete markets and exogenous wages and prices (Singh et al., 1986), the problem can be disaggregated into a recursive two period problem where households first maximise profits and then choose consumption levels (Dillon et al., 2015). In the Ethiopian context, there are many conditions under which the assumptions of complete markets can break down (Hoddinott et al., 2015). Rural Ethiopia is characterized by poor access to markets, prohibitively high transaction costs and less integrated markets due to poor infrastructure. Thus, the condition of separability is less likely to hold. Under nonseparability assumption, the first order conditions from maximizing the utility function will give a reduced form consumption good demand function of the following form

$$V_t = v_t(p^x, p^m, \omega, r_{t+1}, \tilde{Y}_t, p^v, \Phi_f, S_c, \lambda_u, \Phi_{c,h}, \xi_{c,h}) \tag{7}$$

Equation 7 suggests that, when we assume nonseparability, household's demand for food (including nutrients) is also influenced by production factors such as input prices, farm characteristics and climate shocks. The demand for food or nutrients is determined by availability of own production, income from sale of agricultural products and households' preferences for food as well as relative food prices (Dillon et al., 2018). Therefore, the consumption demand equation includes not only variables that affect household income, but also those variables that affect production decisions. In this study, the first stage production decision is represented by households' crop diversification decision. The demand for consumption good (equation 7) can be generalized to the nutrition outcomes i.e., nutrient production, dietary diversity and child growth (Dillon et al., 2015, 2018). The variables that would affect crop diversification and nutrition are selected based on the theoretical model, previous literature and data availability (see Tables 3 and 5 in Annex A for summary of the variables). As an identification strategy to disentangle the joint production and consumption decision by the household, I first model the production decision (crop diversification) as a function of household and farm characteristics and exogenous instruments. In the second stage, exogenous instruments for crop diversification are used to identify the effect on the nutrition outcome indicators (Behrman et al., 1997; Dillon et al., 2015; Hoddinott et al., 2015).

4 Empirical strategy

Following the theoretical model, the relationship between crop diversity and the nutrition outcomes (nutrient production gaps, diet diversity, diet quality, child growth) is represented using the following model

$$y_{it} = \phi D_{it} + \beta X_{it} + a_i + \theta_t + v_{it} \tag{8}$$

where i indexes the household or child in the panel and t denotes time. y_{it} is a measure of the outcomes and D_{it} represents crop diversity. X is a vector of observed household (child), farm and community characteristics. The variables used as controls in the household level analysis are household characteristics, wealth indicators, housing features, proximity to services and climate and shocks (see Table 3 for summary of the variables). For the child level analysis, in addition to those household level controls, additional controls include child characteristics and parental education (see Table 5). Moreover, region and time fixed effects are added to control for potentially omitted variables that are unobserved in the data set including interest rate, agricultural market integration and price expectations (Dillon et al., 2015). These variables also help to control for temporal and spatial differences in infrastructure and policy changes not captured by the other control variables. a_i and θ_t are the household (child) specific and time fixed effects, respectively. v_{it} is the idiosyncratic error term. ϕ is the parameter of interest that denotes the impact of crop diversification.

Estimating the impact of crop diversity on the nutrition outcomes (equation 8) faces numerous econometric issues that could result in endogeneity. The first potential source of endogeneity is the presence of unobserved heterogeneity due to unobserved household characteristics (such as preferences, skills, innate ability, entrepreneurial motives) that lead to selection bias in the choice to diversify or not and the outcomes. The second source of endogeneity comes from time-varying unobserved shocks that simultaneously influence crop diversification (the crop choice decision and how much land to allocate to the different crops) as well as the nutrition outcomes. The source of such type of unobserved endogeneity include omission of relevant time-varying factors, simultaneous responses to idiosyncratic or covariate shocks or measurement errors (Terza et al., 2008). The other source of endogeneity is a simultaneity problem in that nutrition may affect crop diversification or vice versa. Failure to tackle these econometric issues will either overestimate or underestimate the supposed true effect of crop diversification. In what follows, I discuss the empirical strategies that are used to produce valid estimates after addressing the econometrics challenges.

4.1 Estimating impact on continuous outcomes

The impact of crop diversification on continuous outcomes (production nutrient gaps and diet diversity) is estimated using fixed effects instrumental variables (FE-IV) method. In the presence of unobserved heterogeneity due to time-invariant unobservables that could potentially influence both diversification and the outcomes, application of the fixed effects (FE) could help to alleviate the scope of omitted variable bias to some extent. Use of fixed effects alone, however, helps little to control for unobserved endogeneity due to time-varying unobservable factors and potential reverse causality. Therefore, introducing the time varying instruments helps to tackle the remaining endogeneity and reverse causality between crop diversification and the outcomes. The FE-IV method that combines FE with IV helps to circumvent the effects of potential time-invariant and time-variant unobservables that could bias the results.

The FE-IV as applied in this study involves estimating the endogenous variable, i.e., crop diversification in the first stage as follows

$$D_{it} = \delta X_{it} + \gamma Z_{it} + c_i + \vartheta_t + \varepsilon_{it} \tag{9}$$

where D_{it} is a measure of crop diversification; X_{it} is a vector of household, farm and community characteristics as discussed above. Z_{it} is a vector of instrumental variables for crop diversification. I address issues of endogeneity of crop diversification using insights from social networks analysis on the importance of social networks and neighborhood effects in production decisions. I use the average village crop diversification (excluding the household under consideration) as instrument for crop diversification decision at a household level. The basic argument is that, household's production decisions (such as crop choices and land allocation) are very likely to be influenced by the decision of neighboring households due to 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 and Veronesi, 2019; Asfaw et al., 2019; Tesfaye and Tirivayi, 2020). 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. The relevance and validity of the instrument are checked using various tests. In all cases, the null hypothesis of underidentfication (Kleibergen-Paap LM test) is rejected. The Kleibergen-Paap Wald test (test for weak identification) also rejects the null hypothesis of weak instruments in the first-stage equations. Moreover, the Hansen J (Sargan-Hansen) Statistic, a test of overidentification, is not statistically significant. This suggests that there is no enough evidence to reject the null hypothesis that the selected instrument(s) can be excluded from the second stage regressions. Overall, the test results confirm the strength and validity of the instruments.

An important concern is that households might produce similar crops during the course of the panel that leads to less variation in crop diversification. Therefore, the use of FE or FE-IV might result in non significant effects of crop diversification on the outcomes. To address this issue, as an alternative approach to the FE-IV, I estimate the impact using pooled IV regressions. This is particularly important because panel data models are important only when there is sufficient within variation in both the dependent and independent variables of interest. Therefore, in this study, I present and discuss the results from various econometric models.

4.2 Empirical strategy for binary outcome variables (child growth)

To estimate the impact of crop diversification on binary outcomes (diet quality, stunting and wasting), the following latent variable model is specified

$$y^*_{it} = \phi D_{it} + \beta X_{it} + \mu_i + \theta_t + \upsilon_{it} \tag{10}$$

where $y_{it} = 1[y^*_{it} \geq 0]$ for $t = 1, ..., T$ and X_{it} are control variables that include child characteristics, parental education, and household and farm characteristics. To recap, I model crop diversification as in equation 9 as a linear function of the instruments and other covariates as follows

$$D_{it} = \delta X_{it} + \gamma Z_{it} + c_i + \vartheta_t + \varepsilon_{it} \tag{11}$$

The FE-IV method discussed above is not easy and straightforward to apply for nonlinear models. Fixed effects limited dependent variable models are also not appropriate as they are based on normality assumptions and might yield biased and inconsistent estimates (Dercon and Christiaensen, 2011). Linear probability models (LPM) are commonly used to estimate nonlinear response models instead of nonlinear models such as probit or logit (Michler and Josephson, 2017). In this study, I employ a two-stage residual inclusion (2SRI) approach that allows use of IV in nonlinear models.

The 2SRI method, also called the two-step control function, is one of the IV-based approaches to correct for endogeneity bias due to the presence of unobservable confounders in nonlinear models (Terza et al., 2008; Wooldridge, 2014). It helps address potential endogeneity and reverse causality between crop diversity and the nutrition outcomes. The method is used in recent studies (Asfaw et al., 2018; Michler and Josephson, 2017). Following Michler and Josephson (2017) and Papke and Wooldridge (2008), I implement the 2SRI approach in two stages.

The first stage involves regressing crop diversification on the instrumental variables and other covariates using correlated random effects or the Mundlak-Chamberlain device (Chamberlain, 1982; Mundlak, 1978) as follows

$$D_{it} = \delta X_{it} + \gamma Z_{it} + \lambda \bar{M}_i + \eta_{it} \tag{12}$$

where $\bar{M}_i$ is the time average of all time-varying variables included in the crop diversification equation to control for unobserved heterogeneity (Wooldridge, 2010). Equation 12 is estimated using panel correlated random effects (CRE). Residuals from the first stage regressions are retrieved and used used in the second-stage estimation.

In the second stage, the binary outcomes are regressed on the endogenous term (D_{it}), the residuals from the first-stage regression ($\check{D}_{it}$) and other covariates (X_{it}). The residuals are used as substitute for unobserved confounders. The time-average of the time-varying explanatory variables $\bar{V}_i$ including the residuals are also introduced to attenuate the effect of unobserved heterogeneity. The resulting 2SRI specification is

$$y_{it} = \phi D_{it} + \psi \check{D}_{it} + \beta X_{it} + \tau \bar{V}_i + \varsigma^{2SRI}_{it} \tag{13}$$

where y_{it} is the binary indicator for the child growth outcomes, and the other variables are as defined above. The second stage regression is estimated using CRE probit with the help of pooled maximum likelihood estimations (MLE) or generalized least squares (gls). This helps to easily compute average marginal effects. Since the second stage outcome equations include residuals from the first stage reduced form equations, standard errors are bootstrapped to produce valid estimates. To correct for serial correlation and/ or heteroscedasticity, I cluster standard errors at the household (Cameron and Trivedi, 2010; White, 1980).

4.3 Heterogeneous effects

Crop diversification would exert heterogeneous nutrition effects depending on differences in access to markets and exposure to shocks. Depending on other factors, it could also have variable effects on the growth of boys and girls. This is with the view that different households might have different capacities and positions to benefit from diversification. The nutrition effects of crop diversification will be different in different agroecologies and areas experiencing rainfall shortage or surplus. Heterogeneity may also exist with regard to non climate variables such as market isolation and gender of the child. Therefore, unpacking possible heterogeneous effect of crop diversity across different groups is germane to provide evidence for effective targeting of interventions.

With panel data models, heterogeneous effect can be estimated by interacting crop diversification with a variable that captures the heterogeneity of interest. Alternatively, heterogeneous effects can be estimated by running separate regressions for the different subsamples of the data. In this study, I estimate the heterogeneous effects of crop diversification using the following panel data model

$$y_{it} = \alpha D_{it} H_{it} + \rho X_{it} + u_i + \xi_{it} \tag{14}$$

where H_{it} is a variable that captures the heterogeneity of interest (market access, drought shock or gender) and the other variables are as defined above. The results from the heterogeneous effect analysis are presented with the help of graphs.

5 Data and Descriptive Statistics

5.1 Household survey and rainfall data

The source of data for this study is the Ethiopian Socioeconomic Survey (ESS) collected under the Living Standards Measurement Study-Integrated Surveys on Agriculture (LSMS-ISA) of the World Bank in collaboration with Central Statistical Agency (CSA) of Ethiopia. This research is restricted to the rural domain.[2] The survey collects data on household and children over the period 2011-2016 in three waves (2011/12, 2013/14 and 2015/16).[3] Detail information is collected on household demographics, anthropometric measurement for children, housing conditions, food and non-food consumption expenditure, food security, and shocks, among others. The agriculture module captures detail information on post-planting and post-harvest activities including landholding, crop production and disposition, and livestock ownership. In addition to the household data, the survey solicited community level information on access to services such as infrastructure, markets and health services.

[2] 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

[3] Attrition is very, hence attrition bias is not a challenge in the analysis. Household level analysis is undertaken using balanced sample. For child level analysis, I used unbalanced panel.

