Does the adoption of maize-legume cropping diversification and modern seeds affect nutritional security in Ethiopia? Evidence from panel data analysis

P. Marenya[1]; M. Kassie[2]; H. Teklewold[3]; O. Erenstein[4]; M. Qaim[5]; D. Rahut[4]

1: International Maize and Wheat Improvement Center (CIMMYT), , Ethiopia, 2: International Centre of Insect Physiology and Ecology (icipe), , Kenya, 3: Ethiopian Development Research Institute (EDRI), , Ethiopia, 4: International Maize and Wheat Impr

Corresponding author email: p.marenya@cgiar.org

Abstract:

This paper examines the ex-post impact of the combination of cropping- system diversification (CSD) and the adoption of improved maize varieties on child stunting and household nutritional security. To control for selection and endogeneity bias, arising from time-variant and time-invariant individual heterogeneity, the study employs a fixed-effects multinomial endogenous switching regression using large, on a panel data set collected in maize-growing areas of Ethiopia between 2010 and 2013. Results highlight the significant effect of adoption of CSD and improved maize varieties on child stunting; per capita consumption of calories, protein, and iron; and dietary diversity. The greatest impact was achieved when farmers adopted CSD and improved maize varieties jointly rather than individually. Our results are a validation of the need to strengthen smallholder diversification in the face of subsistence production and limited access to food markets. In these scenarios, production of a diversified crop portfolio among low-income rural families should be encouraged, given the limited opportunities for specialization and constrained access to diversified diets through local food markets. Howerver, in the long run, market access to diverse food types is likely to provide more sustainable diet diversification and nutrition.

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Abstract

This paper examines the ex-post impact of the combination of cropping- system diversifications (CSDs) and the adoption of improved maize varieties on child stunting and household nutritional security. To control for selection and endogeneity bias, arising from time-variant and time-invariant individual heterogeneity, the study employs a fixed-effects multinomial endogenous switching regression using large, survey based household data collected in maize-growing areas of Ethiopia between 2010 and 2013. Results highlight the significant effect of adoption of CSDs and improved maize varieties on child stunting; per capita consumption of calories, protein, and iron; and dietary diversity. The greatest impact was achieved when farmers adopted CSDs and improved maize varieties jointly rather than individually. Our results are a validation of the need to strengthen smallholder diversification in the face of subsistence production and limited access to food markets. In these scenarios, production of a diversified crop portfolio among low-income rural families should be encouraged, given the limited opportunities for specialization and constrained access to diversified diets through local food markets. In the long run, market access to diverse food types is likely to provide more sustainable diet diversification, because on-farm diversification has its limits since few households can truly grow all the diversity of foods needed for a healthy diet.

Key words: *Cropping system diversification; modern seeds; nutrition; Multinomial Endogenous Switching regression; Ethiopia.*

Introduction

Malnutrition and food insecurity are key challenges to development in sub-Saharan Africa (SSA), causing widespread disease, poor health and even death. Recent reports show that about 239 million people in SSA are undernourished, and 171 million children under five years of age are stunted, indicating chronic malnutrition (FAO, 2012; Unicef, 2012). In subsistence farming, where a farm household's livelihood hinges mainly on their own production, and where the household is less linked to markets, agricultural innovations that enhance self provision of food are a key pathway to the improvement of food and nutritional security of these households (Qaim, 2014). In many developing countries, improving food security and alleviating poverty has focused on "green revolution" type interventions which have contributed to sizeable production and productivity gains, making food more affordable and reducing rates of undernourishment in the world (Evenson and Gollin, 2003; Gómez and Ricketts, 2013; Qaim, 2014). However, this approach, that relies on promoting monocroping systems, has led to a diminished dietary diversity of nutrients, which is necessary for a healthy life (Masset et al., 2012; Remans et al., 2014). The shift from diversified cropping systems to mono-cropping cereal-based systems has been proved to endanger nutritional security and to discourage dietary diversity, possibly resulting in micronutrient deficiency (Demment et al., 2003; Frison et al., 2006; Negin et al., 2009; DeClerck et al., 2011). Recently there has been a move towards promoting diversification of agricultural food production in order to enhance nutrition and alleviate micronutrient deficiency (Johns and Eyzaguirre, 2006; Ecker and Qaim, 2011; Fanzo et al., 2013; Mazunda and Shively, 2015) while improving and/or maintaining a natural resource base.

