Crop Diversification, Household Nutrition and Child Growth: Empirical Evidence from Ethiopia

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By

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Abstract

Recently, there has been a resurgence of interest in crop diversification as a strategy to deal with a variety of issues, including malnutrition in the context of a changing climate and 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 diversification on child growth using panel survey data, combined with historical weather data. The study finds that crop diversification has a positive but small impact on child growth. Results from analysis of heterogeneous effects show that the positive effects are more pronounced in areas with limited access to markets. The study demonstrates that the positive effects of crop diversification on child growth could be mediated through its positive impacts on household diet diversity, diet quality and income.

Keywords*:* Crop diversification; Child growth; Household diets; Nutrient production gap; Ethiopia

JEL codes: I15, J13, Q16

1. Introduction

Despite some progress in reducing 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., 2021; 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. Given that many of the undernourished people are smallholder farmers and majority of the malnourished children are from rural areas, the question remains how to leverage the benefit of agriculture to improve nutrition (Sibhatu et al., 2018).

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 only a 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 a 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 in 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 improve human health and nutrition by increasing investment in agriculture (Dillon et al., 2018). The United Nation's Sustainable Development Goals (SDGs) accentuate that increasing crop diversification 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 low-income 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 diversification and dietary diversity (Dillon et al., 2015; Hirvonen and Hoddinott, 2017; Jones et al., 2014; Jones, 2017b,a; Sibhatu et al., 2015; Snapp and Fisher, 2015) and (ii) studies that link production diversification 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 diversification, dietary diversity and/or nutrition in developing country farm households reports that the evidence regarding the impact of farm production diversification 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 seeks to make important contributions to the literature by illuminating the link between agriculture and nutrition in the small farm sector in a developing country context using Ethiopia as a case study. First, most studies rely on cross-sectional data, which limits the ability to account for unobserved endogeneity (Lovo and Veronesi, 2019; Sibhatu et al., 2018). This study utilizes rich panel survey data combined with historical weather data that allows one 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 enables capturing the dynamics in crop diversification and its implications on nutrition. Second, unlike previous studies that focus on the link between production diversification and nutrition either at the household or individual level, this study considers the link at both levels. Third, existing studies rely on a single or few measures of crop diversification and nutrition. To address this gap, the study measures the level of crop diversification using various crop diversification indices that also allow one to study the different aspects of multi-cropping regimes and to test the sensitivity of results to different crop diversification measures. The nutrition outcome indicators include household nutrient production gaps, diet quality, food intake, diet diversity, and child growth.[4]

The other contribution of the study stems from the estimation of the heterogeneous effect of crop diversification on child growth by gender of the child, market access and exposure to drought shocks. In relation to this, the study also explores if drought shocks have a negative effect on child growth and if crop diversification mitigates the effect of drought shocks. As an addition to the few studies that employed instrumental variables IV methods beyond simple statistical methods (Sibhatu et al., 2018), this study utilizes panel data IV methods that enable producing robust causal inference by addressing the econometric challenges of potential endogeneity and reverse causality. The study exploits the exogenous variation in crop diversification decisions due to network externality or neighbourhood effects to instrument crop diversification. The rich nature of the data and the selected empirical strategy helps resolve disagreements in the literature by addressing fundamental issues regarding the exogeneity and measurement of crop diversification and its impact on nutrition.

In addition to contributions to the literature, the findings of the study 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 study provides 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 that could help in targeting nutrition improving policies and interventions. Overall, the findings of the study provide useful insights for evidence-enhanced decision-making regarding nutrition interventions and to influence the multi-sectoral approach in addressing the challenges of child malnutrition.

The rest of this paper is structured as follows. Section 2 presents a brief of the study country context. Section 3 presents a simplified conceptual 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 and highlights the policy implications of the findings.

2. Country Context

Ethiopia is largely an agricultural country. The agriculture sector employs about 70% of the labour 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 Sub-Saharan Africa (SSA) countries, climatic variability and extremes have serious implications for a significant proportion (85%) of the population that resides in rural Ethiopia.[5]

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 malnutrition alone 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. In this regard, the government has been implementing different strategies and programmes as part of its national development agenda.

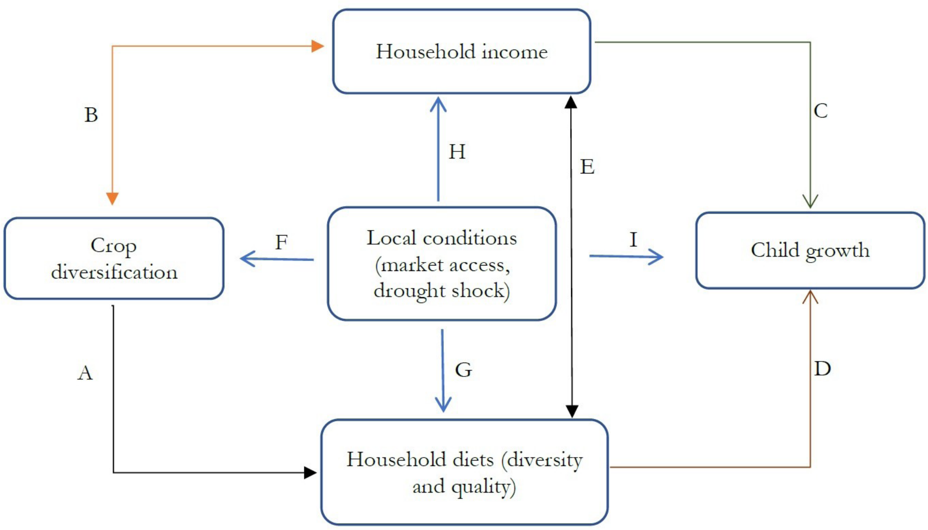
While the food and agriculture sector has fueled economic growth in the country, there is now an increasing interest to leverage agriculture to improve nutrition. This is emphasized in the National Nutrition Plan (NNP) that engages agriculture for improving nutrition and the Growth and Transformation Plan (GTP) II, which emphasizes addressing malnutrition (Beyero et al., 2015). The country has also established various strategies and programmes to mainstream nutrition in agriculture (Beyero et al., 2015). Given that children's diets in Ethiopia are among the least diverse in the world, the Government of Ethiopia has committed to improving the nutritional status of children. For this purpose, the Government of Ethiopia has developed the third National Nutrition Programme (2016–2020) to drive policy actions across multiple key sectors, including health and agriculture. The programme also calls for the promotion of nutrition-sensitive interventions to improve child dietary diversity and, consequently, reduce stunting. The previous NNPs focused on integration and coordination of nutrition-specific interventions that addressed the immediate and underlying causes of sub-optimal growth and development and malnutrition. The National Food and Nutrition Policy (NFP) was endorsed by the Council of Ministers in 2018 based on the global conceptual framework for nutrition security as a change model to address the existing causes of nutrition insecurity at various levels. The policy framework focuses on short, medium, and long-term strategies in an integrated way to address the different layers of nutrition problems. The government has been implementing the Sustainable Undernutrition Reduction in Ethiopia (SURE) programme, the first Government-led integrated health and agriculture sector programme for improving nutrition among children. The Seqota Declaration (SD) launched in 2015 building on the NNP is a high-level commitment of the Government of Ethiopia to end stunting in children under two years by 2030.

Because of the challenges of climate change and malnutrition, there is an increasing interest to adopt agricultural practices such as production of diverse crops that are both climate- and nutrition-smart. Ethiopia is home to 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 of a variety of foods across the country (Hirvonen and Hoddinott, 2017). Therefore, Ethiopia makes a good case to test whether and how increased crop diversification affects household nutrition and child growth.

3. Conceptual Framework

Economic theory asserts that the main driving forces that lead to diversification are the desire for risk management and income smoothing (Barrett et al., 2001; Morduch, 1995; Rosenzweig, 1988). Crop diversification reduces the risk of the return of crop production portfolio by spreading risk across the crops in the portfolio (Benin et al., 2004; Just, 1975). Subsistence farmers often diversify their production to protect themselves from food price risks, downside risks, or lack of food in local markets. The desire for profit maximization and risk minimization are, however, not the only stimuli for diversification in agricultural production (Omamo, 1998; Pope and Prescott, 1980). In rural economies burdened by market imperfections and poorly developed and less integrated markets, crop diversification decisions may also be motivated by nutritional considerations (Bezabih and Di Falco, 2012; Hoddinott et al., 2015; Pellegrini and Tasciotti, 2014). This study utilizes a simplified conceptual framework drawing on the work of Lovo and Veronesi (2019) to guide the analysis of the link between crop diversification and child growth (Figure 1). It considers two sets of mechanisms: (i) household diet diversity and quality, and (ii) crop income, among other possible mechanisms (Ecker and Qaim, 2011; Gó mez et al., 2013; Sibhatu et al., 2015).