The household location is geo-referenced which enables linking the household data with geographic and climate datasets. Using the georeferences, I extract historical rainfall data from the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS). CHIRPS is a quasi-global spatial database (50'S-50'N) with 0.05' resolution (Funk et al., 2015). It uses satellite imagery with in-situ station data to create a gridded rainfall time series (Funk et al., 2015; Michler et al., 2018). While the dataset provides daily rainfall measurements since 1981, I extract rainfall data for 15 years from 2001-2015. This enables calculation of historical average and standard deviation of rainfall, proxy for rainfall variability.

5.2 Crop diversity measures and pattern

Crop diversity is measured using interspecific crop diversity indices: the Count (richness), Shannon-Weaver, and Composite entropy (Table 1 in Annex A). The Count index is the most popular measure of diversity. It measures crop diversity richness based on the number of crops grown by the farm household (Asfaw et al., 2018; Jones et al., 2014; Sibhatu et al., 2015). The index assumes equal contribution of the crops to the household's crop portfolio. The Shannon's (Shannon-Weaver) index is another popular measure of diversity that captures both richness and evenness i.e., the level of equality of the abundance of different crops (Saenz and Thompson, 2017). Since the index has an upper limit this depends on the number of crops grown, this presents a challenge for comparing the degree of diversification across different locations. To overcome this limitation, I also compute Composite entropy index (Arndt et al., 2015; Ghosh et al., 2015). Calculation of the crop diversity indices excludes crops that could have little contribution to nutrition such as spices and cash crops (e.g., cotton).

Table 2 summarizes the crop diversification pattern of the sample households. The Count index shows that the sample households grow about 6 crops, with a slight variation during the course of the panel. The average number of crop groups cultivated by the households is 3. The average of the Shannon-Weaver index is less than the Count index. This indicates that land is not equally distributed to different crops cultivated by the households. The Composite entropy index shows that households are highly diversified. Overall, the results show that crop diversification tends to slightly decrease over the survey period (2012-2016). There is also regeional heterogeniety in crop diversity (Table 7). Among the regions, Benishangul Gumuz, Oromiya and SNNPR tend to have higher crop diversity (above the national average in all survey years). Afar and Somalie, predominantly pastoral regions, tend to have low crop diversity scores. A simple comparison of drought shock incidence and crop diversification suggests that there is no clear pattern of correlation between the two particularly when looking at patterns over regions (Table 7).

5.3 Nutrition outcome indicators

5.3.1 Food intake and production nutrient gaps

Production nutrient gaps (surplus or deficit) for the sample households are calculated by comparing reported production of nutrients relative to recommended daily allowances (RDA). Nutrient adequacy gaps at the household level are assessed using the RDA because it is the level that meets 97.5% of the nutrient requirements (Dillon et al., 2018). RDA refers to the household level total nutrient requirements calculated as the sum of the RDA of all members of the households. Individual energy and nutrient requirements are adjusted for household composition according to sex, age, weight, and assuming moderate activity of individuals in each household to account for within-person variation for each household (FAO, 2004). To get household level estimates, the individual values are aggregated to the household level.

Estimation of the nutrient gap indicators is based on the list of nutrients that are often limited in diets or related to nutrition-related problems in less-developed countries such as stunted growth or anemia (Dillon et al., 2018). The nutrients of interest include iron, thiamine (vitamin B_1), riboflavin (vitamin B_2), niacin (vitamin B_3) and vitamins A and C. To calculate the total nutrient production by the household, I use the food composition table for Ethiopia to assign nutrient values for food items listed in the production modules of the agriculture questionnaire. The energy and nutrient requirements of the households are calculated for each survey round year (2012, 2014 and 2016). Total nutrient production amounts are converted to edible amounts by multiplying the edible amount by the nutrient value. The calculation is done for each nutrient separately for each household. In addition, I compute energy intake gap from production to enrich the discussion. All production amounts are converted to per adult equivalent daily amounts.

Table 4 in Annex A presents summary statistics for the nutrient production and nutrient production gap by survey year. The results show a significant increase in nutrient production over time during the survey periods. In figure 1, I present the proportion of the sample households that met the required daily allowance (RDA) from nutrient production by survey year. The results show that the proportion of households that meet the Iron, Thiamine and niacin requirements from production has increased over time during the survey periods. However, the proportion decreases for energy, riboflavin, vitamin C and vitamin A, at least during the survey periods.

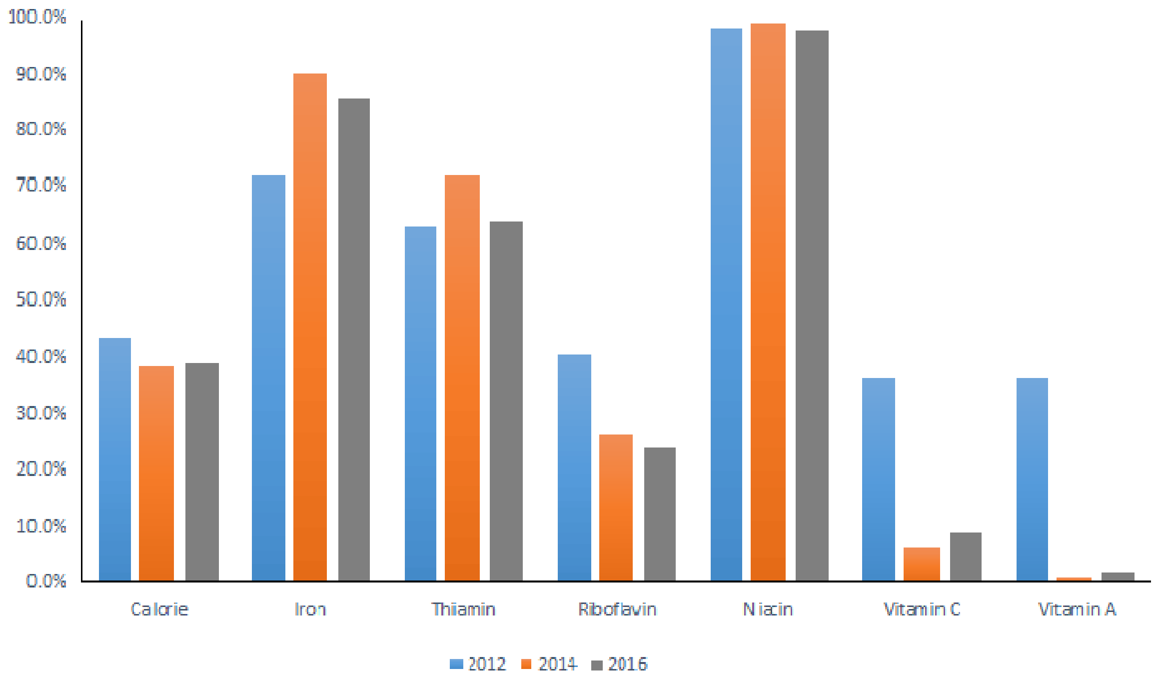

Figure 1: Mean proportion of households that met RDA requirements from nutrient production

5.3.2 Dietary diversity and diet quality

Dietary diversity is an intermediate nutrition outcome indicator and proxy for food access and diet quality (Jones et al., 2014). I develop an indicator of dietary diversity score (DDS) for each household from 12 food groups and food consumption score (FCS) from 9 food groups consumed in a week before the survey.[4] FCS is a frequency and nutrition density weighted DDS

[4]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.

that takes into account dietary diversity, food frequency and relative nutritional importance of different food groups. The weights are assumed to capture nutrient density which encompasses diet quantity (calorie density, actual quantities consumed) and diet quality (protein content and quantity, content and availability of micronutrients). FCS is positively correlated with caloric intake and diet quality at the household level (Jones et al., 2014; Lovon and Mathiassen, 2014). Additional outcome measures are food intake per adult equivalent per day, and diet quality that is calculated as the proportion of calorie obtained from nutritious non-staples cultivated by the household.

Summary statistics for diet diversity and diet quality are provided in Table 3 (Annex A). Households on average consume 6 food items (out of 12) in a week. This indicates that rural Ethiopians on average consume a diverse diet. Dietary diversity slightly increased during the survey periods. The average food consumption score over the three waves is about 40, with no clear trend. The results also show that the diet of rural Ethiopians is dominated by non-nutritious staples since the share of calories obtained from nutritious non-staples cultivated by the households is 14%(for the pooled data), and decreased from 20% in 2012 to 12% in 2016. Figure 1 (Annex A) shows that households that experience drought and live in 25 Km radii to major market tend to have low diet diversity. Diet quality is, on average, low for households that experience drought, live far from markets and in villages where there are no large weekly markets (Figure 2 in Annex A).

5.3.3 Child growth

Child anthropometric measures are calculated using measures of height and weight for all children under 5 years of age obtained from the ESS (LSMS-ISA) data for Ethiopia. First, I compute height-for-age (HAZ) and weight-for-height (WHZ) z-scores. The z-scores describe the number of standard deviations by which the child's anthropometric measurement deviates from the median in the 2006 WHO child growth standard. Second, a z-score cut-off point of -2 is used to generate binary indicators for stunting (a long-term indicator of child nutritional status) and wasting (a short-term indicator of acute malnutrition). A z-score of less than -2 classifies low height-for-age as stunted and low weight-for-height as wasted (WHO, 1995, 1997).

Table 5 presents the summary statistics for the child growth outcomes. The results show that the prevalence of stunted (moderate or severe) growth among children under 5 years of age in rural Ethiopia still stands above 40%. While the proportion of stunted children decreased from about 48% in 2012 to 41% in 2014, what is more striking in the data is that it increases to 43.7% in 2016. Likewise, the prevalence of wasting among under five children remains above 10% during the same period. The proportion of wasted children has increased from 11% in 2012 to 12% in 2016. The data also show that the risks of stunting and wasting co-exist among 3.4% of children under five years of age.

The study also documents regional heterogeneity in the trends of stunting prevalence. Overall, stunting has decreased between 2012 and 2014, but tends to rise in 2016 (Figure 2). Among the regions that have contributed to the rise in the prevalence of stunting are Afar, Oromiya, SNNPR, Gambella and Dire Dawa. Afar is, in particular, the region that experienced drought shock and host high number of stunted children. Tigrai, Amhara, Somali, Benishangul Gumuz and Dire Dawa manage to reduce child stunting between 2014 and 2016. The (pooled) data further show that the proportion of stunted children is higher in Afar, Amhara, Tigrai and SNNP, registering a rate higher than the national average (Table 6 in Annex A). Child wasting is more prevalent in Somalie region followed by Tigrai and Afar with prevalence rates being above the national average (Table 6).