The degree of rigor in the recent literature on the link between agricultural technologies and nutrition is limited compared to the strong evidence based on the impacts of agricultural innovations in terms of productivity, income and poverty (Ruel and Alderman, 2013; Qaim, 2014; Webb and Kennedy, 2014). Previous studies on nutrition mainly focus on the impact of crop/agricultural diversity, proxied either by the number of food groups consumed, number of crops and livestock species produced and/or the Simpson index (Jones et al., 2014; Kumar, 1994; Shively and Sununtnasuk; 2015; Sibhatu et al., 2015), except for the studies by Qaim and Kouser (2013). Hotz et al. (2012), Zeng et al. (2017) and Manda et al. (2016). All these studies consider single technology adoption and cross-sectional survey data. Manda et al. (2016) assessed the association between adoption of improved maize varieties and child malnutrition as proxied by stunting, using cross-sectional data in eastern Zambia, and found that adoption had a significant impact. Qaim and Kouser (2013) examined the ex-post impacts of adoption of Bt cotton technology on calorie and micro-nutrient (zinc, iron, vitamin A) consumption per adult equivalent, and found significant impacts of adoption on nutritional outcomes using observational panel data. Hotz et al. (2012) found a positive impact of orange sweet potato on intake of vitamin A in Uganda, using a randomized controlled trial.

Although empirical evidence has been established on the link between legume-cereal intercropping and rotations and improved seeds and productivity, income, production risk and environment using cross-sectional data (Goshu et al., 2012; Mandal and Bezbaruah, 2013; Njeru, 2013; Teklewold et al., 2013; Kassie et al., 2015b; Manda et al., 2016), there are limited studies in the existing body of empirical literature on the impact of adoption of combinations of technologies and crop diversification on household and individual nutritional outcomes.

This paper assesses the ex-post impacts of adoption of legume cropping-system diversifications (LCSDs) and modern maize varieties individually and jointly on household and individual dietary diversity, household dietary intake (consumption of calories, protein and iron) and child stunting, using comprehensive large farm-household data collected in 2010 and 2013 in maize-growing areas of Ethiopia. A combination of panel data and a multinomial endogenous switching regression in a counterfactual framework is used to deal with selection bias and unobserved heterogeneity underlying endogeneity bias. The multinomial endogenous switching regression framework is similar to the one developed by Bourguignon et al. (2007)[1].

Conceptual framework: Pathways through which a number of interventions influence nutrition

In this section, we conceptualize the link between agricultural production and nutrition. We conceptualize the link between nutrition and growing more diversified crops through five stylized pathways. The *production pathway* is especially crucial for households whose main economic activity is raising food crops. They have little alternative income sources (such as wage income) or small businesses. Therefore, any shortfalls in calories, protein or micronutrients have to be met from increased production on their own farms (Zeng et al., 2017; Kassie et al. 2015a). A second pathway that flows from the production pathway is the *diversification pathway* since access to diversified diets through the markets requires that households have the income (from food or non-food cash-crop production), even those households who do not grow a diverse set of crops can still

The e *production stability pathway* recognizes that protecting yields and or gains from downside risks is important for nutrition. Episodes of crop failure can have devastating and even permanent effects on nutrition, especially that of children (Abay and Hirvonen, 2016). Therefore, cropping patterns that help stabilize yields and impart some resilience to biotic (e.g. drought) and abiotic stressors (e.g. pests, diseases) are important for nutritional wellbeing.

The *income pathway* can occur if households increase the production of more lucrative legumes, leading to more income which is then used to purchase food items not produced in the household (Du et al., 2015). Prior research has shown a greater and significant impact of net crop income from improved maize varieties adopted jointly with LCSDs in Ethiopia, Malawi and

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[1] We say "conceptually straightforward" because in reality the contribution of increased production to nutrition will depend on other intervening factors not least the relative increase in incomes accruable from increased production, the intra-household distribution of such incomes, other health factors of individuals in the household or whether there is adequate diversity of their own food production or whether access to diverse diets (fresh fruits, vegetables, animal proteins) are affordably available in local food markets. The six stylized pathways in this section explore these nuances.

Zambia (Teklewold et al., 2013; Kassie et al., 2015b; Manda et al., 2016), but this outcome will be realized only if farmers have access to markets and these markets are functioning well.