Figure 1: The link from crop diversification to child growth



Source: Based on Lovo and Veronesi (2019)

3.1 Household Diets

Regarding the first mechanism (link A in Figure 1), previous empirical evidence provides support for a direct relationship between agricultural diversification and dietary diversity and quality (Dillon et al., 2015; 2018; Hirvonen and Hoddinott, 2017). Given that smallholder farmers typically consume most of what they produce, increasing production diversity could improve household diets and nutrition (Sibhatu et al., 2018; Jones, 2017b, a). For subsistence households, the choice of agricultural outputs largely determines the diversity and quality of their diets.

This mechanism or pathway is likely to be more effective when households have limited access to markets and are exposed to climate variability and extremes (Ecker and Qaim, 2011; Lovo and Veronesi, 2019). Incomplete markets mean that households cannot easily insure themselves from exogenous shocks, and they cannot depend on markets to fully satisfy their food demand. In particular, the absence of an output market is a condition that determines the non-separability between production and consumption decisions of farm households (de Janvry et al., 1991; Singh et al., 1986; Taylor and Adelman, 2003). This is an indication that increased agricultural diversification can directly influence nutrition (Carletto et al., 2017; Hoddinott et al., 2015). The relationship between crop diversification and household diets is expected to diminish as households get more access to markets (Lovo and Veronesi, 2019). In the absence of markets, diversification of production becomes a more prominent determinant of dietary diversity.

The pathway from crop diversification to child health outcomes is explained by the effect of dietary diversity (link D in Figure 1). The relationship between dietary diversity and child growth outcomes has been investigated separately in the literature. Studies show that dietary diversity plays a crucial role in children's health status in low-income countries such as those in SSA (Aboagye et al., 2021; Arimond and Ruel, 2004). These studies document a significant association between dietary diversity and children's undernutrition outcomes, including stunting, wasting, and height-for-age Z-scores (HAZ). Dietary diversity is also found to reflect diet quality and nutritional status in several developing countries (Jones et al., 2014). This is partly explained by the positive relationship between dietary diversity and micronutrient intakes (Lovo and Veronesi, 2019).

3.2 Income Mechanism

The second mechanism that relates crop diversification to child growth is the income effect (links B and C in Figure 1). Households might diversify their production for income purposes depending on their market orientation and market access. The resulting income would allow households to purchase food and nutrients from markets, ultimately improving the quality of diets and reducing household micronutrient consumption gaps. The relationship between crop diversification and income is, a priori, ambiguous (Lovo and Veronesi, 2019). Diversification reduces the overall production risk and can help households cope better with negative weather or price shocks (Lovo and Veronesi, 2019). It would improve the capacity of local food systems to produce diverse crops in the face of environmental shocks (Global Panel, 2015). It can also allow farmers to produce crops that can be sold at different times during the year (Di Falco and Perrings, 2005). Diversification can have opposite (negative) effects on income due to possible foregone benefits from specialization (opportunity cost of diversification). 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, however, high transaction costs may limit the attractiveness of crop specialization to enable households to earn more income and maximize profit (Goetz, 1993). Reliance on monocropping contributes to low agricultural productivity and exposes rural households to production and price risks (Tesfaye and Tirivayi, 2020). Few studies relate crop diversification to household income in the literature and find a positive association between the two (Pellegrini and Tasciotti, 2014; Michler and Josephson, 2017). Considering link C, Lovo and Veronesi (2019) document a positive association between income and child growth outcomes.

3.3 Other Conditions

Crop choices are likely to be driven by profit considerations and consumption-related factors in semi-subsistence economies. Profit considerations are determined by farm-specific conditions such as land, labour, agroecological conditions, and access to input and output markets. Therefore, the possible interaction between production choices, income and consumption, and the presence of unobservable factors that can affect both crop choices and child growth would complicate establishing a causal relationship between crop diversification and child growth. For example, parents' skills, health, decision-making responsibility, and awareness about crop varieties and nutrition would affect both crop diversification and child growth outcomes. Hirvonen et al. (2017), for example, find that nutrition knowledge leads to considerable improvements in children's diet in areas with good market access. The role of the gender of the decision-maker in terms of crop choices is also likely to matter. As documented in Smale et al. (2015), there is a close relationship between women's diets and the diets of their children, and this is likely to affect their crop choices when in charge of agricultural decisions.

Agroecological and local market conditions could influence crop choices (link F in Figure 1). Geographic and agroecological conditions might limit the benefits of crop choices, for instance that of specializing in cash crops (Orr, 2000). Another important determinant of crop choices is access to inputs such as seeds. Better access to seeds could be correlated with both greater crop variety and better access to other infrastructure or information, and therefore better child growth outcomes (link I in Figure 1). Overall, local conditions determine the availability of crop varieties at the local level. Thus, crop diversification at the household level can also influence children's growth by capturing the local availability of crops if neighbours' choices are correlated (link G in Figure 1). A positive correlation is more likely to emerge in areas where markets are small and less connected with national or sub-national food markets (Ecker and Qaim, 2011). The empirical analysis that follows attempts to disentangle the effects of crop diversification on child health, with a greater focus on household diets and income mechanisms.

4. Empirical Strategy

4.1 Estimating Impacts on Child Growth

The relationship between crop diversity and child growth outcomes (stunting and wasting) is represented using the following model:[6]

$$y_{it} = \beta D_{it} + \varphi X_{it} + a_i + \upsilon_{it} \quad (1)$$

where i indexes the child and t denotes time. y_{it} denotes the child growth outcomes and D_{it} is a measure of crop diversification. X is a vector of observed household or child characteristics. The household characteristics included in X include household demographics and composition (household size, gender of head, age of head, education of head), wealth indicators (land holding, livestock holding, asset index, non-agribusiness ownership, consumption expenditure), housing features (improved water source, improved sanitation, electricity access), proximity to services (health post, roads, markets), and climate and shocks (see Table A3 in Appendix A for a summary of the variables).[7] Moreover, region and time dummies are introduced to control for potentially omitted variables that are unobserved in the dataset, including common aggregated shocks, agricultural market integration, price expectations, and temporal and spatial differences in infrastructure and policy changes (Dillon et al., 2015; Lovo and Veronesi, 2019). The child growth outcome specifications control for child characteristics (child age and sex) and parental education in addition to the household characteristics (see Table A3 in Appendix A). The choice of the control variables is guided by theory, empirical studies (Dillon et al., 2015; Lovo and Veronesi, 2019), and data availability. a_i and υ_{it} are the individual-specific fixed effects and the idiosyncratic error term, respectively. β is the parameter of interest that denotes the impact of crop diversification on child growth.

Estimating the impact of crop diversity on child growth 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, and entrepreneurial motives) that lead to selection bias in a household's crop diversification decisions (the crop choice decision and how much land to allocate to the different crops). The second source of endogeneity comes from time-varying unobserved shocks that would simultaneously affect crop diversification and child growth. The source of such unobserved endogeneity includes 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 under-estimate the supposed true effect of crop diversification.

The impact of crop diversification on child growth outcomes is estimated using instrumental variables (IV) methods to address the endogeneity issues discussed above. With panel data available, the common approach is the 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, the application of the FE-IV could help to control for unobserved endogeneity due to time-varying unobservable factors and potential reverse causality. However, the FE-IV method is not straightforward to apply for nonlinear models (binary child growth outcomes in this case). Fixed effects limited dependent variable models are also not appropriate because 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). An important concern is that households might produce similar crops over time, and that would result in less variation in crop diversification. The descriptive statistics presented in Table 1 also show the presence of little variation in the crop diversification measures during the survey periods. Therefore, the results from the FE or LPM IV methods might lead to a conclusion that the effect of crop diversification on the outcomes is insignificant. To address this issue, the pooled probit IV is used as the preferred approach to estimate the impacts.