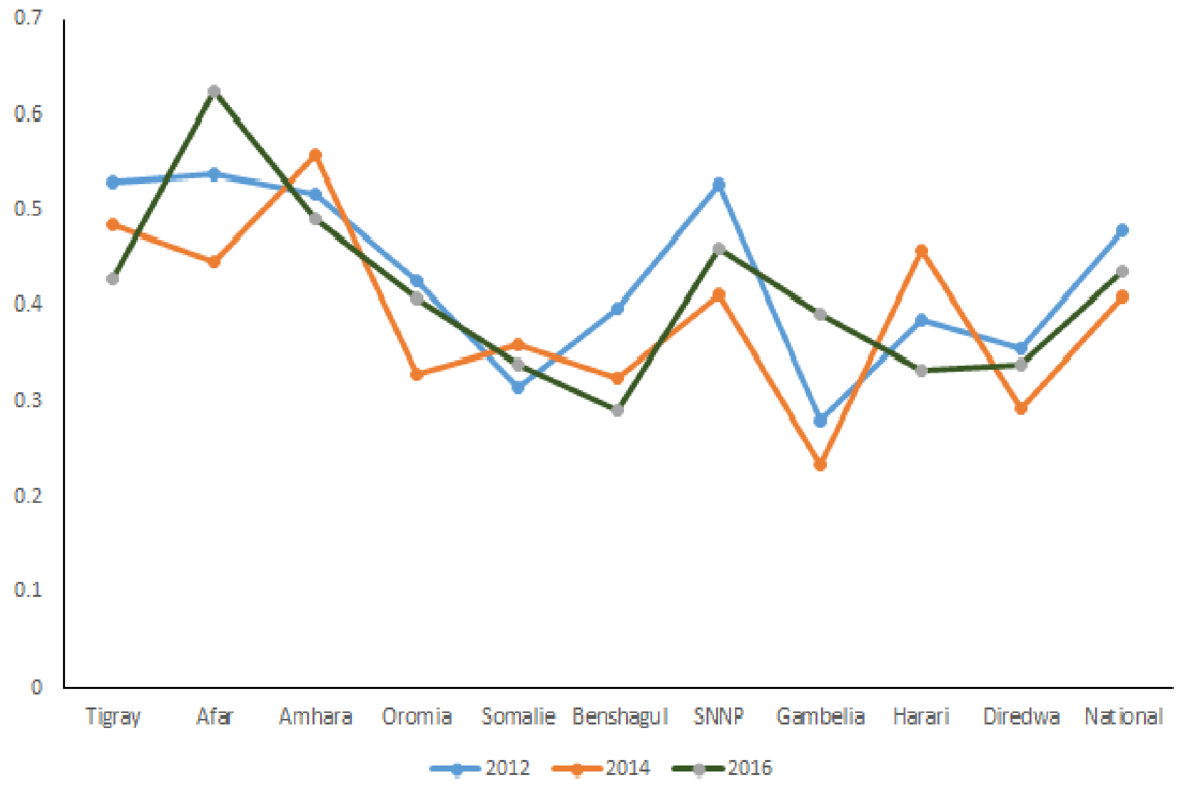

Figure 2: Child stunting trends by region

I depict the persistence or path dependence in child malnutrition by exploiting the panel nature of the data. With a transition matrix analysis, the data show that about 72% of the children that were not stunted in one period remain non stunted in the next period. About 51% that were stunted in one period remain stunted in the next period, suggesting high persistence of stunting. About 49% of non-stunted children in one period become stunted in the next period, an indication of high risk of stunting. On average, about 28% of stunted children in one period become non stunted in the next period. The results suggest the presence of dramatic path dependence in child malnutrition as well as mobility of children in and out of stunting.

Using a correlation analysis, I have analyzed the relationship between crop diversity and child growth (see Table 9 in Annex B). The results show that the crop count index is positively and significantly correlated with HAZ and WHZ scores. There is also a negative and significant correlation between crop count index and child stunting and wasting. However, I find no significant correlation between the other crop diversity indices and the child growth outcomes. While the correlation analysis results suggest relationships, they do not show causal relationships. In the next section, I present the causal relations using econometric models that account for endogeneity.

6 Results

This section presents the main results on the relationship between crop diversification and household nutrition and child growth. The results are obtained by estimating the relationships with several specifications and robustness checks. First, I estimate the impacts of crop diversification on child health using various measures for the outcomes and crop diversification. Moreover, I explore potential heterogeneous effects of crop diversity on child growth by testing whether the effect differs by gender of the child (for boys and girls), exposure to drought shock and market access. Second, I assess the impact on household nutrition using nutrient production gaps, diet diversity, diet quality and food intake.

6.1 Child growth effects of crop diversity

6.1.1 Baseline results

I begin with the relationship between crop diversity (count, crop groups, Shannon-weaver and composite entropy) and child growth outcomes height-for-age z-score, weight-for-height z-score, stunting and wasting) obtained using fixed effects (child and year) regressions. Fixed effects is used for the continuous outcome variables and fixed effects logit is used for the binary outcome variables. The econometric models consider the effect of changes in crop diversification over time on children's health accounting for time-invariant unobservable child and parental characteristics such as skills, propensity to seek information, innate and pre-natal child attributes (Lovo and Veronesi, 2019). However, the approaches do not fully account for endogeneity, thus crop diversity is treated as exogenous in the specifications. All regressions include controls for child and household characteristics, and standard errors are clustered at the household level.

Table 1 presents the fixed effects regressions results (panel A). The results show that height-for-age z-score (HAZ score) is positively associated with crop diversity. However, significant effect of crop diversity is observed only for the crop count index. The result implies that cultivating one more crop increases the HAZ score by 0.085, which is equivalent to 4.3% of a standard deviation or 8.7% of the within-child variation. There is no significant association between crop diversification and WHZ score. When considering the binary indicators for child health, the results from the fixed effect logit show that all crop diversity indices except the number of crop groups have negative and significant effect on stunting. Again, there is no significant relationship between crop diversity and child wasting, irrespective of the crop diversity metrics. Results from pooled OLS and pooled logit (not reported for the sake of space) also show the absence of significant association between crop diversity and child growth outcomes.

6.1.2 Instrumental variables (IV) methods results

One of the major concerns regarding the estimates from the fixed effects is that increased crop diversification could be the result of unobserved coping strategies or technology diffusion (Lovo and Veronesi, 2019). Moreover, government interventions that promote crop diversification could also affect child health through improving nutrition. Therefore, this may create upward bias to the baseline estimates. If government programs target poorer households with worst child health outcomes, this would create rather a downward bias to the estimates. I used instrumental variables (IV) approaches with the pooled data and with panel data to address the potential challenges of endogeneity. As discussed in section 4, the instrument used for crop diversification is the average village level crop diversification (for all indices) computed after excluding a household own crop diversification.

In Panel B of Table 1, I present the results obtained from fixed effects instrumental variables (FE-IV) method. This specification allows exploring the relation between change in crop diversification over time and child health outcomes after addressing endogeneity. The estimated coefficients on HAZ score are not significant for all crop diversity indices. However, there is significant effect of the number of crop groups and the composite entropy index on WHZ score. The effect of one additional crop group on the WHZ score is found to be 0.403 (29.3% a standard deviation or 63.2% of within-child standard deviation). However, the results show that crop diversification does not have significant impact on child stunting and wasting irrespective of the crop diversity metrics. The results from the two-stage residual inclusion show that crop

Table 1: Crop diversity and child growth

	Count index	Crop groups	Shannon index	Composite entropy
A: Fixed effects (OLS, logit)				
(1) Height-for-age	0.085**	0.064	0.305	0.347
	(0.034)	(0.074)	(0.187)	(0.419)
(2) Weight-for-height	-0.015	0.034	-0.017	0.338
	(0.029)	(0.061)	(0.157)	(0.346)
(3) Stunting	-0.106**	0.010	-0.676**	-1.188*
	(0.047)	(0.106)	(0.270)	(0.610)
(4) Wasting	0.024	-0.191	0.026	-0.517
	(0.081)	(0.169)	(0.390)	(0.856)
B:Fixed effects or LPM IV				
(1) Height-for-age	0.033	-0.205	0.079	-0.015
	(0.083)	(0.219)	(0.738)	(1.878)
(2) Weight-for-height	0.037	0.403**	0.759	2.712*
	(0.071)	(0.192)	(0.630)	(1.553)
(3) Stunting	-0.005	0.053	-0.047	-0.038
	(0.022)	(0.062)	(0.210)	(0.541)
(4) Wasting	-0.016	-0.073*	-0.190	-0.426
	(0.014)	(0.039)	(0.157)	(0.400)
C:Two-Stage Residual Inclusion (2SRI)				
(1) Stunting	-0.019	0.016	-0.124	-0.167
	(0.016)	(0.046)	(0.208)	(0.546)
(2) Wasting	-0.014	-0.004	-0.223*	-0.560*
	(0.013)	(0.028)	(0.130)	(0.295)

Note: In Panels A and B, (1) and (2) report results for Height-for-age z-score (HAZ score) and Weight-for-height z-score (WHZ score) where crop diversity is estimated using four indices (Count, number of crop groups, Shannon, and Composite entropy); (3) and (4) report estimates for child stunting and wasting; in Panel C, I report estimates from the two-stage residual inclusion (2SRI); All regressions include child and household characteristics and time fixed effect; Standard errors in parentheses are clustered at the household level; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

diversity has significant negative effect on child wasting, but only for the Shannon and Composite entropy indices (panel C of Table 1). Overall, the results show that rural household can achieve reduction in child malnutrition by cultivating more crops and equitably allocating their land across all the crops they cultivate.

Additional results are provided in Table 10 (Annex B). The estimates are based on pooled OLS IV for HAZ and WHZ scores and pooled probit IV for stunting and wasting. The econometric models enable estimation of the impacts assuming that both crop diversity and the child growth outcomes do not significantly vary over time. The results show that crop diversification (for most of the crop diversity indices) has positive and significant effect on HAZ and WHZ scores. The magnitude of the effects are higher for the land concentration indices (Shannon and Composite) than the count indices (crop count and number of crop groups). Moreover, crop diversity through increasing the number of crop groups significantly reduces child stunting, whereas increase in equitable allocation of land has significant effect on reducing child wasting.

The results of the base specification (Panel A) and the IV regressions (Panel B) suggest that crop diversification positively affects HAZ score and negatively affect child stunting, both measures of long term child nutritional status. More important, increase in crop diversification through more equitable allocation of cultivated land across crops generates higher child health impacts than expanding the portfolio of crops. The magnitude of the estimated impacts is found to be small in most cases. This is not surprising given high persistence in childhood anthropometric measures which implies that changes in crop choices are less likely to generate large effects on child nutrition over time (Lovo and Veronesi, 2019). The results from the IV methods in Panel B show that crop diversification (the number of crop groups and composite entropy index) have positive effect on WHZ scores. Moreover, the IV results in Panel B show that crop diversification through increasing equitable allocation of land across crops cultivated by the household has positive effect on reducing child wasting.

6.2 Heterogeneous effects

In this section, I explore whether the effect of crop diversification varies according to the gender of the child, exposure to shocks and access to markets. This helps, to some extent, to investigate whether the small average effects of crop diversification on child growth masks the significant differences among different groups of children and households. To get the estimates, I interact the crop diversification measures with child gender, exposure to drought shocks and market access. First, I explore whether the effect of crop diversification on child stunting and wasting varies for boys and girls. Figure 3 reports the average marginal effects obtained from probit IV regressions estimated separately for boys and girls. The coefficient of the crop count index is positive and significant for HAZ score. The results show that crop diversity does not generate heterogeneous effects on stunting of boys and girls. However, it reduces wasting for girls by 4 percentage points. Results for the Shannon index show that crop diversity reduces wasting among girls by 31 percentage points and by 25 percentage points among boys, on average. The results suggest that, despite lack of significant results for the whole sample, crop diversity would have differential child growth effects for boys and girls. Results from analysis using the HAZ and WHZ scores as outcomes show that there are no effects for boys and girls (Figure 5 in Annex C).