The success of the income pathway also depends on (or interacts with) a fifth pathway, the *women empowerment pathway* (Ruel and Alderman, 2013; Sauer et al. 2016; de Jager et al., 2017). The women empowerment pathway postulates that if increased income strengthens women's purchasing power, this will bode well for nutrition as women are often the main custodians of household nutrition (especially that of children). If intra-household income distribution is conducive (or can be made to be conducive) to this pathway, it is an important avenue for strengthening nutrition.

Data and Descriptive sample Statistics

Household survey

The data used in this paper are from comprehensive large-panel and cross-sectional farm-household survey data collected in 2010 and 2013 in all maize-growing agro-ecological zones of Ethiopia (see Figure 1). We use cross-sectional data to assess the links between adoption and child stunting and a mother's dietary diversity score, while panel data was used to assess technology adoption on a per capita calorie, protein and iron consumption basis, and a household's dietary diversity index. The surveys were carried out by the International Wheat and Maize Improvement Center (CIMMYT) in collaboration with the Ethiopian Institute of Agricultural Research (EIAR). A multi-stage random-sampling proportionate procedure was employed to select villages from each district, and households from each village. The survey covered 39 districts from the four regional states of Ethiopia covering various agro-ecologies (Figure 1). The 2010 sample covered 2400 random farm households, while the follow-up survey in 2013 covered 2289 households[2].

[2]The attrition rate is about 4.6%. This is true attrition as either the household left the village or passed away.

[Insert Figure 1 here.]

In both years, a structured questionnaire was prepared, and the sampled respondents were interviewed using trained and experienced enumerators with knowledge of the local language. The survey covered various modules: consumption, dietary diversity, technology adoption, production, sanitation (toilet type, water source and distance to water source), access to services (e.g., distance their water source and to health, extension, and market services), production constraints, and asset ownership. Food consumption data relating to 70 food items and covering a 12-month period were elicited at the household level. Sample households in the study areas relied more on home production: in 2010 and 2013, 23% and 25% of households purchased food. The quantities of food consumed included those from their own production, market purchases, in-kind food transfers, and out-of-home meals and snacks. From the total of 2289 sample households revisited in 2013, we obtained weight and height data for 1814 children up to 60 months of age.[3]

Households were asked to provide a detailed description of their household, crop plots and crop production, and the village, which included the following characteristics: input and output market access, household composition, education, asset ownership including livestock, various sources of income, participation in credit and off-farm activities, membership of formal and informal organizations, number of grain traders known, current crop-production shocks/stresses experienced, participation and confidence in extension services, and land tenure. A wide range of plot-specific attributes such as soil fertility, depth, slope, farm size in hectares, and walking distance of plot from residence that could affect adoption and nutrition through food production were also collected. In addition to the above-mentioned variables, location variables were included in the regression models. These helped to capture geographic heterogeneities such as differences in spatial variation in agro-ecology, and infrastructure and farming systems of the country. Definitions of explanatory variables along with summary statistics are shown in Table 1.

[3]For child malnutrition analysis, we only consider data collected in 2013 by health professionals.

[Table 1]

Measuring outcome variables: Dietary quality, food diversity and child malnutrition

This study measures household dietary intake and food diversity using a 12-month period of reported food-consumption behavior of the randomly-selected farm households. Alongside these outcomes child stunting and the mother's dietary diversity score are analyzed. In the economic and nutritional science literature, several nutrition indicators are used as outcome variables in impact assessment. One of the basic methods frequently used is the unweighted sum of the number of food items/groups and/or the number of crops consumed by the household during a specific period of time. However, this method does not capture the corresponding weights of each food item, meaning that all food groups are equally weighted regardless of the nutritional content (Nguyen and Winters, 2011). To overcome this problem, two sets of nutrition indicators are employed in this study: household diet diversity and per adult equivalent nutrient intake (calories, protein, and iron).

The household dietary diversity index is constructed using the Simpson index of food diversity (Nguyen and Winters, 2011; Liu et al., 2014). This measure reflects household access to a variety of foods, and is a proxy for the nutritional adequacy of individual diets (Ruel, 2003; (Kennedy et al., 2007). Dietary diversity is a vital element of diet quality, and the consumption of a variety of foods across and within food groups and across different varieties of specific foods more or less guarantees an adequate intake of essential nutrients and important non-nutrient factors. Giving emphasis to the relative importance of each food group, diversity is measured not only by the number of food groups but also by their distribution, so that maximum diversity occurs when consumption shares are equally distributed among food groups. Mathematically, the Simpson index (SI) is defined as a function of a household's consumption share of each food item:

$$SI = 1 - \sum_{i=1}^{n} w_i^2 ,$$

where w_i is the calorie share of food item *i* in the total amount of calories consumed.