The pooled probit IV method used to estimate equation 1 involves estimating the crop diversification equation in the first stage as follows:

$$D_{it} = \alpha Z_{it} + c_i + \varepsilon_{it} \tag{2}$$

where D_{it} is a measure of crop diversification; Z_{it} is a vector of control variables that include household characteristics discussed above (in equation 1). Z_{it} also includes the instrumental variable (IV) for crop diversification. To address the issue of endogeneity of crop diversification, the study uses insights from social networks analysis that demonstrates the importance of social networks and neighbourhood effects in production decisions. The average village crop diversification or the leave-out mean crop diversification (excluding the household under consideration) is used as an instrument for household crop diversification. The basic argument is that household's production decisions (e.g., crop choices and land allocation) are likely to be influenced by the decision of neighbouring 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. However, the leave-out mean diversification at the household level is expected not to be correlated with the household unobserved heterogeneity and child growth (Asfaw et al., 2019; Wooldridge, 2010).[8] The relevance of the IV is tested using the first stage results (Table A7 in Appendix B), which show the coefficient of the village level crop diversification variable to be positive and statistically significant. The weak identification test statistics (Kleibergen-Paap Wald test) are higher than the Stock-Yogo weak ID test critical values. The test rejects the null hypothesis of a weak instrument in the first-stage equations. The test results suggest that the instrument can be excluded from the second stage regressions. Overall, the test results confirm the strength and validity of the instrument. c_i and ε_{it} are the individual-specific effects and the idiosyncratic error term, respectively. In addition to the pooled probit IV approach, equations 2 and 1 are estimated jointly in a three-step (with the conditional mixed process or cmp) framework where in the first step crop diversification is estimated as a function of the IV and household level controls (Z_{it}). In the second stage, the estimated crop diversification is allowed to affect household diets and crop income. In the third stage, the estimated household diet and crop income are allowed to affect child growth (Lovo and Veronesi, 2019).[9]

4.2 Heterogeneous Effects

Crop diversification would exert heterogeneous child growth 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 child growth effects of crop diversification will be different in different agro-ecologies and areas experiencing rainfall shortage or surplus. Heterogeneity may also exist concerning non-climate variables such as market isolation and gender of the child. Therefore, unpacking possible heterogeneous effects of crop diversification across different groups is germane to provide evidence for effective targeting of interventions.

Heterogeneous effects can be estimated by interacting crop diversification with a variable that captures the heterogeneity of interest. Alternatively, they can be estimated by running separate regressions for the different sub-samples of the data. In this study, the heterogeneous effects of crop diversification are estimated by running separate regressions by market access, drought shock, or gender.

4.3 Impact Pathways

As discussed in section 3, two mechanisms could explain the relationship between crop diversification and child growth: (i) household diet diversity and diet quality, and (ii) crop income. To test the mechanisms, the link between crop diversification and child growth is illustrated as a system of equations that encompasses diet diversity, diet quality, and income as follows:

$$y_1 = f_1(Z_1) + e_1$$

$$y_2 = f_2(y_1; Z_2) + e_2 \quad y_3 = f_3(y_2; Z_3) + e_3 \tag{3}$$

where y_1 is crop diversification, y_2 is household diet diversity, diet quality, or income, and y_3 is child growth outcome (stunting/wasting). Z_1 represents control variables included in the crop diversification equation (Z_{it} in equation 2), Z_2 includes household characteristics, and Z_3 includes household and child characteristics (X_{it} in equation 1); $f(:)$ are the link functions. Equation 3 is estimated as a three-step model where crop diversification, the household level outcomes (diet diversity, diet quality, and income), and the child growth outcomes are jointly estimated in three steps. This allows the estimated diet diversity, diet quality, and income (as a function of crop diversification) are allowed to affect the child growth outcomes (Stunting and Wasting). The equation is estimated within a conditional mixed-process (cmp) framework, which helps to take account of possible correlations between the errors and therefore improve efficiency (Lovo and Veronesi, 2019).

5. Data and Descriptive Statistics

5.1 Household Survey and Rainfall Data

The data for this study come from the Ethiopian Socio-economic Survey (ESS) administered under the Living Standards Measurement Study-Integrated Surveys on Agriculture (LSMS-ISA) of the World Bank in collaboration with the Central Statistical Agency (CSA) of Ethiopia.[10] The survey collects data on household and children over the period 2011-2016 in three waves (2011/12, 2013/14 and 2015/16). Detailed information is collected on household demographics, anthropometric measurement for children, housing conditions, food and non-food consumption expenditure, food security, and shocks, among others. ESS has an agriculture module that captures detailed information on post-planting and post-harvest activities, including landholding, crop production and disposition, and livestock ownership. The survey also solicited community-level information on access to services such as infrastructure, markets, and health services. This research is restricted to the rural domain of the ESS.

The household location in ESS is geo-referenced, which enables linking the household data with geographic and climate datasets at the enumeration area (EA). Using the geo-references, historical rainfall data are extracted 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 insitu station data to create a gridded rainfall time series (Funk et al., 2015; Michler et al., 2018). From the dataset, rainfall data are extracted for 15 years from 2001 to 2015. This enables the calculation of historical average and standard deviation of rainfall, a proxy for long-term rainfall variability. Annual temperature data are readily available at the household level as part of the ESS.

5.2 Crop Diversification Measures and Pattern

Crop diversity is measured using interspecific crop diversity indices: the number of crop groups (richness) and the Shannon-Weaver. The number of crop groups, like the commonly used crop count index or the number of crops, is a measure of 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 the equal contribution of the crop groups 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. Two additional crop diversification measures are used to show the crop diversification patterns: the number of crops and the Composite entropy index. 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 A1 in Appendix A provides the definition and computation formula for the indices.

Appendix Table A1 summarizes the crop diversification pattern. The Count index shows that households grow about 6 crops, with a slight variation during the survey period. 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, an indication that land is not equally distributed to different crops cultivated by the households. The average Composite entropy index is 0.54, which indicates that rural households operate diversified farms. Overall, the results show that crop diversification tends to slightly decrease between 2012 and 2016. There is also regional heterogeneity in crop diversification. While Benishangul Gumuz, Oromiya and SNNPR tend to have higher crop diversification (above the national average in all survey years), Afar and Somali, the predominantly pastoral regions, appear to have low crop diversification (Table A2 in Appendix A).

Table 1: Crop diversification pattern

		Survey year				*Pooled*	
	2012	2014	2016	Mean	Median	Minimum	Maximum
Number of crops	6.545 (3.352)	6.370 (3.115)	6.252 (3.467)	6.377 (3.321)	6.00	1.00	22.0
Crop groups	3.318 (1.252)	3.282 (1.252)	3.163 (1.225)	3.248 (1.244)	3.00	1.00	6.00
Shannon index	1.214 (0.467)	1.185 (0.469)	1.127 (0.467)	1.172 (0.469)	1.232	0.00	2.337
Composite entropy index	0.552 (0.172)	0.542 (0.176)	0.522 (0.178)	0.537 (0.176)	0.577	0.00	0.877
Observations	1,385	1,762	1,579	4,726	4,726	4,726	4,726

Note: Mean coefficients; Standard deviations in parentheses.

To better understand the crop choice patterns of the households, the study presents the share of households cultivating a given crop are (Table A5 in Appendix A) and the share of cultivated land under the crops cultivated by the households (Table A6 in

Appendix A). According to Table A5, the major cereal crops are maize, teff, sorghum, wheat, and barley that are cultivated by more than 30% of the households. The share of cultivated land under these cereals is also higher than other crops cultivated by the households. Overall, about 91% of the households cultivate cereal crops that capture more than 60% of the total cultivated land (Table A6 in Appendix A). Vegetables and root crops appear to be the second important crop groups cultivated by 62% of the households and account for 11% of the cultivated land. Except for enset (false banana), which is the most important root crop, the share of land allocated to other vegetables and root crops is less than 1%. Traditional cash crops (such as coffee, chat, cotton, tobacco, etc) come third in terms of importance; they are cultivated by 53% of the households and account for about 10% of the cultivated area. Regarding fruits, banana, mangoes, and avocados are cultivated by many households. Legumes are cultivated by about 48% of the households and capture about 8% of the cultivated land. Among legumes, horse beans, haricot bean and field pea are cultivated by a larger share of the households. Overall, the data shows that the agricultural households' crop production portfolio includes cereals, cash crops, vegetables and root crops.