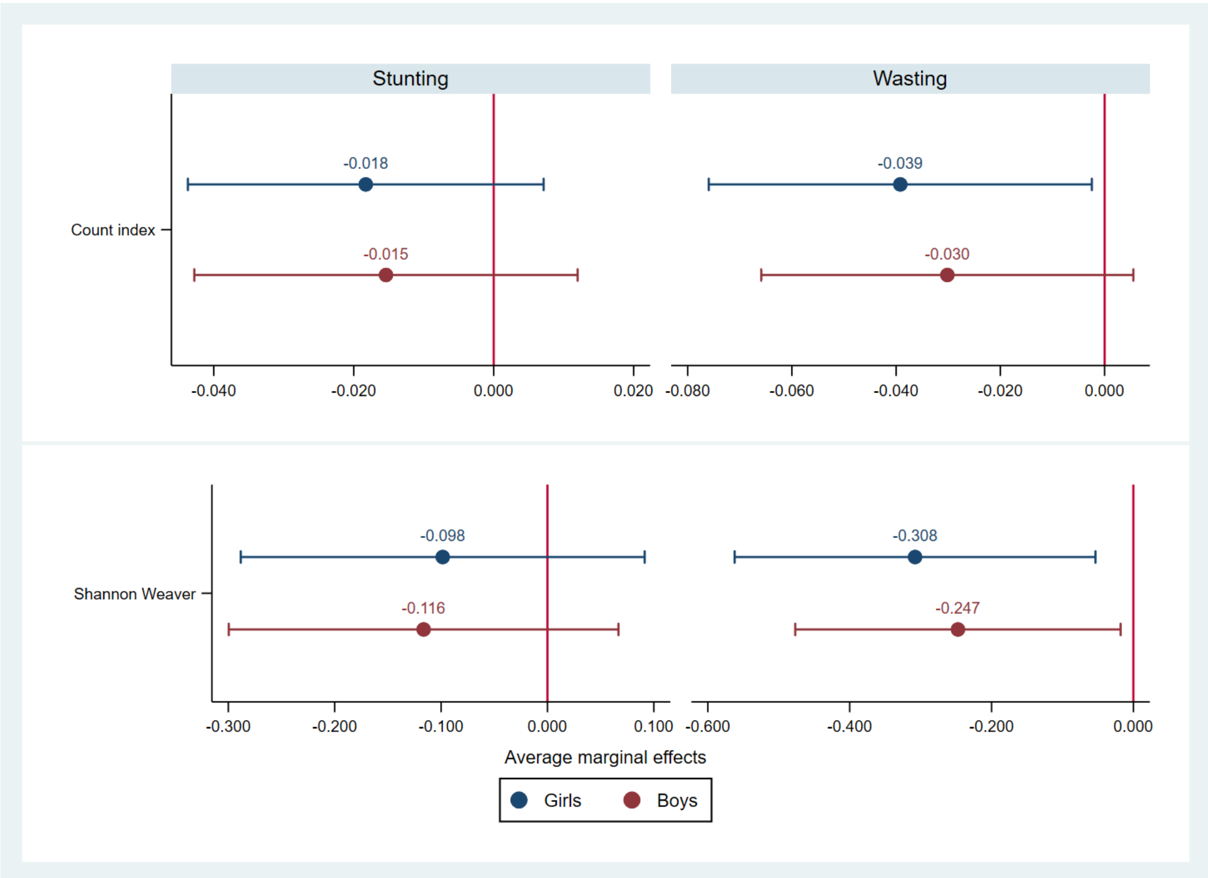

Figure 3: Child growth effects of crop diversity by sex of child

To enrich the discussion, I demonstrate if drought shocks have differential growth effects for boys and girls (Figure 4). Three general patterns emerge from this analysis: First, stunting has declined between 2012 and 2014 by 7 percentage points (or 14.5%) for both boys and girls. However, it has significantly increased between 2014 and 2016 by 2.6 percentage points (or 6.5%). Second, stunting appears to be higher for boys and girls under shock exposure than in periods where no shock are experienced. In connection to this, stunting has been higher for both boys and girls in 2012 (this period is associated with the 2011 East African drought) and falls in 2014 (no drought), and again increased in 2016 (the period that corresponds with the 2015 drought). Third, the effect of drought on child stunting has been substantial for boys in 2012, but it tends to be slightly higher on girls in 2014 and 2016. Overall, the descriptive statistics results suggest that exposure to shock has negative effect on the growth of both boys and girls.

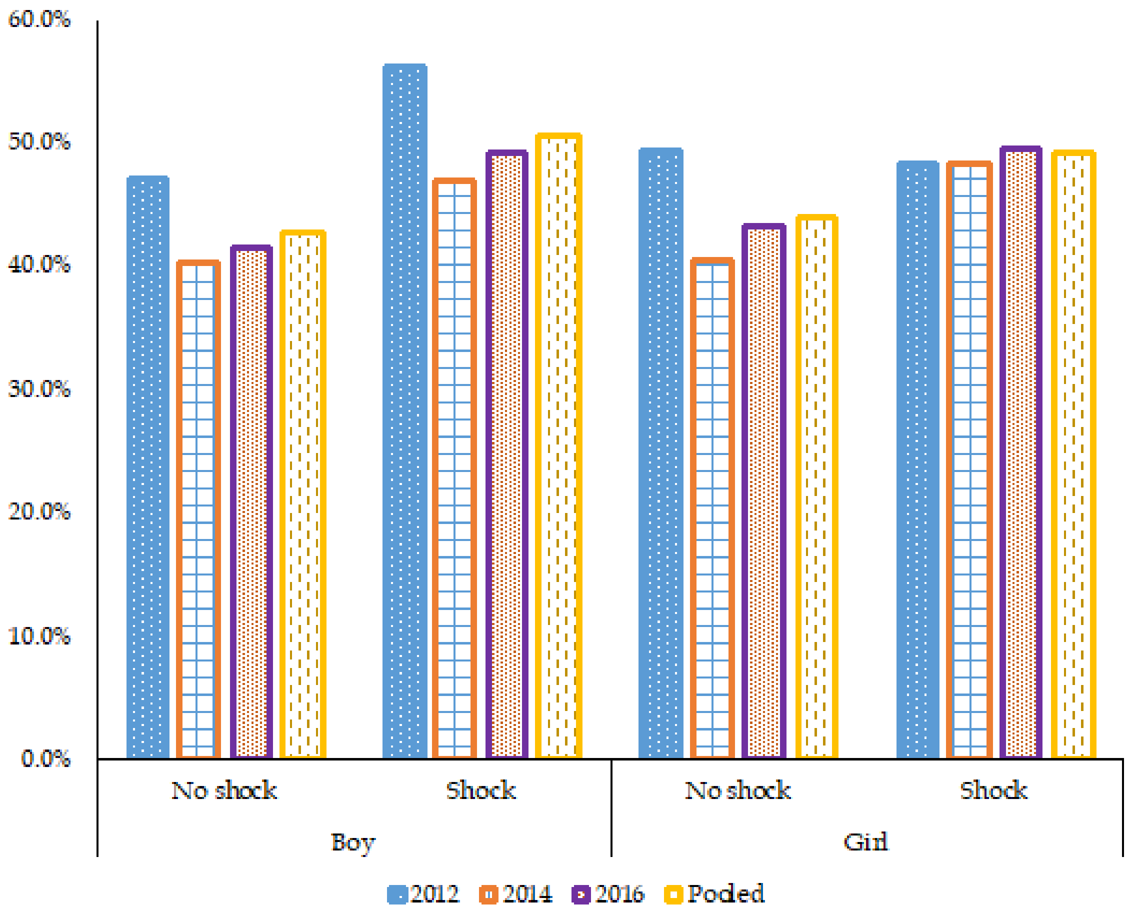

Figure 4: Child growth and drought exposure

Using a dummy variable that captures whether the household experienced drought shock or not (self-reported drought shock), I explore if crop diversity has varying effect on child growth. The result in figure 5 suggests that crop diversification (count and Shannon index) have positive effect on reducing child wasting under conditions of no drought shock. However, there is no significant effect on the child outcomes under conditions of drought shock. The coefficient of the drought shock variable is insignificant for both count and Shannon indices. This indicates that the devastating droughts (e.g., the 2015 drought) do not lead to widespread increases in child malnutrition in the drought-exposed areas (Hirvonen et al., 2018). Thus, children residing in areas that experience drought do not have worse health (nutrition) profile compared to those who are not (or less) exposed to drought as indicated by insignificant coefficient of the drought shock variable (Figure 6 in Annex C). The interaction of drought shock variable with the crop diversity indices is not significant. The results provide no evidence to conclude that crop diversification provides child health resilience benefits against drought, after accounting for child and household characteristics.

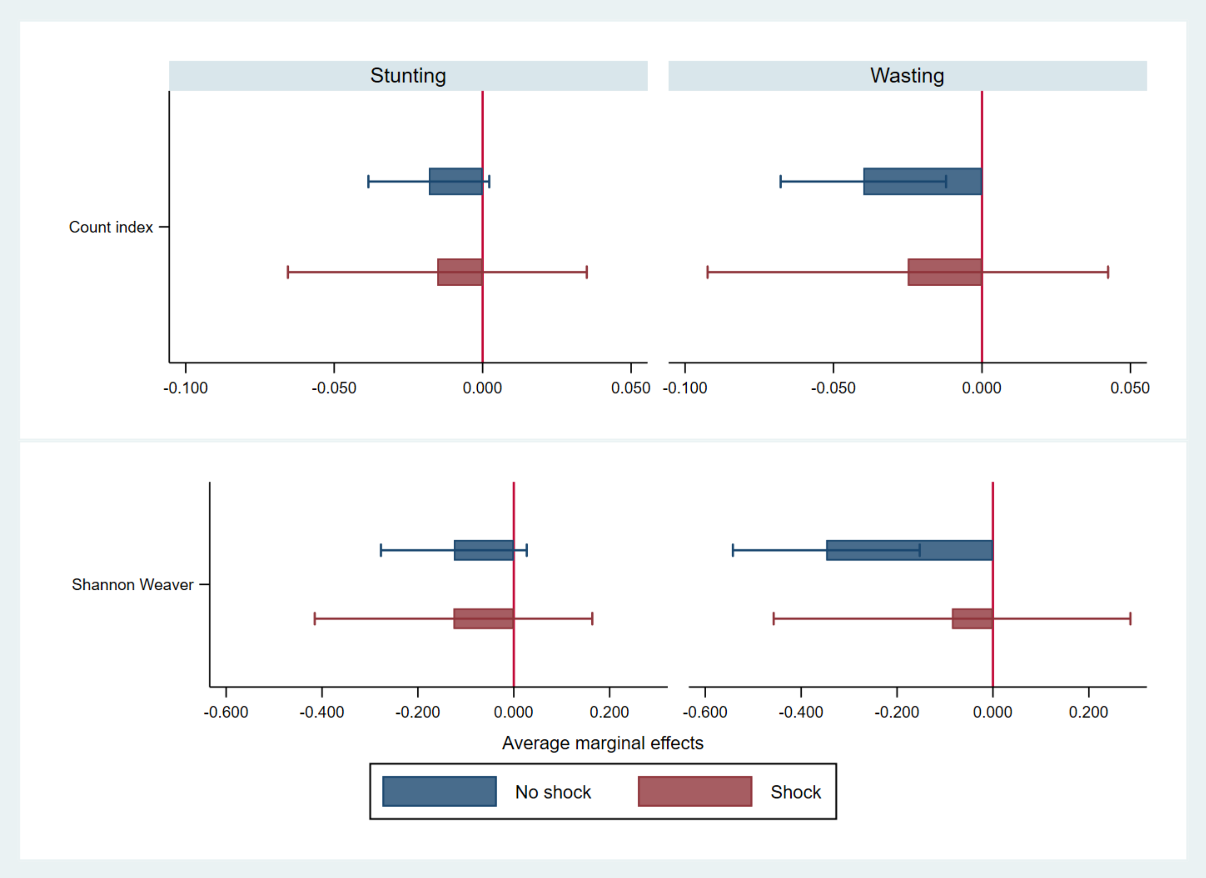

Figure 5: Child growth effects of crop diversity by exposure to drought shock

Finally, I test if access to market mediates the effect of crop diversification on child health. To this purpose, I use the presence of large weekly market in the village (dummy variable) as indicator for market access. The results show that crop diversification (both crop count and Shannon indices) have positive effect on reducing child stunting among households that live in villages where no large weekly markets exist (Figure 6). This result suggests that crop diversification will improve child health in areas with less or no access to markets (Hirvonen et al., 2018; Sibhatu et al., 2018). However, the result show that crop diversification reduces child wasting under conditions where large weekly markets exist in the village. Additional results (Figure 6 in Annex C) show that crop diversification does not exert effect on HAZ by market access. However, it increases WHZ score in areas where large weekly markets exist. Lovo and Veronesi (2019) also find that crop diversification is weakly associated with HAZ score for households closer to food markets in Tanzania. Overall, the results suggest that market access mediates the effects of crop diversification on child growth.