The Simpson index ranges from zero to one: the higher the index the more diversified the diet. If a household consumes only one food item, the index is zero, and it comes close to one if the household's total food consumption is spread equally among a number of food items. Total calorie consumption is calculated by adding consumption levels of food items in the past twelve months. Food consumption data, covering more than 70 food items, were collected at the household level. The data captured quantities of food consumed from home production, market purchases, and from other sources outside the house, e.g., relatives, government/non-government aid, or food received in exchange for labor over a twelve-month period. Food was grouped into nine categories (see Fig. 2): (i) cereals, (ii) pulses, (iii) oil crops, (iv) vegetables, (v) fruits, (vi) meat/eggs, (vii) fish, (viii) dairy products, and (ix) beverages (FAO, 2011).

Along with dietary diversity, three measures of dietary quality (calories, protein, and micronutrient (iron) consumption per adult equivalent per day) were also computed from the data. In Ethiopia, iron deficiency anemia is a widespread problem affecting about 49% of children aged between six and nine months and 17% of women aged 15-49 (Central Statistical Agency and ICF International, 2012). The quantity of consumed food items was converted into calories, proteins and iron using locally-relevant food composition tables from the Ethiopian Health and Nutrition Institute. Research demonstrates that there is a strong association between dietary diversity and nutritional status, particularly micronutrient density of the diet (Arimond and Ruel, 2004; Hoddinott and Yohannes, 2002). Our data also exhibit a positive correlation between food diversity and per-adult equivalent consumption of calories, proteins, and iron (Figure 3). In addition, we considered child stunting as a nutrition indicator. The percentage of rural children under five years of age who were stunted was higher (34%) compared to other anthropometric indicators such as wasting and underweight which gave about 9% and 25% respectively (Central Statistical Agency, 2014).

[Insert Figures 2 and 3 here]

Sample descriptive characteristics

Outcome variables

Sample statistics of the outcome variables (per-adult equivalent consumption of calories, proteins and iron, and degree of dietary diversity including the Simpson index) are presented in Table 2. The result indicates that the average daily per capita calorie consumption is about 2200 kcal. This is almost equal to the average daily per capita calorie requirement needed to maintain a healthy population, but is slightly higher than the national average calorie consumption – 1950 kcal (FAOSTAT, 2010). Even if the average calorie consumption is slightly above the national average, 50% of the sample farm households consumed fewer calories than this daily physiological requirement. The result is consistent for both the 2010 and 2013 survey periods. The average dietary protein consumption per day per person was about 42 grams. This is slightly below the national average dietary protein consumption (57 gm per person per day). The average Simpson index values were 0.80 in 2010 and 0.87 in 2013. The large number of indices shows that rural farm households exhibit a high level of diversity. Dietary intake and food diversity are all higher in 2013 than in 2010 and this is statistically significant at the 5% level.

[Table 2]

The association between adoption of CSDs and modern maize varieties and child malnutrition was measured using height-for-age Z-score (HAZ). Children with a height-for-age Z- score (HAZ) of less than -2 were classified as stunted, and those with a HAZ of less than -3 were regarded as severely stunted (WHO, 2006). Policy-makers with an interest in malnutrition may be more motivated by statistics indicating the overall prevalence of malnutrition than in Z-scores per se. We therefore generated a binary variable to estimate the probability that a child was stunted, equal to one if a child's height-for-age Z-score was lower than -2 and zero otherwise. Of the children studied, (956 boys and 858 girls),34% were stunted.

Adoption variables

Our adoption variables represent the adoption of CSDs – defined as spatial (maize-legume intercropping) and temporal (maize-legume rotation) – and the use of improved maize seeds and their combination (Table 3). About 97% and 95% of sample households grew maize in 2010 and 2013 respectively, on average on 40% of the total cultivated area. Haricot beans were the dominant legume intercropped and rotated with maize.

Adoption analysis of CSDs and improved maize seeds lead to four technology sets from which farmers are able to choose. Of the total maize plots, about 37% did not benefit from any of these practices (V_0D_0) in 2010 (where D is CSDs and V refers to improved maize varieties) but this rate is significantly reduced to 13% in 2013. On the other hand, joint adoption of both practices (V_1D_1) increased from 8% in 2010 to 29% in the 2013 cropping season. Another interesting result is that adoption of packages containing only improved seeds (V_1D_0) decreased significantly from 46% in 2010 to 36% in the 2013 season. However, the adoption of CSDs alone (V_0D_1) increased in 2013 compared to 2010.