5.3 Outcome Measures

5.3.1 Child growth

Child growth or malnutrition outcomes are based on child anthropometric measures that are calculated using measures of height and weight for all children under 5 years of age obtained from the ESS (LSMS-ISA) data. First, height-for-age (HAZ) and weight-for-height (WHZ) z-scores are computed. 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 2 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 is still 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 has increased to 43.7% in 2016. The proportion of wasted children was around 11%, with no change during the 2012-2016 period.. The data also show that 3.4% of children under 5 years of age are both stunted and wasted, an indication of the co-existence of high risks of stunting and wasting in children.

Table 2: Descriptive statistics: Child growth outcomes

	Survey year			Pooled			
	2012	2014	2016	Mean	Median	Min.	Max.
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 and wasted	0.038	0.032	0.033	0.034	0.000	0.000	1.000
	(0.192)	(0.176)	(0.179)	(0.182)			
Observations	1,385	1,762	1,579	4,726	4,726	4,726	4,726

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

By exploiting the panel nature of the data and using a transition matrix, the study depicts the persistence of child malnutrition. 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 the non-stunted children in one period become stunted in the next period, an indication of a high risk of stunting. On average, about 28% of stunted children in one period become non-stunted in the next period. Overall, the results suggest the presence of dramatic path dependence in child malnutrition and mobility of children in and out of stunting.

5.3.2 Diet diversity, quality, and income

Diet diversity is an intermediate nutrition outcome indicator and proxy for food access and diet quality (Jones et al., 2014). An indicator of dietary diversity score (DDS) is developed for each household from 12 food groups consumed in a week before the survey.[11] Additional outcome measures are food (energy) production per adult equivalent per day and diet quality, which is calculated as the proportion of calories obtained from nutritious non-staples cultivated by the household.

Summary statistics for diet diversity, diet quality, and income are provided in Table 3. Households on average consume 6 food items (out of 12) in a week, an indication that rural Ethiopians consume a diverse diet. Diet diversity slightly increased between 2012 and 2016. 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. This suggests that rural Ethiopians' diet is dominated by non-nutritious staples. The average crop income increased between 2012 and 2016. However, there is high inequality among rural households as indicated by high standard deviations.

Table 3: Descriptive statistics: Household diets and income

	Survey year			*Pooled*			
	2012	2014	2016	Mean	Median	Min.	Max.
Dietary diversity	5.66 (1.80)	5.89 (1.72)	6.03 (1.67)	5.88 (1.73)	6.00	0.00	12.00
Diet quality	0.20 (0.34)	0.13 (0.19)	0.12 (0.19)	0.14 (0.23)	0.03	0.00	1.00
Crop income ('000)	2.39 (5.23)	2.47 (3.26)	2.98 (4.73)	2.65 (4.43)	1.22	-1.39	21.98
Observations	1,385	1,762	1,579	4,726	4,726	4,726	4,726

Note: Diet quality: calorie from nutritious non-staples cultivated by the household; Crop income is in thousands Birr. Mean coefficients reported, standard deviations in parentheses.

5.3.3 Food intake and production nutrient gaps

Production nutrient gaps (surplus or deficit) are calculated by comparing reported production of nutrients relative to recommended daily allowances (RDA). RDA refers to the household level total nutrient requirements calculated as the sum of the RDA of all members of the households. It is the level that meets 97.5% of the nutrient requirements and is used to assess the nutrient adequacy gaps at the household level (Dillon et al., 2018). 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). Household level estimates are obtained by aggregating the individual values. The energy and nutrient requirements of the households are calculated for each survey round year (2012, 2014 and 2016).

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. The total nutrient production by the household is calculated using the food composition table for Ethiopia, which provides nutrient values of food consumption items. First, nutrient values are assigned for food items listed in the production modules of the agriculture questionnaire. The total nutrient production amounts are then 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, energy intake gap from production is computed. All production amounts are converted to per adult equivalent daily amounts.

Table A4 in Appendix 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. Figure 1 (Appendix A) presents the proportion of households that met the required daily allowance (RDA) from nutrient production by survey year. The proportion of households that met Iron, thiamine and niacin requirements from production increased between 2012 and 2016. However, the proportion decreases for energy, riboflavin, vitamin C and vitamin A, at least during the survey periods. The main econometric analysis in this paper focuses on diet diversity, diet quality, and income as pathways for the child growth impacts of crop diversification. Table A9 in Appendix B provides the estimated impacts of crop diversification on calorie and nutrient production gaps.

6. Empirical Results

This section presents the main results on the relationship between crop diversification and child growth. The first part of the section presents the results on the impacts of crop diversification on child growth. This is followed by a discussion of the potential heterogeneous effects of crop diversification on child growth obtained by testing whether the effect differs by gender of the child, exposure to drought shock, and market access. The third part of the section discusses the impact pathways, focusing on the impacts of crop diversification on diet diversity, diet quality, and income, and the impact of the three variables on child growth.

6.1 Child Growth Effects of Crop Diversification

Table 4 presents the impact estimates of crop diversification on child growth outcomes obtained from alternative econometric specifications that allow estimating the direct impacts of crop diversification on child growth. Panel A of Table 4 provides the results obtained from the three-step framework (cmp), where crop diversification is estimated in the first stage. In the second stage, the estimated crop diversification is allowed to directly affect the child growth outcomes. The results show that the coefficients of both the number of crop groups and the Shannon index of crop diversification are negative and statistically significant. An increase in the number of crop groups cultivated by the household is associated with a reduction in child stunting and wasting by 2.5 and 1.8 percentage points, respectively. Likewise, a 1 unit increase in the Shannon index of crop diversification is associated with a reduction in stunting and wasting of 5.8 percentage points. The result implies that cultivating one more crop reduces the likelihood of child wasting by 2.8 percentage points.

Table 4: Estimated impact of crop diversification on child growth

	Stunting		*Wasting*	
	Crop groups	Shannon index	Crop groups	Shannon index
(A) CMP	-0.025** (0.011)	-0.058* (0.034)	0.018*** (0.007)	0.058*** (0.021)
(B) Probit IV	-0.027** (0.012)	-0.063* (0.034)	-0.035 (0.023)	-0.045** (0.020)

Note: Panel A reports results (marginal effects) from the Conditional mixed process (cmp) for stunting and wasting by the type of crop diversification metrics; Panel B reports estimates from the pooled probit IV method. All regressions include child and household characteristics, region and time-fixed effects, and time-averages of time-varying variables; Standard errors in parentheses are clustered at the individual level; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Panel B of Table 4 provides results obtained from the pooled probit IV regressions. As discussed earlier, the pooled data econometric models provide more useful impact estimate results because both crop diversification and child growth outcomes do not significantly vary over time. The results show that crop diversification has a positive and significant effect on child growth. An increase in the number of crop groups cultivated by the household reduces stunting by 2.7 percentage points. However, the effect on wasting is insignificant. An increase in the Shannon index by 1 unit is associated with a reduction in stunting by 6.3 percentage points and wasting by 4.5 percentage points. The results from the three-step estimation and the pooled probit-IV are consistent.

Overall, the results show that rural households can achieve a reduction in child malnutrition by cultivating more crops and equitably allocating their land across the crops they cultivate. However, the magnitude of the effects is higher for the land concentration index (Shannon) than the number of crop groups. These results imply that crop diversification through equitable allocation of land generates higher child growth effects than by expanding the crop production portfolio by cultivating more crops or groups of crops. Consistent with the finding of a previous related study (Lovo and Veronesi, 2019), the magnitude of the estimated impacts is found to be small in most cases. A plausible explanation is the presence of high persistence in child growth or malnutrition, which implies that changes in crop choices are less likely to generate large effects on child nutrition over time (Lovo and Veronesi, 2019). It could also be because the child growth impacts of crop diversification could occur with a certain delay, an issue not empirically tackled in this paper because of data limitations. The small magnitude of the estimated impact also suggests the need for heterogeneous effects analysis to see if the impact differs for different groups.