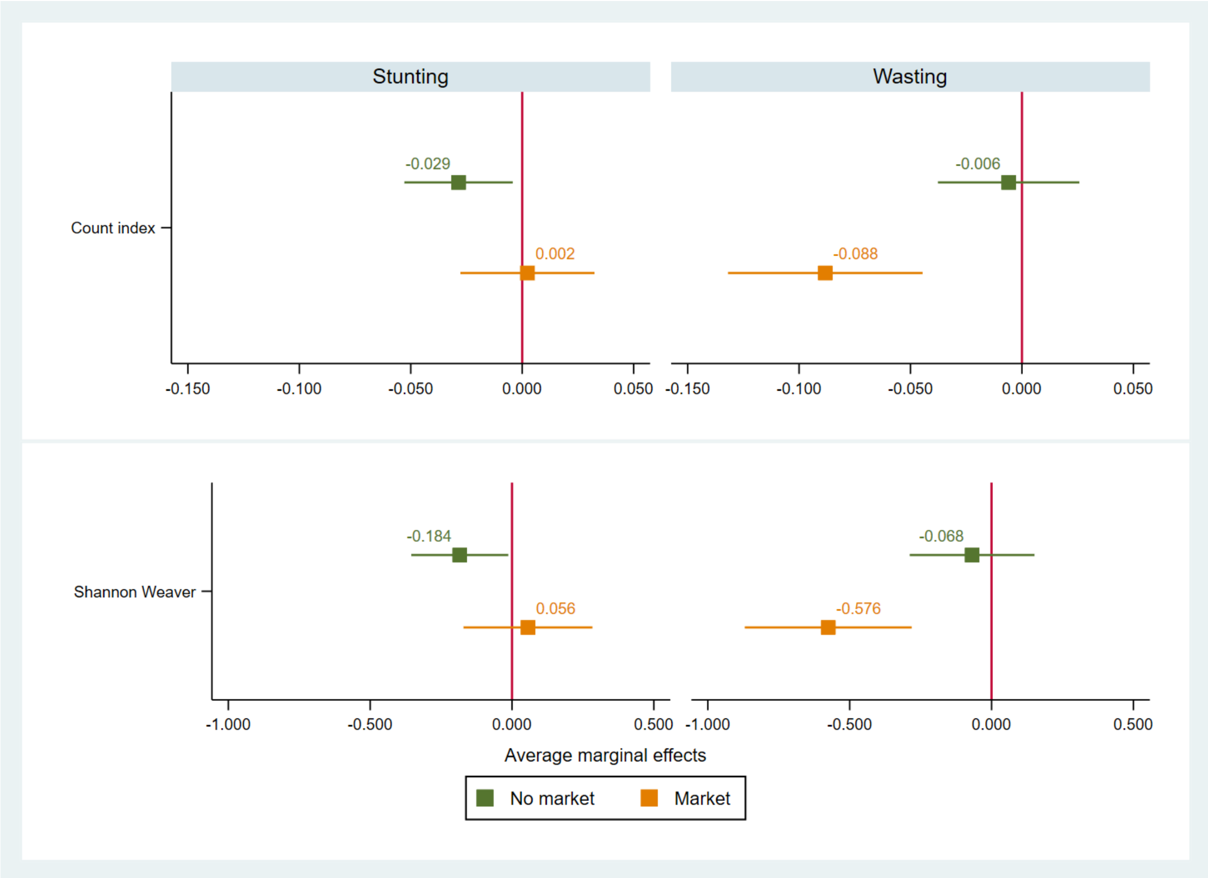

Figure 6: Child growth effects of crop diversity by market

6.3 Underlying mechanism: Crop diversity, diet diversity and diet quality

The results reported so far have shown that greater crop diversification is beneficial for children health as it is associated with an increase in HAZ and WHZ and a decrease in the risk of child stunting and wasting under different conditions. I estimate the impact of crop diversity on household diets (measured using dietary diversity) to elucidate the underlying mechanism through crop diversity will influence child health. Since diet diversity is measured at the household level, this indicator is less likely to fully capture the degree to which child diet diversity is affected by crop diversity. However, it still provides some evidence on the relationship between the measure of crop diversification and dietary diversity. This is particularly true because child growth indicators are correlated with household nutrition indicators (Table 8 in Annex B). This indicates that children in households with better diets are less likely to be stunted and wasted.

A bivariate correlation analysis between diet diversity and crop diversity (Figures 3 and 4 in Annex C) suggests a significant positive correlation between crop diversity and diet diversity. With different econometric models that allow different assumptions about the nature of the relationship between crop diversification and dietary diversity and accounting for the effect of other confounding effects, I have estimated the effects of crop diversity on household diet diversity. Results are presented in Table 2.

Table 2: The effect of crop diversity on aggregate household diets

	Count index	Crop groups	Shannon index	Composite entropy
(1) Pooled OLS	0.041**	0.104***	0.150**	0.252
	(0.013)	(0.030)	(0.076)	(0.166)
(2) Fixed effects	0.024*	0.020	0.115	0.200
	(0.013)	(0.028)	(0.072)	(0.158)
(3) Pooled OLS IV	0.085***	0.254***	0.331***	0.551**
	(0.010)	(0.025)	(0.075)	(0.215)
(4) FE-IV	0.098***	0.244***	0.479*	0.637
	(0.030)	(0.083)	(0.282)	(0.729)

Note: Dependent variable is household dietary diversity score. (1) Reports the results obtained from pooled OLS regression. (2) reports results of an alternative specification of the dietary diversity equation using fixed effects (household and time). (3) reports results from pooled OLS with IV, and (4) reports estimates from the fixed effects IV method. Robust clustered standard errors in all regressions; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

The results from the pooled OLS (using cross household variation) and fixed effects (within variation) show that diet diversity is positively associated with crop diversity (all indices except the Composite entropy index). The relationship remains even after I address potential endogeneity of crop diversification using village level crop diversity as instrument for household level crop diversity. When considering within household variation to estimate the relationship between the two variables using fixed effects IV approach, I find a positive and significant association between crop diversification and diet diversity. In case of significant associations, one additional crop (crop group) or a 1 unit increase in equitable allocation of land across crops cultivated is associated with an increase in average diet diversity in the range of 0.10 (crop count) and 0.48(Shannon index). The results suggest that households with a higher crop diversity display greater dietary or nutritional diversity through greater availability of food varieties. As in previous studies, however, the magnitude of the impact is small (Lovo and Veronesi, 2019; Sibhatu et al., 2018). Notwithstanding this, the results show that the effect of crop diversification on child health would operate through greater diet diversity. However, there could be other mechanisms at play through which agricultural production influences human nutrition.

Table 3: The effect of crop diversity on diet quality

	Count index	Crop groups	Shannon-Weaver	Composite Entropy
(1) Pooled probit	0.065***	0.163***	0.331***	0.592***
	(0.002)	(0.003)	(0.011)	(0.029)
(2) Pooled probit IV	0.024*	0.020	0.115	0.200
	(0.013)	(0.028)	(0.072)	(0.158)
(3) 2SRI	0.004	-0.006	0.106**	0.395***
	(0.004)	(0.010)	(0.042)	(0.136)
(4) FE-IV	0.005*	0.002	0.093*	0.252
	(0.005)	(0.012)	(0.051)	(0.157)

Note: Dependent variable is diet quality. (1) Reports the results (marginal effects) obtained from pooled probit regression. (2) reports results of an alternative specification of the dietary diversity equation using fixed effects (household and time). (3) reports results from pooled OLS with IV, and (4) reports estimates from the fixed effects IV method. Robust clustered standard errors in all regressions; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 3 presents the average marginal effects of crop diversity on diet quality. As discussed earlier, diet quality is measured as the share of food intake or calories obtained from nutritious non-staples cultivated by the household. Overall, the results show that diet quality is strongly correlated with crop diversity. Results from the pooled probit and probit IV (conditional maximum likelihood estimation) methods show that the share of quality diets in households calorie production increases with crop diversification. The effects appears to be more higher with increase in equitable allocation of land across the crops cultivated by the household. This result suggests that reallocation of land among crops would improve diet quality that the mere addition of crops in the portfolio or allocating more land to few crops.

6.4 Crop diversity and nutrient production gaps

In addition to estimating the effect of crop diversity on diet diversity and diet quality, I assess its impact on nutrient production gaps. As discussed earlier, nutrient production gaps are calculated as the difference between the total nutrient production and the recommended daily allowance (RDA) for selected macro and micro- nutrients. I also estimate the impact on calorie production.

Table 4: Calorie and nutrient production gap and crop production diversity

	Count index	Crop groups	Shannon-Weaver	Composite Entropy
(1) Food intake (kcal)	260.04***	288.10	854.72	-1,370.71
	(89.94)	(299.70)	(1330.98)	(4,709.82)
(2) Iron (mg)	15.49***	20.77	82.25	104.22
	(5.66)	(17.47)	(76.46)	(199.30)
(3) Thiamin (mg)	1.71**	0.89	2.02	-5.76
	(0.71)	(3.19)	(3.37)	(20.06)
(4) Riboflavin (mg)	0.05**	0.084	0.23	-0.30
	(0.03)	(0.08)	(0.42)	(1.64)
(5) Niacin (mg)	1.33**	0.75	2.043	-11.43
	(1.16)	(1.89)	(7.90)	(29.32)
(6) Vitamin C (mg)	5.34***	9.02**	48.76***	59.43
	(1.79)	(3.99)	(17.23)	(48.05)

Note: Dependent variables are energy intake (calorie) and nutrient production gaps; The results are based on fixed effects IV method; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

The results from the main econometric model (fixed effects IV) show that crop diversification has the potential to close nutrient production gaps (Table 4). Calorie and nutrient production gaps are found to be significantly correlated with crop diversity (mainly the crop count index). However, the effect of crop diversity on calorie and nutrient production seems to be achieved by adding more crops to the production portfolio, not necessarily by equitably allocating farm land among existing crops. The results, to some extent, suggest that farmer innovations that motivate production of new crops would help to improve household nutrition.

7 Conclusion

Poor household nutrition and child malnutrition are predominant in Sub-Saharan Africa. Agricultural diversification has been recognized as a strategy to improve nutrition and human health, in addition to its benefit as a climate risk coping strategy. Very little empirical evidence exists on the links between crop diversification, household nutrition and child growth. The study contributes to the literature and the policy discourse by investigating the impact of crop diversification on household nutrition and child growth. I utilize three-wave panel data from the Ethiopian Socio-economic Survey (ESS) that spans the period 2012-2016. The empirical strategies employed in the study help analyzing the effects of crop diversification on the outcomes under different assumptions about the nature of the relationships between the two.

The results show that crop diversification has a positive but small impact on child growth outcomes. The child growth benefits are achieved through its role in increasing HAZ and WHZ scores and reducing the risk of child wasting and stunting. The positive effect of crop diversification on child growth suggests that agricultural policies should have a greater focus on agricultural diversification in general, and on crop diversification and nutritional quality of the production in particular. While the descriptive statistics results show that child stunting is correlated with exposure to drought shock, I find no evidence that household's exposure to drought shock translates to catastrophe in terms of child undernutrition, after accounting for child and household characteristics. Although crop diversification exerts positive child health effects, I do not find evidence that crop diversification mitigates the negative impact of drought shocks on child health. Furthermore, the study highlights that crop diversification has stronger child health (reduced child stunting) in areas with limited access to local markets. Nonetheless, the effects on reducing child wasting are larger for children living in households with access to local markets. The results also show that crop diversification does not produce varying growth effects for boys and girls.

Regarding the relationship between household nutrition and crop diversity, the results show that crop diversity has positive effect on diet diversity. However, the magnitude of the impact is small. The diet of rural Ethiopians is diversified as they consume about 6 food items on average, but their calorie production seems to be dominated by non-nutritious staples. The results from the econometric models suggest that crop diversification, particularly increasing the the number of crops cultivated by the household has the potential to improve diet quality. Analysis of the effect of crop diversification on nutrient production gaps indicates that crop diversification through expanding the production portfolio has significant effect on increasing nutrient production and nutrient production gap. The positive and significant effects of crop diversification on nutrient production, diet diversity and diet quality is reassuring that crop diversification would improve child growth.

From policy perspectives, the findings suggest that policies that target improving nutrition should focus on promoting crop diversification particularly. However, given the possibly high opportunity cost of crop diversification, the results imply that further research is required to compare the nutrition impact of crop diversification with other agricultural policies and interventions. This would help to identify complementary strategies that would improve the contribution of crop diversification to human nutrition. The results further suggest that policies that target crop diversification as a nutrition enhancing strategy need to take into account the economic and agroecological conditions.

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Annex A: Descriptive statistics

Table 1: Calculation of crop diversification indices

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

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 2: Crop diversity pattern by survey year

Crop diversity index	**2012**	**2014**	**2016**	**Pooled**
Count index	6.545	6.370	6.252	6.377
	(3.352)	(3.115)	(3.467)	(3.321)
Number of crop groups	3.318	3.282	3.163	3.248
	(1.252)	(1.252)	(1.225)	(1.244)
Shannon-Weaver index	1.214	1.185	1.127	1.172
	(0.467)	(0.469)	(0.467)	(0.469)
Composite entropy index	0.552	0.542	0.522	0.537
	(0.172)	(0.176)	(0.178)	(0.176)
Observations	2,455	2,455	2,455	7365

Note: Mean coefficients; Standard deviations in parentheses.