[Table 3]

We also note mobility in adoption and non-adoption of technologies between 2010 and 2013 (Table 4). For instance, of the total number of maize plots that did not receive either practice (827) in 2010, 44%, 11% and 26% of the plots were, respectively, covered by modern maize seeds, CSDs and a combination of the two in 2013. Yet about 19% of the maize plots still remained without either of the two practices. Interestingly, we also observed persistence in adoption of the combination of CSDs and modern seeds, and a move towards adoption of modern seeds and CSDs in combination, as opposed to adoption of only one of these. Of the total number of plots benefitting from a combination of modern seeds and CSDs (266) in 2010, more than 60% of the plots still benefitted from both practices in 2013. Failure to adopt either practice was only observed on about

7% of maize plots. Similarly, joint adoption of CSDs and modern seeds was observed in 2013 on more than 50% of the plots that were once covered by CSDs or modern maize seeds alone in 2010.

[Table 4]

Econometric estimation strategy

Two potential problems are commonly encountered in impact evaluation using observational data. A farmer's adoption decision may not be random, but is likely to be influenced by unobservable factors (e.g., expectation of yield and nutritional gain from adoption, managerial skills, motivation) and thus straightforward regression analysis on the impact of adoption leads to biased results. This is a well-known sample selection-bias problem due to unobserved individual effects. In the panel data context, this is time-variant individual heterogeneity. The presence of unobserved heterogeneity in the outcome equations if correlated with observed explanatory variables can also lead to inconsistent estimates. The multinomial endogenous switching regression (that involves a two-step estimation approach) combined with panel data can help tackle these two problems. Our two-step approach first estimates the multinomial logit model using the Mundlak (1978) approach to obtain estimates of the time-variant individual heterogeneity (inverse Mills ratios) causing selection bias. The outcome equations are then estimated by fixed effects, including inverse Mills ratios estimates from the first stage as additional explanatory variables. The use of Mundlak in the first step and a fixed effects approach in the second step capture time-invariant individual heterogeneity underlying endogeneity and inverse Mills ratios and take care of time-varying heterogeneity. The Mundlak approach allows for the inclusion of the means of the time-varying explanatory variables in the adoption equations as additional explanatory variables in the multinomial logit model, as a proxy for removing the time-invariant individual effects. Modeling this dependence allows for an unbiased estimation of the parameters, regardless of whether or not the explanatory variables and the individual effects are independent in the equations (Ebbes et al., 2004). The use of multinomial switching regression in addition to addressing selection bias problems allows for capturing the slope effect of adoption variables as they fully interact with explanatory variables (see Equation (3)).

The multinomial switching endogenous regression framework involves estimating a multinomial selection equation followed by an outcome equation for each technology choice. Our sample is partitioned into four mutually-exclusive technology sets (Table 3). A farm household is assumed to choose from four mutually-exclusive technology sets j (j=0,1,...,3) for his plot i in time t, where '$j = 0$' denotes non-adoption of either of the technologies, while the remaining technology sets ($j = 1, \ldots ,3$) contain at least one improved technology. A farm household h chooses technology set s if its utility U outweighs the utility that could be obtained from all other alternatives:

$$\mathrm{U_s} > max\left(U_j\right)$$

$$j = 1, \ldots, J$$

$$j \neq s$$

The utility derived from each technology set depends on household, plot and location characteristics and is expressed as follows:

$$U_{hit,j} = X_{hit}\beta_j + \alpha_h + \varepsilon_{hit,j} j = 0 \ldots J \quad (1)$$

where X_{hit} is a matrix of household, plot and location characteristics, β_j are parameters to be estimated, α_h is unobserved time-constant heterogeneity and ε_{hit} is the disturbance term with the usual assumptions.

We observe the technology choice but not the utility derived from the technology set. We employ a multinomial logit model to map the latent utility into the technology set choice, assuming that the error terms are identically and independently Gumbel distributed. Thus the probability that a farm household h selects technology set j on his plot i in time t and under each market regime is estimated:

$$Prob\ (j = s) = \frac{\exp(X_{hit}\beta_s\ + \bar{X}_{hi})}{\sum_{j=1}^{J} \exp\left(X_{hit}\beta_j\ + \bar{X}_{hi}\right)} \tag{2}$$

where $\bar{X}_{hi}$ is time-varying average regressors.