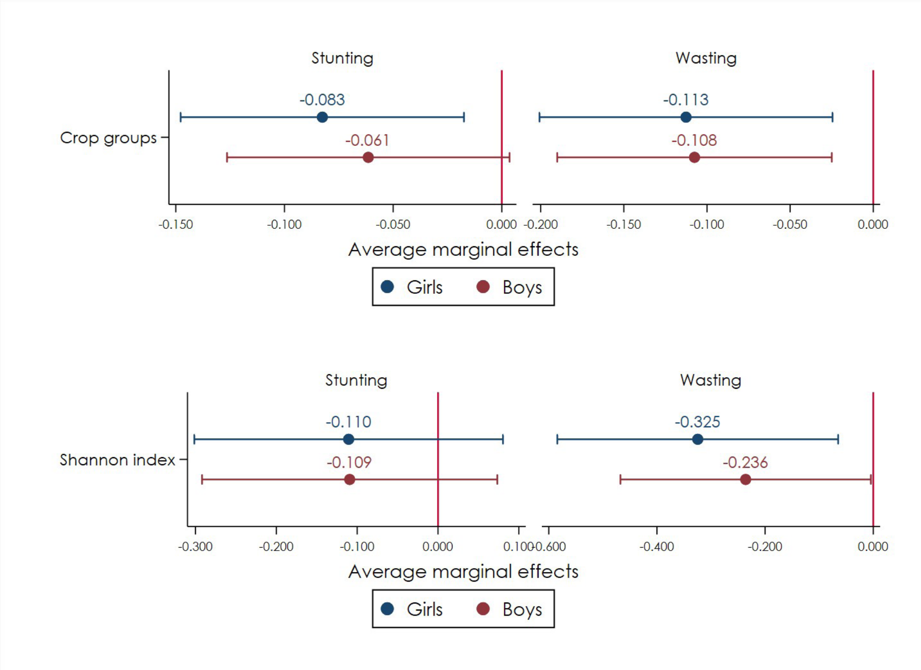
6.2 Heterogeneous Effects

The study explores whether the effect of crop diversification (measured using the number of crop groups cultivated by the household and the Shannon index) varies by the gender of the child, exposure to shocks, and access to markets. To get the estimates of the heterogeneous effects, the crop diversification measures are interacted with the child gender, drought shock, and market access dummies.

6.2.1 Heterogeneous effects by gender

To begin with, the marginal effects of crop diversification on stunting and wasting of boys and girls obtained from probit IV regressions are given in Figure 2. Increasing the number of crop groups cultivated by the household by 1 is associated with a reduction in stunting among girls by 8.3 percentage points. It also reduces wasting among girls and boys by about 11 percentage points. Using the Shannon index as a measure of crop diversification, the results show that crop diversification reduces child wasting by 32.5 and 23.6 percentage points for girls and boys, respectively. Despite the lack of significant results for the whole sample, the results suggest that crop diversification would have differential effects on the growth of boys and girls.

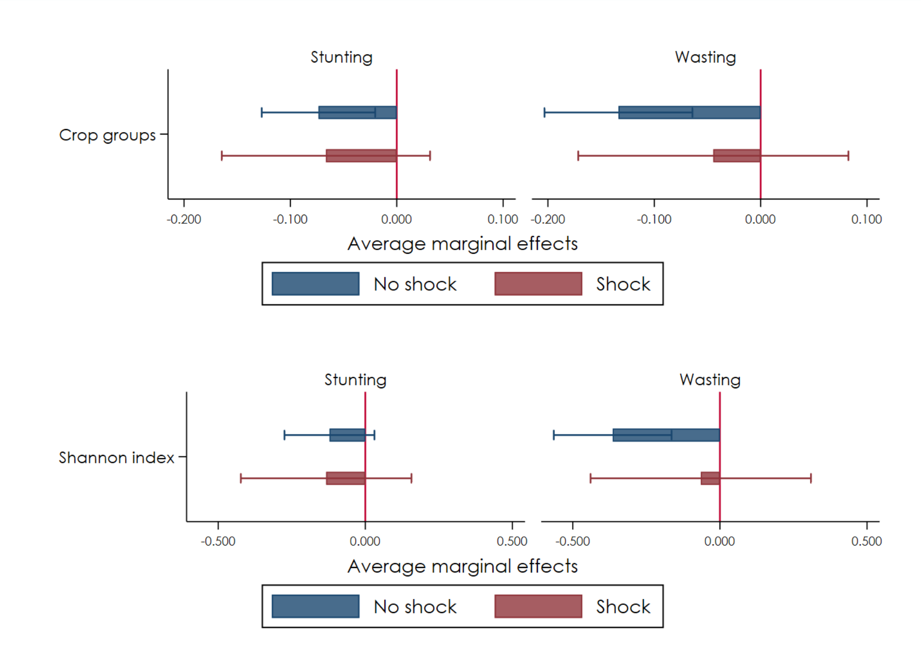
Figure 2: Child growth effects of crop diversification by gender of the child



6.2.2 Drought shocks, crop diversification, and child growth

One interest in this paper is to see if exposure to drought shocks has adverse effects on child growth, and if any, whether crop diversification plays a mitigating role. The result suggests that crop diversification (both the Crop groups and Shannon index) does not have a significant impact on child growth outcomes (wasting and stunting) under the conditions of drought shock (Figure 3). The insignificant effect of drought shock indicates that children residing in areas that experience drought do not have worse health (nutrition) profiles compared to those who are not (or less) exposed to drought. This indicates that the devastating drought (e.g., the 2015 drought) does not lead to widespread increases in child malnutrition in the drought-exposed areas (Hirvonen et al., 2020).[12] Overall, the results do not provide evidence regarding the resilience benefits of crop diversification that could be achieved through mitigating any negative child growth effects of drought shocks.

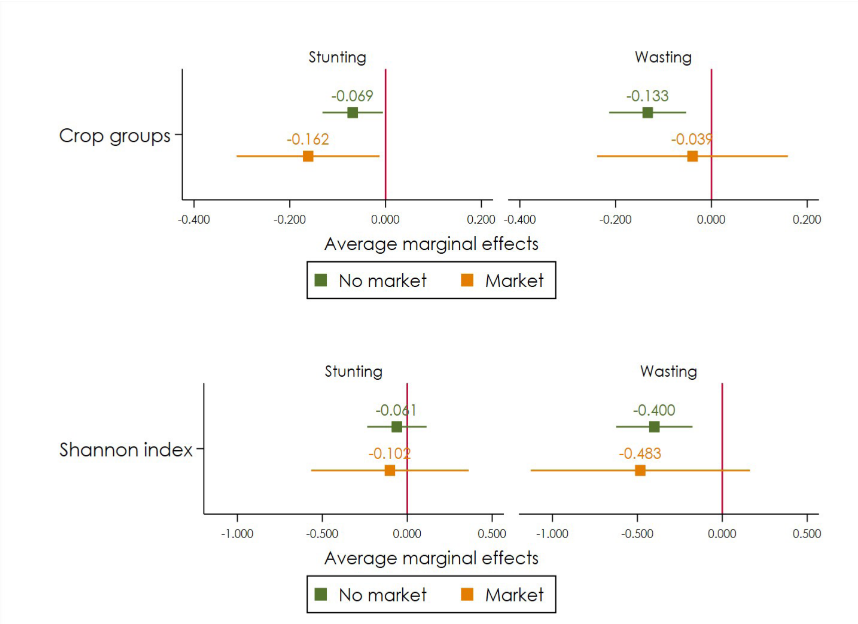
Figure 3: Child growth effects of crop diversity by exposure to drought shock



6.2.3 Heterogeneous effects by market access

The study tests if market access mediates the effect of crop diversification on child growth. The results show that crop diversification through increasing the number of crop groups cultivated has a positive effect on reducing child stunting and wasting among households that live in villages with no large weekly markets (Figure 4). An increase in the Shannon index of crop diversification is also found to be associated with a decrease in child wasting in areas with limited market access. The results suggest that crop diversification will improve child health in areas with limited access to (local) markets (Hirvonen et al., 2020; Sibhatu et al., 2018). Lovo and Veronesi (2019) also demonstrate that crop diversification is weakly associated with child health HAZ score for households closer to food markets in Tanzania. Overall, the results indicate that market access mediates the effects of crop diversification on child growth.