Table 3: Descriptive statistics: household diets and characteristics by survey year

	Survey year			Pooled			
	2012	**2014**	**2016**	**Mean**	**Median**	**Minimum**	**Maximum**
Diet diversity and quality							
Dietary diversity score	5.66	5.89	6.03	5.88	6.00	0.00	12.00
	(1.80)	(1.72)	(1.67)	(1.73)			
Food consumption score	41.7	43.21	41.87	42.27	42.00	0.00	101.50
	(17.67)	(16.77)	(16.09)	(16.81)			
Diet quality	0.20	0.13	0.12	0.14	0.03	0.00	1.00
	(0.34)	(0.19)	(0.19)	(0.23)			
Household characteristics							
Household size	6.23	6.25	6.27	6.25	6.00	1.00	16.00
	(2.13)	(2.13)	(2.20)	(2.16)			
Female headed	0.12	0.13	0.14	0.13	0.00	0.00	1.00
	(0.33)	(0.34)	(0.35)	(0.34)			
Age of head	45.1	46.01	47.28	46.21	44.00	8.00	98.00
	(13.91)	(13.65)	(13.67)	(13.76)			
Head is literate	0.45	0.46	0.48	0.46	0.00	0.00	1.00
	(0.50)	(0.50)	(0.50)	(0.50)			
Wealth indicators							
Land size (hectares)	1.22	1.35	1.33	1.31	0.94	0.00	9.98
	(1.53)	(1.30)	(1.25)	(1.35)			
Tropical Livestock Units	3.84	3.98	4.72	4.22	3.23	0.00	94.29
	(3.24)	(4.12)	(6.17)	(4.83)			
Asset wealth index	-0.07	-1.08	-1.16	-0.81	-1.00	-2.43	34.90
	(3.04)	(0.75)	(0.86)	(1.85)			
Housing features							
Improved water source	0.49	0.62	0.72	0.62	1.00	0.00	1.00
	(0.50)	(0.49)	(0.45)	(0.49)			
Improved sanitation	0.01	0.02	0.44	0.17	0.00	0.00	1.00
	(0.09)	(0.15)	(0.50)	(0.38)			
Electricity	0.05	0.06	0.07	0.06	0.00	0.00	1.00
	(0.23)	(0.24)	(0.26)	(0.24)			
Non agribusiness	1.94	1.92	1.94	1.93	2.00	1.00	2.00
	(0.24)	(0.27)	(0.24)	(0.25)			
Proximity to services							
Health post	0.92	0.93	0.94	0.93	1.00	0.00	1.00
	(0.26)	(0.26)	(0.24)	(0.25)			
Weekly market	0.45	0.54	0.6	0.53	1.00	0.00	1.00
	(0.50)	(0.50)	(0.49)	(0.50)			
Distance to market (Km)	64.12	62.84	63.29	63.38	52.30	2.80	283.00
	(45.07)	(45.31)	(45.77)	(45.41)			
Distance to major road (Km)	13.91	14.13	14.25	14.11	10.20	0.00	239.20
	(14.10)	(15.04)	(15.10)	(14.79)			
Climate and shocks							
Drought shock	0.14	0.08	0.27	0.17	0.00	0.00	1.00
	(0.34)	(0.27)	(0.44)	(0.37)			
Average annual rainfall (mm)	1221.84	1231.23	1221.03	1224.67	1200.27	163.87	2143.67
	(331.57)	(337.60)	(344.22)	(338.30)			
Std.Dev. annual rainfall	108.86	110.74	120.41	113.78	112.85	19.90	190.37
	(25.00)	(23.63)	(26.70)	(25.73)			
Shortage annual rainfall	0.05	0.09	1.37	0.55	0.00	0.00	2.78
	(0.15)	(0.26)	(0.87)	(0.84)			
Mean Temperature (^0C)	18.36	18.35	18.41	18.37	18.70	10.20	29.40
	(2.93)	(2.92)	(2.96)	(2.94)			
Elevation (m)	2010.47	2007.2	1996.71	2004.26	1932.00	201.00	3451.00
	(467.29)	(472.21)	(473.76)	(471.32)			
Observations	2,455	2,455	2,455	7,365	7,365	7,365	7,365

Note: Diet quality: calorie from nutritious non-staples cultivated by the household; Mean coefficients for values by survey year; Standard deviations in parentheses.

Table 4: Nutrient production and gaps by survey year

	Production				Nutrient production gap			
	2012	2014	2016	Pooled	2012	2014	2016	Pooled
Energy (kcal)	1011.77	2986.18	3167.26	2637.06	-1188.23	786.18	967.26	437.06
	(1,790.35)	(6,289.55)	(8,678.13)	(6,870.17)	(1,790.35)	(6,289.55)	(8,678.13)	(6,870.17)
Iron (mg)	50.12	132.63	143.46	119.39	40.76	122.31	132.94	109.19
	(102.81)	(244.42)	(557.27)	(392.16)	(102.84)	(243.99)	(557.19)	(391.98)
Thiamin (mg)	6.55	18.57	20.23	16.67	5.69	17.61	19.2	15.71
	(15.29)	(47.17)	(117.98)	(81.49)	(15.28)	(47.11)	(117.96)	(81.47)
Riboflavin (mg)	0.32	0.88	0.91	0.77	-0.58	-0.12	-0.16	-0.24
	(0.61)	(1.46)	(2.32)	(1.77)	(0.62)	(1.41)	(2.33)	(1.76)
Niacin (mg)	5.96	19.49	20.39	16.95	5.93	19.45	20.35	16.92
	(10.62)	(53.07)	(55.16)	(48.60)	(10.62)	(53.06)	(55.15)	(48.59)
Vitamin C (mg)	5.82	21.61	22.89	18.75	-48.53	-39.24	-43.13	-42.84
	(12.77)	(88.82)	(47.31)	(62.83)	(16.96)	(89.41)	(53.20)	(65.00)
Vitamin A (mcg)	4.62	25.05	17.04	17.37	-603.45	-649.09	-699.97	-660.25
	(13.55)	(257.43)	(93.01)	(168.54)	(108.05)	(322.19)	(290.08)	(278.04)
Observations	1,463	2,433	2,381	6,277	1,463	2,433	2,381	6,277

Note: Nutrient production gap is calculated as RDA - nutrient production; positive values indicate surplus; Mean coefficients for values by survey year; Standard deviations in parentheses.