The estimation of the multinomial logit model will generate inverse Mills ratios $(\hat{\lambda})$ for each technology set that will be added as additional explanatory variables in the second stage outcome equations to capture individual heterogeneity underlying selection bias.[4]

$$\begin{cases} Regime\ 1\colon Q_{hit,0} = \beta_0 Z_{hit0} + \psi_{h0} + \sigma_0 \hat{\lambda}_{hit,0} + u_{hit,0}\, if j = 0 \\ \vdots \\ Regime\ 4\colon Q_{hit,J} = \beta_J Z_{hit} + \psi_{hJ} + \sigma_J \hat{\lambda}_{hit,J} + u_{hit,J}\, if j = J, \qquad J = 1, 2,3 \end{cases} \tag{3}$$

Here $Q's$ are vectors of outcomes (per capita consumption of calories, protein and iron, Simpson index, mother's dietary diversity score and child stunting), Z is a vector of covariates influencing nutrition outcomes, ψ is the unobserved time-invariant household heterogeneity, and $u's$ are a vector of error terms.

As argued by (Lokshin and Glinskaya, 2009) the system of equations (2-3) is identified by non-linearities of the inverse Mills ratios, even if the variables in X and Z overlap completely. Despite this, we use the following variables as exclusion restrictions: walking distance to input markets, walking distance to an extension office, membership of an inputs' marketing group, and farmers' confidence in the skills of extension workers. We conduct a simple post-estimation test to check the validity of the instruments and the results confirm that, in nearly all cases, these variables are jointly significant in the adoption equations but not in the outcome equations. A simple correlation analysis between these instruments and outcome variables shows that there is an insignificant correlation.

Estimation of Average Adoption Effects

[4]See Bourguignon et al. (2007) for the derivation of selection bias correction terms from the choice model.

The outcome equations are estimated by fixed effects except the child stunting outcome. The use of fixed estimates eliminates the individual fixed effects (ψ). The above econometric approaches help in defining adopters' actual and counterfactual expected outcomes as follows:[5]

$$E(Q_{hit,J}|j = J) = \beta_J Z_{hit} + \sigma_J \hat{\lambda}_{hit,J} \quad (4)$$

This is the actual expected value of outcomes for adopters, directly computed from our sample data. On the other hand, the expected counterfactual value of outcomes for adopters (i.e., expected outcome values if adopters had not adopted any of technology sets) is defined as:

$$E(Q_{hit,0}|j = J) = \beta_0 Z_{hit} + \sigma_0 \hat{\lambda}_{hit,J} \quad (5)$$

Equation (5) states what the outcomes of adopters would have been if their characteristics had had the same returns as the characteristics of non-adopters. These expected values are used to compute unbiased estimates of the effects of adoption on adopters. The average effects of adoption on the adopters (ATT) are computed as the difference between equations (4) and (5):

$$ATT = E(Q_{hit,J}|j = J) - E(Q_{hit,0}|j = J) = (\beta_J - \beta_0)Z_{hit} + (\sigma_J - \sigma_0)\hat{\lambda}_{hit,J} \quad (6)$$

The practical application of a multinomial switching regression has been used by Teklewold et al.(2013) and Kassie et al. (2015a) among others.

Results and discussion

Descriptive statistics

Table 5 shows consumption of macro- (calories and protein) and micro-nutrients (iron) by adoption status. The test for equality of nutrients consumption shows that there is a strong relationship between adoption and household nutrition at the 5% or less significance level[6]. There is also a positive association between food diversity and adoption. The magnitude of dietary intake and the

[5]A similar approach can be extended to get the actual and counterfactual outcomes for non-adopters. The focus of this paper is estimating the average adoption effects.
[6]Results not reported here.

dietary diversity indices increase with a combination of practices. The results suggest a complementary relationship between the two practices that improves the level of household nutrition. A non-parametric dietary intake and food diversity distribution analysis also provide similar qualitative results (Figure 2). Without implying any causal relationship, the cumulative distribution of per-adult equivalent calorie, protein and iron consumption, shows that joint adoption of CSDs and improved maize (V_1D_1) dominates adoption of CSDs without improved maize (V_0D_1) or those involving only improved seeds (V_1D_0) in the per-adult equivalent calorie, protein and iron consumption cumulative distribution of households.