Figure 4: Child growth effects of crop diversity by market



6.3 Underlying Mechanisms

The results reported so far have shown that greater crop diversification is beneficial for children's health as it is associated with a reduction in child stunting and wasting. As discussed in section 3, two main mechanisms can explain the relationship between crop diversification and child growth: (i) household diet diversity or quality, and (ii) income effect. This sub-section tests if these mechanisms are at play. As discussed above, the impact mechanisms are established through a system of equations estimated jointly in a conditional mixed process framework.

6.3.1 Impacts of crop diversification on household diets and income

To begin with, Table 5 presents the second step estimates of equation 3 that shows the relationship between crop diversification and household diets and income.

Table 5: The impacts of crop diversification on household diets and income: Conditional mixed process estimates

	Diet diversity	*Diet quality*	*Income*
Crop groups	0.239***	0.325**	0.160**
	(0.035)	(0.027)	(0.081)
Shannon index	0.456***	0.923***	0.515**
	(0.095)	(0.076)	(0.211)

Note: Results are presented only for the key variables of interest. These are the second step estimates obtained by jointly estimating the system of equation (equation 3) within the Conditional mixed process (cmp). The first step involves estimating crop diversification as a function of the IV (village level crop diversification). In the second step, dietary diversity/diet quality/income is estimated as a function of crop diversification. In the third step, the estimated dietary diversity/diet quality/income is allowed to affect child growth outcomes. All equations include household and child characteristics, region and time fixed effects, and time averages of time-varying variables. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

The results show that household diet diversity is positively associated with crop diversification. One additional crop group cultivated by the household or a 1 unit increase in the Shannon index (equitable allocation of land across crops cultivated) is associated with an increase in the household diet diversity of 0.24 and 0.46, respectively. The results indicate that households with a higher crop diversity display greater dietary or nutritional diversity. 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 growth would operate through greater diet diversity (Lovo and Veronesi, 2019).

Diet quality is positively associated with crop diversification. The results show that the share of quality diets in households' calorie production increases with crop diversification. The effect appears to be higher with a more equitable allocation of land across the crops cultivated by the household (Shannon index) than the number of crop groups cultivated. This result suggests that reallocation of land among crops would improve diet quality than the mere addition of crops in the portfolio or allocating more land to a few crops.

The results further indicate that crop diversification has a positive and significant impact on household crop income. Each additional crop group cultivated by a household generates about 160 Birr income. An increase in the Shannon index by 1 unit leads to an increase in household crop income by 515 Birr. Overall, the results show that crop diversification has a higher and more significant impact on crop income with a more equitable allocation of land across crops cultivated than increasing the number of crops or crop groups cultivated. Previous studies also demonstrate a positive association between crop diversification and income (Asfaw et al., 2019).

6.3.2 Impacts of household diets and income on child growth

To elucidate the mechanisms through which crop diversification impacts child growth, this section discusses the results of the third step of the system of equations estimated. Table 6 presents the estimated impacts. The results show that household dietary diversity is the strongest mechanism through which crop diversification affects child growth. For the number of crop groups, a 1 unit increase in the household dietary diversity is associated with a decrease in child stunting and wasting by 8.7 and 7.4 percentage points, respectively. For the Shannon index of crop diversification, a 1 unit increase in household dietary diversity leads to a decrease in child stunting and wasting of 10.4 and 11.7 percentage points, respectively. The results indicate that crop diversification impacts child growth through household diets. Diet quality has a significant effect on child wasting only when the crop diversification measure is the Shannon index. This indicates that crop diversification contributes to reduction of child wasting by improving the quality of household diets.

Table 6: The impacts of household diets and income on child growth: Conditional mixed process estimates

	Stunting		*Wasting*	
	Crop groups	Shannon index	Crop groups	Shannon index
Dietary diversity	-0.087**	-0.104**	-0.074**	-0.117***
	(0.035)	(0.047)	(0.030)	(0.034)
Diet quality	0.031	0.04	-0.038	-0.043*
	(0.035)	(0.035)	(0.024)	(0.024)
Income	-0.086	-0.063	-0.079	-0.082***
	(0.056)	(0.048)	(0.037)	(0.026)

Note: The estimates are obtained by jointly estimating the system of equation specified in equation 3 within a Conditional mixed process (cmp). These are estimates from the third step that shows the effects of dietary diversity, diet quality, and income on the child growth outcomes. All equations include household and child characteristics, region and time fixed effects, and time averages of time-varying variables. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

The second mechanism through which crop diversification would affect child growth is the income effect. To elucidate this underlying mechanism, the study estimates the impact of crop income (estimated as a function of crop diversification) on child growth. The results in Table 6 show that an increase in household crop income is associated with a decrease in child wasting when the measure of crop diversification is the Shannon index. This could be because crop diversification through a more equitable allocation of land across crops cultivated has a higher and more significant impact on crop income than diversification by increasing the number of crops cultivated. The finding suggests that the effect of crop diversification on child growth (child wasting in particular) would operate through increased crop income.

7. Conclusion

Child malnutrition is predominant in Sub-Saharan Africa (SSA). 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. However, very little empirical evidence exists on the links between crop diversification and child growth. This study seeks to contribute to the literature and the policy discourse by investigating the impact of crop diversification on child growth using three-wave panel data that span the period 2012-2016 from the Ethiopian Socio-economic Survey (ESS), conducted as part of the Living Standards Measurement Study - Integrated Surveys on Agriculture (LSMS-ISA) of the World Bank, combined with historical rainfall data. The study also elucidates two possible pathways – household diets and income – through which crop diversification would impact child growth.

The results show that crop diversification has a positive but small impact on child growth by reducing the risk of stunting and wasting. The positive impact 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. Although crop diversification exerts positive child health effects, the study does not find evidence that crop diversification mitigates the negative impact of drought shocks on child health. This could be because a household's exposure to drought shock does not translate to catastrophe in terms of child stunting or wasting. Furthermore, the study highlights that crop diversification has stronger child growth benefits among girls and in areas with limited access to markets.

Rural Ethiopians' diet is diversified; however, their diet seems to be dominated by non- nutritious staples as indicated by a lower share of calories produced from non-staple nutritious crops. The econometric model results show that crop diversification has a positive and significant but small impact on diet diversity. Crop diversification, particularly increasing the number of crops cultivated by the household, has a positive impact on diet quality. The study also finds evidence that crop diversification has a positive impact on crop income. The findings of the study also show that dietary diversity is the strongest channel through which crop diversification affects child growth. Diet quality and crop income appear to be mechanisms through which crop diversification through equitable allocation of land among crops cultivated by the household impacts child growth by reducing the risk of child wasting.

From a policy perspective, the findings of the study suggest that policies that target achieving nutritional gains should promote crop diversification to improve the quality and variety of the products from their production. This needs supporting farmers through alleviating resource constraints and providing access to reliable price information and inputs. Integrating diversification strategies into the extension system of the country could also help promote diverse production systems that feature cereals, cash crops, and legumes. Given the possibly high opportunity cost of crop diversification, further research is required to compare the nutrition impacts 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 that could mediate the nutrition impacts of crop diversification.

Notes

1 This paper is published in the Food Policy Journal as: Wondimagegn Tesfaye, “Crop diversification and child malnutrition in rural Ethiopia: Impacts and pathways, Food Policy, 2022, 102336. ISSN 0306-9192. *https://doi.org/10.1016/j.foodpol.2022.102336.* https://www.sciencedirect.com/science/article/pii/S0306919222001087.

2 This work is financially supported by the Bill and Melinda Gates Foundation (BMGF) through the African Economic Research Consortium (AERC). Special thanks to Brinda Ramasawmy, Rodney Smith, and Lingue´re Mbaye (resource persons) for their support. I would like to thank participants of the AERC-BMGF Workshops for their constructive comments. E-mail: wtesfaye@worldbank.org or wondie22@gmail.com

3 World Bank Group, Ethiopia Email: wondie22@gmail.com.

4 See section 5.3 for definition and measurement of the outcomes.

5 *https://ccafs.cgiar.org/publications/climate-smart-agriculture-ethiopia.XCzUK-FxKjcs*.

6 This is the baseline specification used to estimate the direct effect of crop diversification on child growth. The specification used to show the impact pathways through which crop diversification affects child growth is discussed in 4.3.

7 These household-level controls are also used in the household diets, diet quality, and income regressions.

8 As discussed in Lovo and Veronesi (2019), we can consider the village-level crop diversification as an imperfect IV for household-level crop diversification because it might violate the stable unit treatment value assumption required for a standard IV.