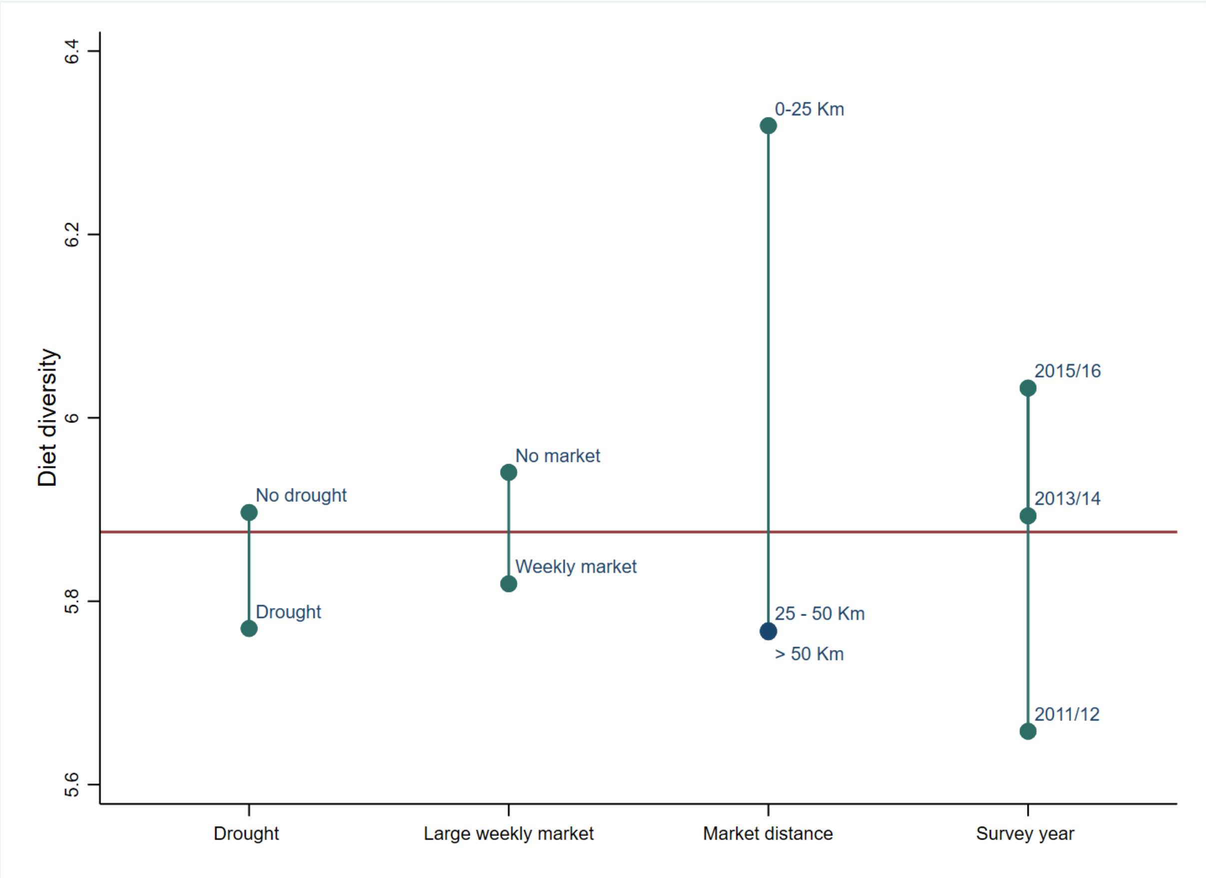

Figure 1: Diet diversity by groups

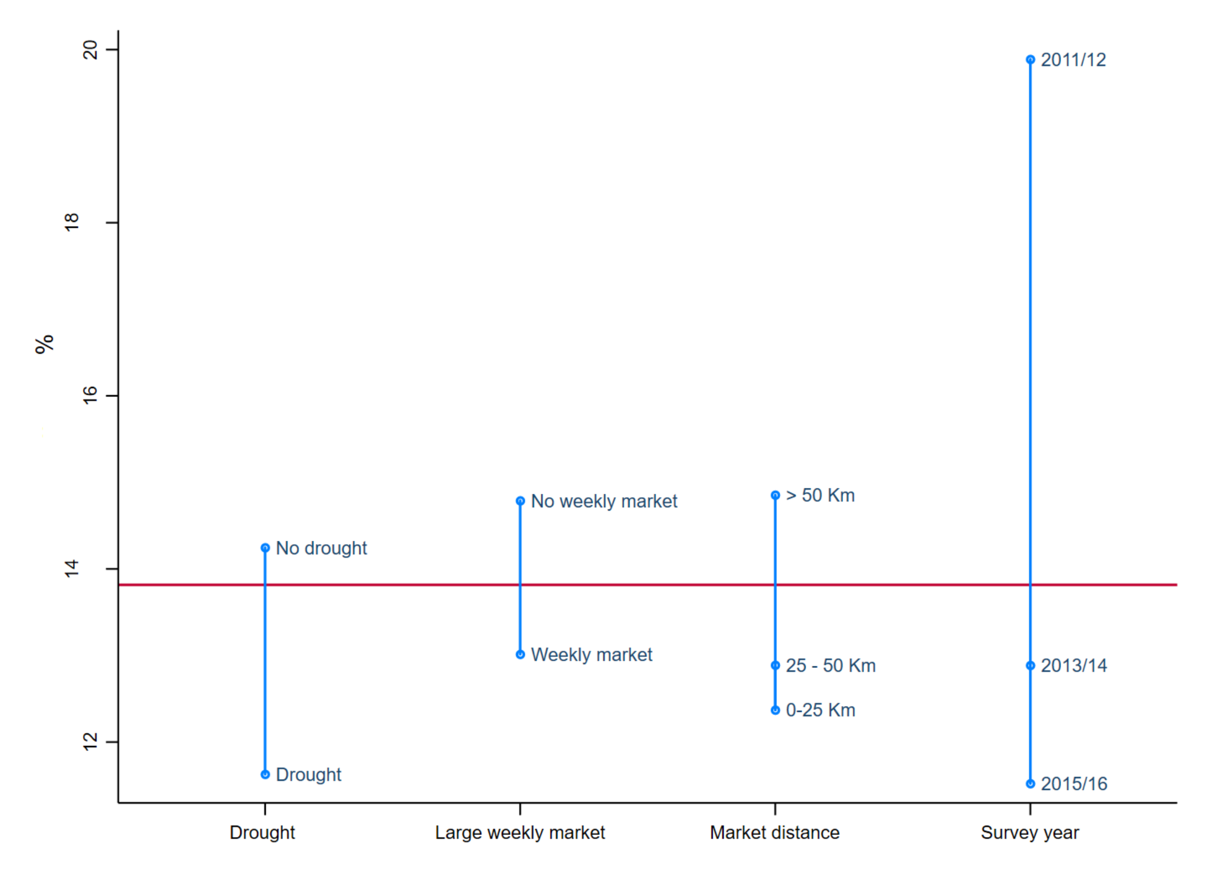

Figure 2: Diet quality by groups

Table 5: Descriptive statistics for child health and characteristics

	Survey year			**Pooled**			
	2012	**2014**	**2016**	**Mean**	**Median**	**Min.**	**Max.**
Child health (growth)							
Height-for-age Z-score	-1.789	-1.568	-1.604	-1.648	-1.720	-6.000	6.000
	(1.902)	(1.867)	(2.128)	(1.975)			
Weight-for-height Z-score	-0.317	-0.405	-0.238	-0.319	-0.350	-4.960	4.970
	(1.486)	(1.458)	(1.558)	(1.504)			
Stunted	0.479	0.41	0.437	0.44	0.000	0.000	1.000
	(0.500)	(0.492)	(0.496)	(0.496)			
Wasted	0.11	0.112	0.111	0.111	0.000	0.000	1.000
	(0.313)	(0.316)	(0.314)	(0.314)			
Stunted & wasted	0.038	0.032	0.033	0.034	0.000	0.000	1.000
	(0.192)	(0.176)	(0.179)	(0.182)			
Child characteristics							
Age (months)	32.34	32.86	33.37	32.88	34.000	0.000	59.000
	(15.37)	(15.36)	(15.48)	(15.41)			
Sex of child (1=Boy)	0.538	0.514	0.535	0.529	1.000	0.000	1.000
	(0.499)	(0.500)	(0.499)	(0.499)			
Parent education							
Mother is illiterate	0.686	0.707	0.674	0.689	1.000	0.000	1.000
	(0.464)	(0.455)	(0.469)	(0.463)			
Father is illiterate	0.419	0.436	0.416	0.424	0.000	0.000	1.000
	(0.493)	(0.496)	(0.493)	(0.494)			
Observations	2,280	2,223	2,004	6,507	6,507	6,507	6,507

Note: Mean coefficients for survey year values; Standard deviations in parentheses.

Table 6: Crop diversity, drought and child malnutrition by region

Region	**Drought (%)**	**Crop diversity**	**Stunting (%)**	**Wasting (%)**
Tigray	22.0%	4.68	48.19%	13.82%
Afar	36.6%	1.95	53.35%	12.80%
Amhara	14.4%	5.97	52.22%	10.06%
Oromia	16.1%	6.87	38.55%	10.79%
Somalie	57.9%	2.47	34.36%	22.08%
Benishangul	0.0%	7.24	34.50%	10.22%
SNNP	17.5%	6.67	46.78%	10.52%
Gambelia	3.3%	4.15	30.21%	14.59%
Harari	29.9%	5.17	38.99%	5.79%
Dire Dawa	47.5%	3.44	32.69%	10.88%
National	16.8%	6.38	44.02%	11.11%

Table 7: Crop diversity and shock exposure trends by region

Region	**Shock**			**Crop diversity**		
	2012	**2014**	**2016**	**2012**	**2014**	**2016**
Tigray	9.8%	13.9%	41.4%	4.80	4.56	4.67
Afar	15.0%	14.3%	88.5%	1.49	1.86	2.72
Amhara	5.3%	11.0%	24.7%	6.18	6.13	5.66
Oromia	13.0%	7.4%	25.9%	7.01	6.77	6.87
Somalie	57.3%	38.5%	75.7%	2.97	2.28	2.44
Benishangul	0.0%	0.0%	0.0%	7.61	7.05	6.95
SNNP	22.7%	3.6%	25.2%	6.83	6.69	6.49
Gambelia	0.0%	0.0%	8.3%	3.00	4.66	4.49
Harari	0.0%	0.4%	79.3%	4.85	5.33	5.31
Dire Dawa	23.6%	25.7%	85.3%	3.40	3.54	3.39
National	13.8%	8.2%	26.9%	6.54	6.37	6.25

Annex B: Correlation and regression analysis results

Table 8: Correlation between child growth and household diets

	HAZ score	WHZ score	Stunted	Wasted	Diet diversity
WHZ score	-0.279***				
Stunted	-0.769***	0.202***			
Wasted	0.124***	-0.613***	-0.068***		
Diet diversity	0.099***	0.004	-0.110***	-0.034**	
Food consumption	0.035**	-0.012	-0.034**	0.012	0.215***

Note: HAZ score = Height-for-age Z-score; WHZ score=Weight-for-height Z-score; Food consumption is total consumption expenditure on food; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 9: Correlation between child growth and crop diversity

	HAZ score	WHZ score	Stunted	Wasted
Count index	0.026*	0.025*	-0.036***	-0.028**
Crop groups	0.019	0.005	-0.023*	0
Shannon-Weaver	0.017	0.012	-0.008	-0.013
Composite entropy	0.004	0.005	0.01	-0.007

Note: HAZ score = Height-for-age Z-score; WHZ score=Weight-for-height Z-score; Crop groups refers to number of crop groups; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

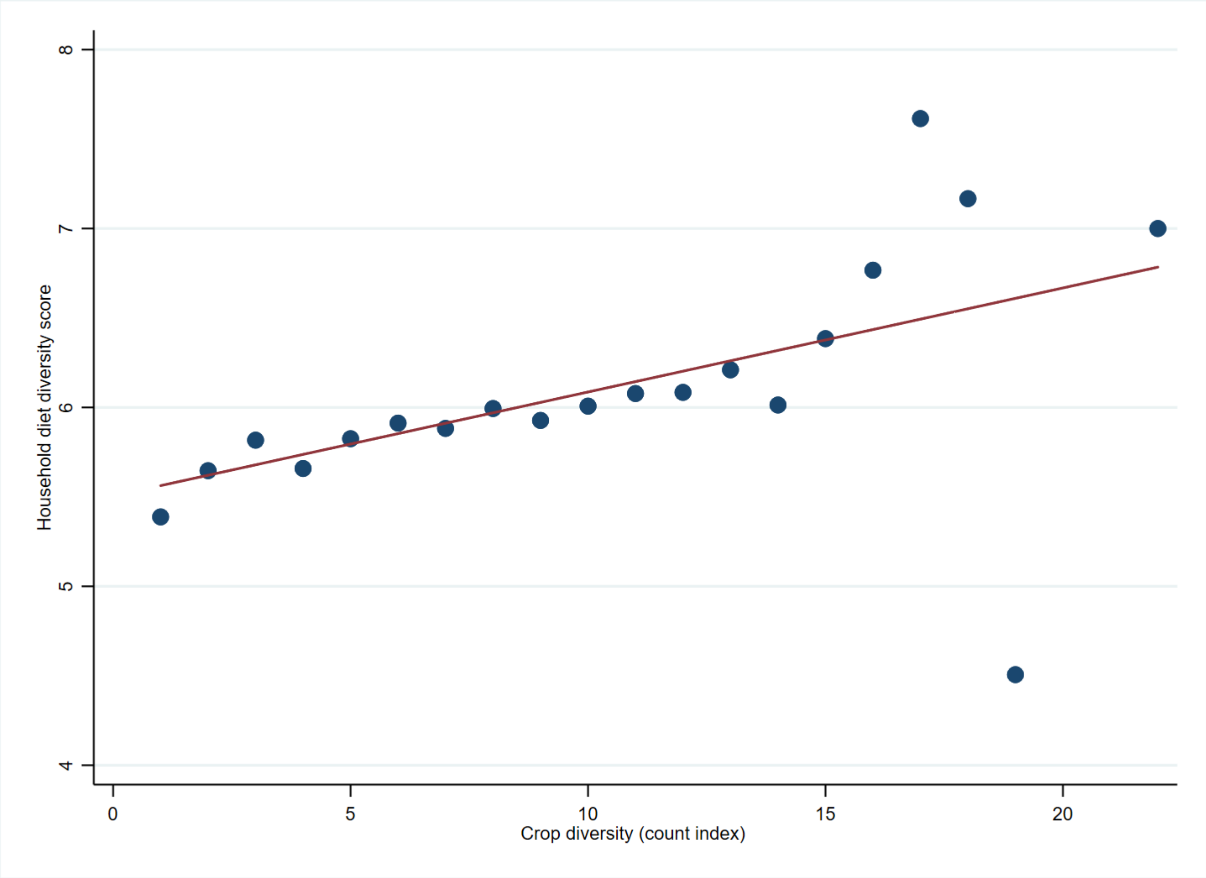

Figure 3: Diet diversity and count index

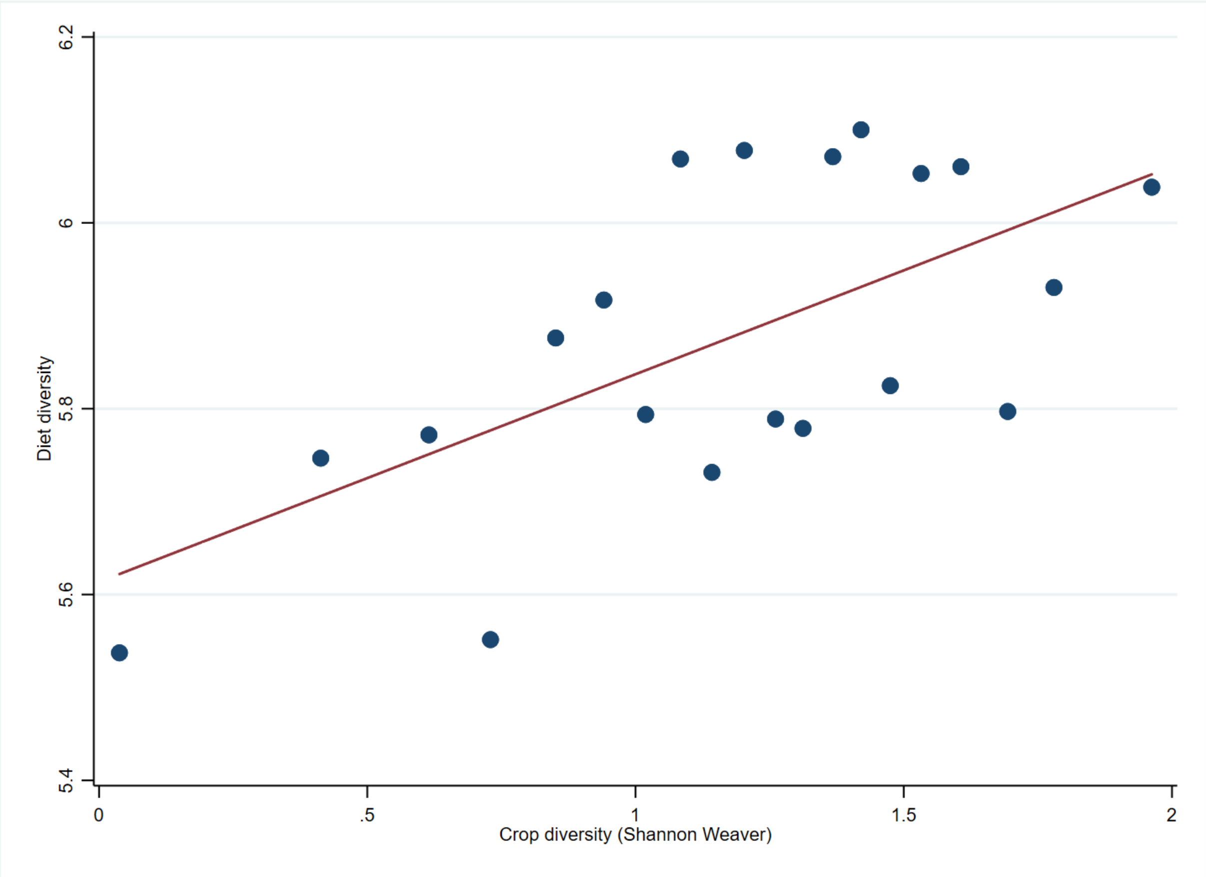

Figure 4: Diet diversity and Shannon index

Table 10: Impacts of crop diversity on child growth: Additional results

	Count index	**Crop groups**	**Shannon index**	**Composite entropy**
Pooled OLS IV				
(1) Height-for-age Z-score	0.012	0.081*	0.226*	0.638*
	(0.017)	(0.044)	(0.127)	(0.348)
(2) Weight-for-height Z-score	0.022*	0.077**	0.270***	0.899***
	(0.013)	(0.033)	(0.096)	(0.263)
Pooled probit IV				
(3) Stunting	-0.011	-0.066*	-0.142	-0.332
	(0.014)	(0.034)	(0.101)	(0.272)
(4) Wasting	-0.033**	-0.099***	-0.315***	-0.903***
	(0.016)	(0.038)	(0.121)	(0.323)