9 Both the pooled probit IV and the cmp specifications include the time averages of time-varying variables. The child growth regressions also include child characteristics in addition to household level controls.

10 Details of the survey including sample size, sampling methods, data, and other supporting materials can be accessed from the website: https://www.worldbank.org/en/programs/lsms/initiatives/lsms-ISA.

11 The 12 food groups are: (i) cereals, (ii) roots and 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.

12 Hirvonen et al. (2020), using the same survey and weather data, show that drought shocks lead to increased child malnutrition rates in areas with limited access to improved roads compared to areas with better road connectivity.

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Appendix A: Descriptive statistics

Table A1: Calculation of crop diversification indices

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

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 A2: Crop diversification, drought and child malnutrition by region

Region	*Drought (%)*	*Number of crops*	*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 A3: Descriptive statistics: Household and child characteristics by survey year

	Survey year			*Pooled*			
	2012	*2014*	*2016*	*Mean*	*Median*	*Minimum*	*Maximum*
Household characteristics							
Household size	6.23 (2.13)	6.25 (2.13)	6.27 (2.20)	6.25 (2.16)	6.00	1.00	16.00
Female-headed	0.12 (0.33)	0.13 (0.34)	0.14 (0.35)	0.13 (0.34)	0.00	0.00	1.00
Age of head	45.1 (13.91)	46.01 (13.65)	47.28 (13.67)	46.21 (13.76)	44.00	8.00	98.00

Head is literate	0.45 (0.50)	0.46 (0.50)	0.48 (0.50)	0.46 (0.50)	0.00	0.00	1.00
Wealth indicators							
Land size (hectares)	1.22 (1.53)	1.35 (1.30)	1.33 (1.25)	1.31 (1.35)	0.94	0.00	9.98
Livestock holding (TLUs)	3.84 (3.24)	3.98 (4.12)	4.72 (6.17)	4.22 (4.83)	3.23	0.00	94.29
Asset wealth index	-0.07 (3.04)	-1.08 (0.75)	-1.16 (0.86)	-0.81 (1.85)	-1.00	-2.43	34.90
Non-agribusiness	1.94 (0.24)	1.92 (0.27)	1.94 (0.24)	1.93 (0.25)	2.00	1.00	2.00
Housing features							
Improved water source	0.49 (0.50)	0.62 (0.49)	0.72 (0.45)	0.62 (0.49)	1.00	0.00	1.00
Improved sanitation	0.01 (0.09)	0.02 (0.15)	0.44 (0.50)	0.17 (0.38)	0.00	0.00	1.00
Electricity access	0.05 (0.23)	0.06 (0.24)	0.07 (0.26)	0.06 (0.24)	0.00	0.00	1.00
Proximity to services							
Health post in 5 Kms	0.92 (0.26)	0.93 (0.26)	0.94 (0.24)	0.93 (0.25)	1.00	0.00	1.00
Weekly market	0.45 (0.50)	0.54 (0.50)	0.6 (0.49)	0.53 (0.50)	1.00	0.00	1.00
Distance to market (Km)	64.12 (45.07)	62.84 (45.31)	63.29 (45.77)	63.38 (45.41)	52.30	2.80	283.00
Distance to major road (Km)	13.91 (14.10)	14.13 (15.04)	14.25 (15.10)	14.11 (14.79)	10.20	0.00	239.20
Climate and shocks							
Drought shock	0.14 (0.34)	0.08 (0.27)	0.27 (0.44)	0.17 (0.37)	0.00	0.00	1.00
Mean annual rainfall (mm)	1221.84 (331.57)	1231.23 (337.60)	1221.03 (344.22)	1224.67 (338.30)	1200.27	163.87	2143.67
Std. dev. rainfall	108.86 (25.00)	110.74 (23.63)	120.41 (26.70)	113.78 (25.73)	112.85	19.90	190.37
Rainfall shortage	0.05 (0.15)	0.09 (0.26)	1.37 (0.87)	0.55 (0.84)	0.00	0.00	2.78
Mean temperature (0C)	18.36 (2.93)	18.35 (2.92)	18.41 (2.96)	18.37 (2.94)	18.70	10.20	29.40
Elevation (m)	2010.47 (467.29)	2007.2 (472.21)	1996.71 (473.76)	2004.26 (471.32)	1932.00	201.00	3451.00
Child characteristics							

Age (months)	32.34 (15.37)	32.86 (15.36)	33.37 (15.48)	32.88 (15.41)	34.000	0.000	59.000
Sex of child (1=Boy)	0.538 (0.499)	0.514 (0.500)	0.535 (0.499)	0.529 (0.499)	1.000	0.000	1.000
Parent education							
Mother is illiterate	0.686 (0.464)	0.707 (0.455)	0.674 (0.469)	0.689 (0.463)	1.000	0.000	1.000
Father is illiterate	0.419 (0.493)	0.436 (0.496)	0.416 (0.493)	0.424 (0.494)	0.000	0.000	1.000
Observations	1,385	1,762	1,579	4,726	4,726	4,726	4,726

Note: Mean coefficients reported, standard deviations in parentheses. Distance to Health Post - A child lives in a household that is under 5km from a health post; access to electricity A child lives in a household with an electrical connection; Access to improved water A childhas access to an improved water source (piped water, a protected water source). The increase in the rainfall shortage value in 2016 reflects the drought shock the country has experienced during the 2015/16 period (Hirvonen et al., 2020)