Note: All regressions include controls, region and time fixed effects; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Annex C: Heterogeneous effects of crop diversity

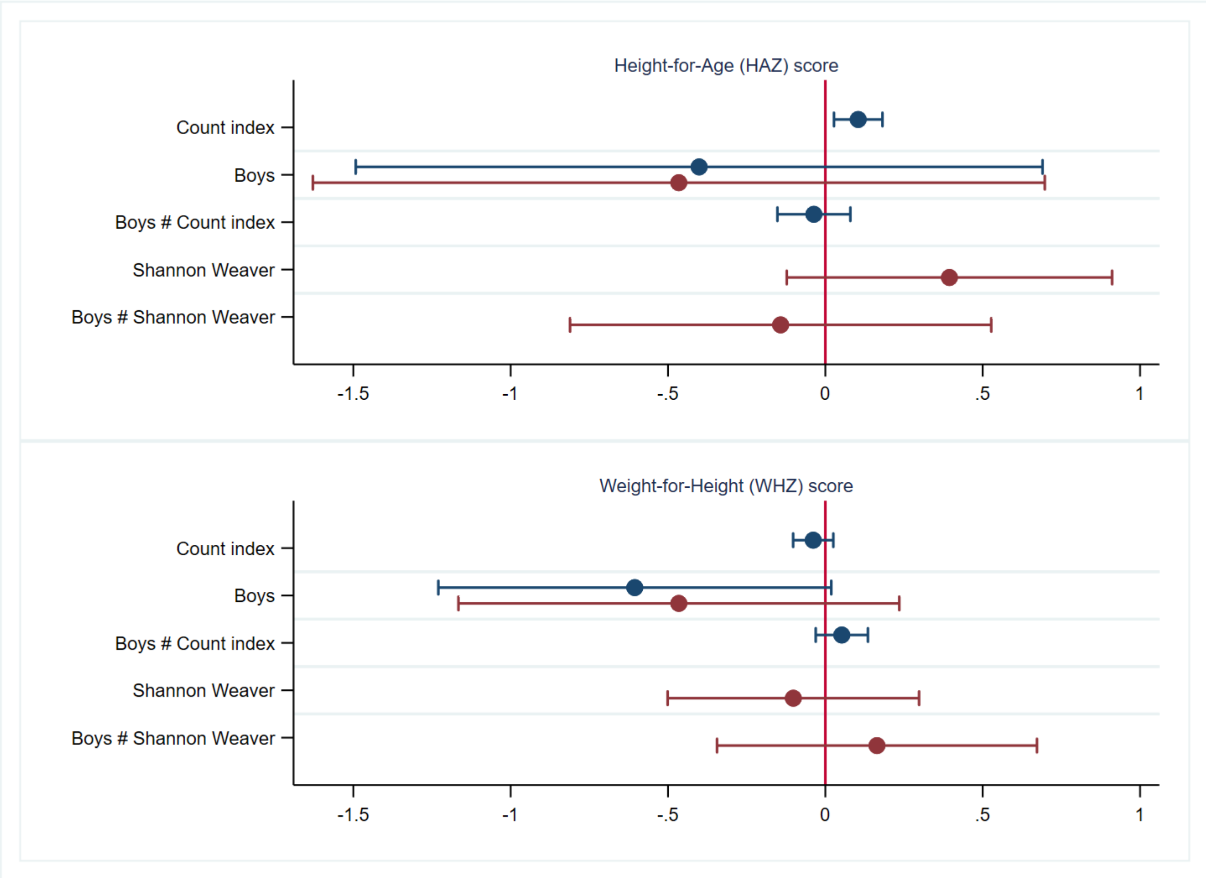

Figure 5: Child growth effects of crop diversity by sex of child

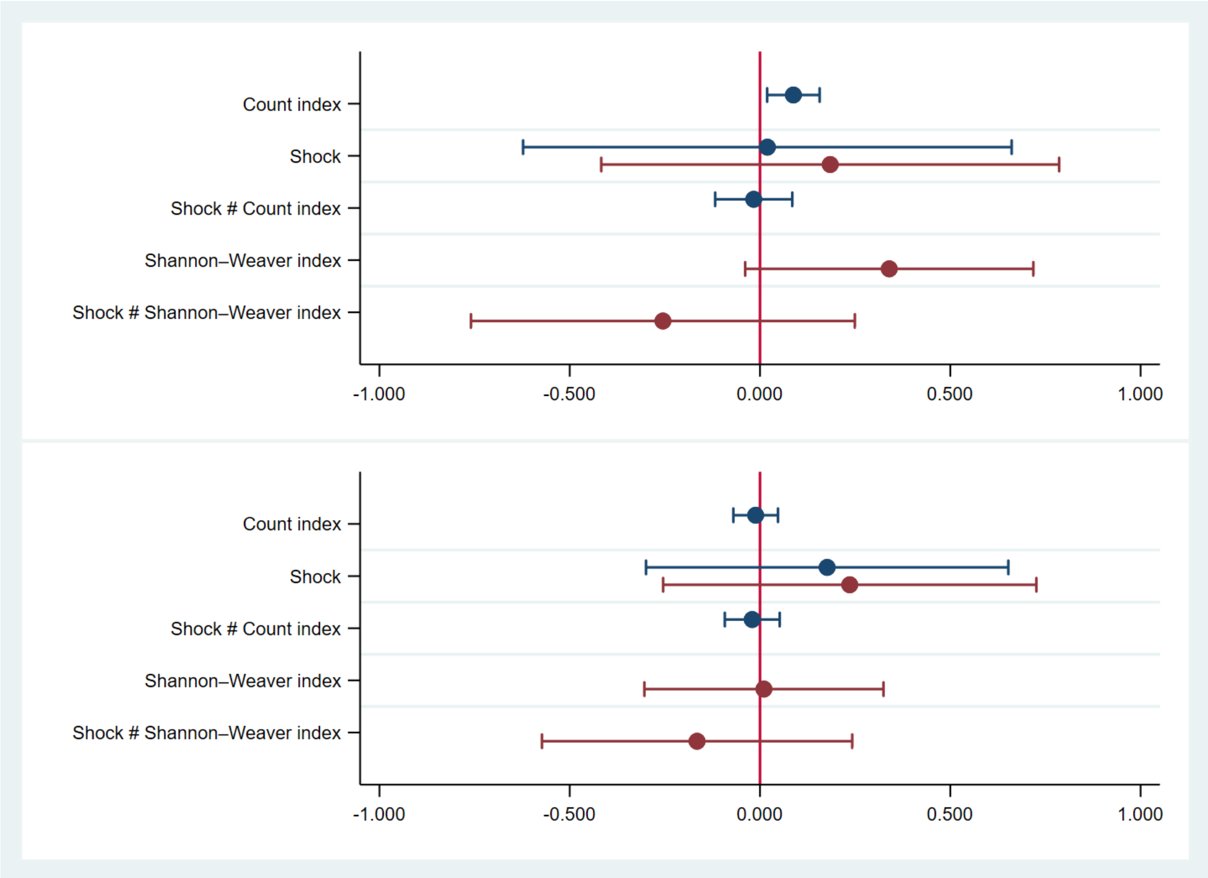

Figure 6: Child growth effects of crop diversity by drought exposure

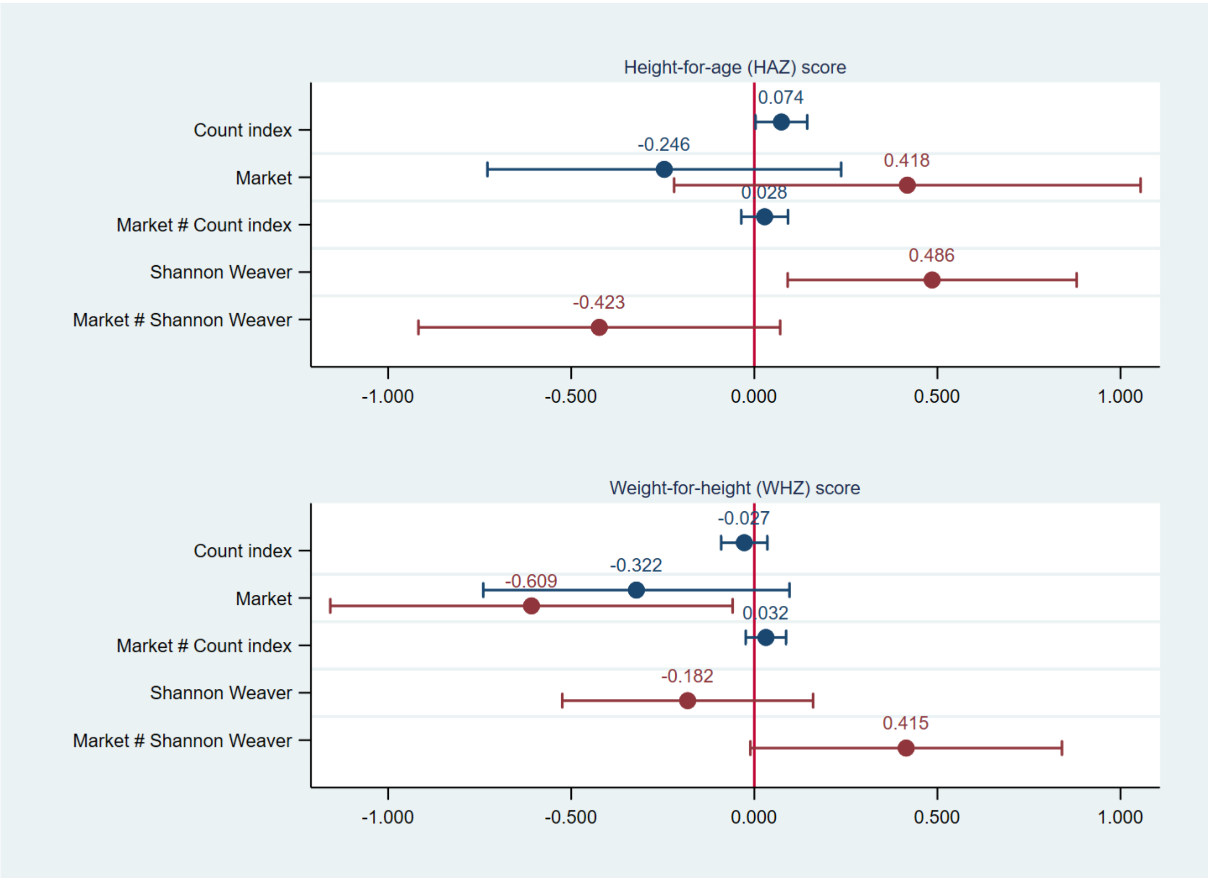

Figure 7: Child growth effects of crop diversity by market