Table A4: Nutrient production and gaps by survey year

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

Figure A1: Proportion of households that met RDA from nutrient production

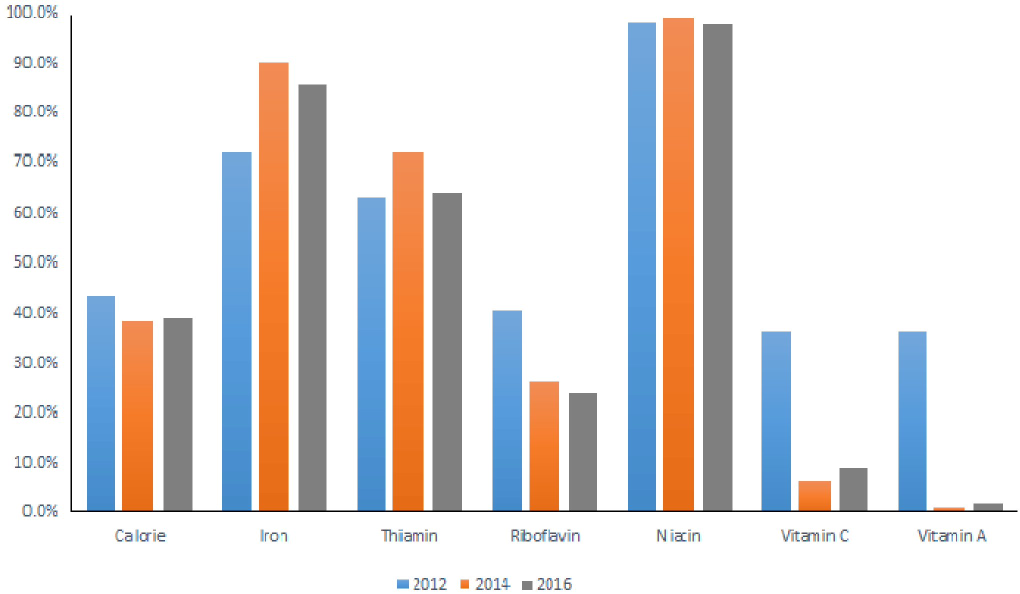

Table A5: Proportion of household cultivating crops and area share by year

	Proportion of HHs cultivating: (%)				*Share of cultivated area (%)*			
Crop type	2012	2014	2016	Pooled	2012	2014	2016	Pooled
Barley	29.5	31.0	28.8	29.7	7.04	6.84	6.54	6.78
Maize	64.8	60.6	63.8	63.0	15.61	15.72	16.54	16.00
Millet	13.3	13.4	12.0	12.8	2.85	2.72	2.57	2.70
Oats	1.7	2.5	1.6	1.9	0.25	0.38	0.16	0.26
Rice	0.7	0.5	0.7	0.6	0.09	0.06	0.13	0.10
Sorghum	38.8	35.8	35.5	36.5	12.65	11.49	12.37	12.15
Teff	45.1	49.2	43.1	45.7	13.34	16.99	14.67	15.08
Wheat	30.4	33.7	34.1	32.9	8.13	9.02	10.04	9.16
Other cereals	0.4	0.7	0.1	0.4	0.06	0.18	0.01	0.08
Chickpeas	8.9	7.9	8.6	8.4	1.24	0.90	1.14	1.08
Haricot bean	21.8	19.9	5.5	15.0	3.22	2.65	0.48	1.98
Horse bean	23.9	29.8	23.3	25.7	2.71	3.37	2.45	2.84
Lentils	5.6	6.9	6.7	6.4	0.54	0.76	0.76	0.70
Field pea	9.9	13.3	12.3	12.0	1.02	1.81	1.56	1.49
Vetch	5.5	6.3	5.1	5.6	0.89	0.82	0.62	0.76
Gibto	1.8	0.9	0.5	1.0	0.17	0.09	0.08	0.11
Soybean	0.8	0.5	0.8	0.7	0.06	0.08	0.12	0.09
Cotton seed	7.7	7.4	6.2	7.0	0.59	0.45	0.52	0.52
Line seed	2.4	2.5	2.2	2.4	0.45	0.38	0.28	0.36
Ground nuts	10.3	10.0	8.6	9.5	1.77	1.51	1.37	1.53
Nueg	9.0	7.8	5.4	7.2	0.50	0.29	0.27	0.34
Rape seed	7.4	5.1	6.6	6.3	1.68	1.19	1.75	1.54

Sesame	1.2	1.5	1.0	1.2	0.05	0.05	0.04	0.05
Bananas	18.8	16.3	18.5	17.8	0.71	0.62	0.74	0.69
Lemons	1.3	1.5	1.9	1.6	0.01	0.04	0.05	0.04
Mango	6.8	7.5	10.7	8.5	0.14	0.12	0.22	0.16
Oranges	3.4	2.9	3.7	3.4	0.06	0.04	0.04	0.04
Papaya	5.0	4.4	4.6	4.6	0.13	0.07	0.08	0.09
Guava	2.4	1.9	3.0	2.4	0.06	0.03	0.06	0.05
Peach	0.9	1.1	1.0	1.0	0.01	0.01	0.03	0.02
Avocados	9.3	10.1	10.2	9.9	0.22	0.27	0.27	0.25
Cactus	0.3	0.6	16.1	6.4	0.08	0.16	2.49	1.02
Other fruit	3.8	2.7	2.6	2.9	0.15	0.05	0.18	0.13
Beer root	3.0	2.5	2.9	2.8	0.02	0.01	0.01	0.01
Cabbage	3.4	2.6	3.1	3.0	0.04	0.02	0.02	0.03
Carrot	0.7	0.8	0.8	0.8	0.01	0.00	0.03	0.01
Garlic	10.6	16.8	8.5	11.9	0.22	0.31	0.13	0.22
Kale	21.8	18.8	18.7	19.6	0.87	0.61	0.50	0.64
Onion	6.7	3.7	4.3	4.8	0.23	0.05	0.15	0.14
Green pepper	8.7	6.9	9.4	8.4	0.24	0.12	0.11	0.15
Spinach	0.5	0.5	1.1	0.8	0.01	0.02	0.01	0.01
Potatoes	8.3	8.9	6.8	7.9	0.66	0.67	0.43	0.58
Pumpkins	13.7	11.3	10.2	11.6	0.49	0.40	0.22	0.36
Sweet potatoes	13.6	10.0	7.9	10.2	1.22	0.97	0.49	0.86
Tomatoes	1.7	1.2	2.7	1.9	0.11	0.08	0.04	0.07
Godere	11.8	9.4	11.2	10.8	0.72	0.62	0.59	0.64
Cassava	0.1	2.2	2.0	1.5	0.00	0.20	0.20	0.14
Enset	32.1	30.7	31.5	31.4	6.17	5.43	5.91	5.82
Other roots	7.8	4.2	7.3	6.4	0.39	0.08	0.22	0.22
Other vegetables	2.2	1.6	1.1	1.6	0.04	0.07	0.09	0.07
Fenugreek	5.9	4.9	5.4	5.4	0.38	0.18	0.23	0.25
Ginger	1.8	1.2	0.9	1.2	0.03	0.02	0.01	0.02
Red pepper	18.9	12.7	14.8	15.2	1.49	0.86	1.30	1.20
Chat	18.9	19.6	20.4	19.7	2.56	3.37	3.13	3.05
Coffee	32.4	31.3	32.3	32.0	5.95	6.01	6.26	6.09
Cotton	1.2	0.9	0.6	0.9	0.07	0.03	0.06	0.05
Gesho	14.4	16.2	18.4	16.5	0.63	0.21	0.44	0.42
Sugar cane	7.1	5.8	7.4	6.8	0.30	0.22	0.18	0.23
Tobacco	2.2	1.8	2.2	2.1	0.10	0.02	0.02	0.04
Observations	2,704	2,885	2,872	8,461	2,704	2,885	2,872	8,461

Table A6: Proportion of household cultivating crop groups and area share by year

	Proportion of HHs cultivating: (%)				*Share of cultivated area (%)*			
Crop groups	2012	2014	2016	Pooled	2012	2014	2016	Pooled
Cereals	90.9	91.0	90.1	90.6	60.0	63.4	63.0	62.3
Legumes	51.4	53.0	39.8	47.6	8.8	9.7	6.8	8.3
Oil crops	30.7	27.9	25.4	27.7	5.1	3.9	4.2	4.3

Cash crops	52.0	52.3	54.0	52.8	9.6	9.9	10.1	9.9
Vegetables & roots	64.8	64.1	57.9	61.9	12.2	10.5	9.6	10.6
Fruits	28.2	26.9	39.1	31.9	1.6	1.4	4.2	2.5
Spices	30.5	22.9	27.2	26.6	2.3	1.2	1.7	1.7
Other crops	8.0	4.2	7.3	6.4	0.4	0.1	0.2	0.2
Observations	2,704	2,885	2,872	8,461	2,704	2,885	2,872	8,461

Appendix B: Additional analysis results

Table A7: Drivers of crop diversification: Conditional mixed process (cmp) estimates

	Count index	*Shannon index*
Household size	0.026 (0.023)	0.020* (0.010)
Age of head	0.002 (0.005)	0.000 (0.002)
Head is literate	0.087 (0.067)	-0.029 (0.028)
Asset index	-0.027* (0.015)	-0.008 (0.007)
Household consumption	-0.016 (0.041)	-0.006 (0.016)
Non-agribusiness	-0.109 (0.091)	-0.069* (0.036)
Distance to major road (Km)	0.001 (0.001)	0.001*** 0.000
Distance to market (Km)	-0.001* (0.001)	-0.000** 0.000
Farm size (ha)	0.103*** (0.027)	0.028** (0.011)
Livestock holding (TLU)	-0.074** (0.032)	0.007 (0.013)
Rainfall shortage	0.024 (0.027)	0.012 (0.012)
Mean Temperature (^{o}C)	0.009 (0.007)	0.012*** (0.003)
Temperature X Elevation	-0.000 (0.000)	-0.000 (0.000)
Village crop diversity	0.853*** (0.017)	0.798*** (0.018)
Constant	-0.493 (0.364)	-0.847*** (0.162)
Observations	4,726	4,726

Note: The results are first step estimates from the Conditional mixed process. Household consumption, farm size, and livestock holdings are in log. Year and region dummies and time averages of time-varying variables included; Standard errors in parentheses are clustered at the individual level; The weak identification test statistics are higher than the Stock-Yogo weak ID test critical values. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A8: Impacts of crop diversification on child growth: Additional results

	Count index	*Crop groups*	*Shannon index*	*Composite entropy*
(1) Height-for-age Z-score	0.012 (0.017)	0.081* (0.044)	0.226* (0.127)	0.638* (0.348)
(2) Weight-for-height Z-score	0.022* (0.013)	0.077** (0.033)	0.270*** (0.096)	0.899*** (0.263)

Note: Results from IV (pooled data); all regressions include controls, region and time fixed effects; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A9: Estimated effects of crop diversification on calorie and nutrient production gaps

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

Note: Dependent variables are calorie and nutrient production gaps; The results are based on fixed effects IV regressions; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

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