[Table 5]

Econometric results

The adoption estimation results are provided in the appendix (Table 1A). In the interests of brevity and because we are primarily interested in the ATT, we do not discuss the adoption function estimates. However, it is worth mentioning that the null hypothesis that all coefficients of the mean of time-varying covariates are jointly statistically equal to zero is rejected in almost all equations. This supports the presence of a correlation between unobserved household fixed effects and observed covariates. The results also show that the statistical significance of various explanatory variables differs across technology sets.

In the second stage, we estimate fixed effects regression on per-capita daily consumption of calories, protein and iron, and use the Simpson index for each combination of practices controlling for selection bias derived from the first stage.[7]Results from the second stage are not discussed nor presented for similar reasons to those mentioned above[8]. A good number of variables have shown significant correlation with the outcome variables.

Average adoption effects

[7]However, child stunting was estimated using pooled linear and probit regressions as we have one-year data (2013).
[8]The result is available from the authors upon request.

In this section we report and discuss the conditional average effects of adoption on dietary intake (per capita calorie, protein and iron consumption), and diet diversity (Simpson index) (Table 6).

[Table 6]

The results highlight the fact that the adoption of practices either individually or jointly provides higher per capita calorie, protein and iron consumption compared with non-adoption (Table 6). In all counterfactual cases, farm households who actually adopted would have consumed fewer per-capita calories if they had not adopted (see column D of Table 6). Importantly, the combination of CSDs and improved maize varieties provides more per capita calorie consumption (269 kcal), compared with per-capita calorie consumption with the adoption of either improved maize variety alone (193 kcal.) or CSDs alone (212 kcal). The potential additional gains of calorie consumption from joint adoption are statistically significantly higher by 3.5 and 2.5 percentage points respectively than from the adoption of CSDs and modern seeds individually. The results for protein and iron show a similar trend in that the consumption effect is higher when the practices are used in combination, rather than individually.

Table 7 presents the relationship between adoption and child stunting. Results show that stunting prevalence is lower with adoption of technologies than with non-adoption. It is important to note that with the adoption of the combination of practices there is a greater reduction in the prevalence of stunting in children (up to 15%), compared to the reduction following the adoption of either improved maize varieties (12%) or CSDs (2%) in isolation. The overall results underscore the fact that adoption of CSDs jointly with yield-enhancing technology can mitigate household nutritional insecurity and child malnutrition in rural areas in the face of pervasive market imperfections, and climate change and variability. Data presented in Tables 6 and Table 7 show that the average adoption effects of adopters is computed as the difference between actual and counterfactual expected outcomes estimated in Equation (6).

[Table 7]

With regard to dietary diversity (measured by the mothers' dietary diversity) we found that, for farmers who adopted only modern seeds, the average dietary diversity score is significantly higher than it would have been if the adopters had not adopted (Table 8). The result is in agreement with Snapp and Fisher (2015) who found that the adoption of hybrid seed is significantly associated with food crop diversity in Malawi. Similarly, our findings show that farm households who adopted CSDs consumed highly-diversified diets. This is in line with Herforth (2010) and Jones et al. (2014) who examined the relationship between farm diversity and dietary diversity among households in some sub-Saharan African countries (Tanzania, Kenya and Malawi) and concluded that there is a strong relationship between dietary diversity and farm diversity. The significant relationship between crop diversity and dietary diversity is probably more closely related to consumption of households from their own-produced food than consumption of market-purchased food (Herforth, 2010).

[Table 8]

Conclusions

The sub-Saharan African (SSA) governments today are facing the problem of how to secure adequate food for all that is healthy, safe and of high quality in an environmentally-sustainable manner (Pinstrup-Andersen, 2009; Godfray et al., 2010). This study contributes to our understanding of the association between adoption of CSDs and modern maize seeds and nutritional security, food diversity and child stunting in rural Ethiopia. To our knowledge no study to date has systematically assessed the impact of the adoption of CSDs in combination with modern seeds on nutritional outcomes. The study uses panel multinomial endogenous switching regression in a counterfactual framework to account for both sample selection bias and endogeneity problems stemming from unobserved time-variant and time-invariant individual heterogeneity.

Regression results based on 2010 and 2013 data highlight a strong and robust relationship between adoption and household dietary intake (per capita daily consumption of calories, protein and iron), household food diversity, and child stunting. A counterfactual comparison indicates that the adoption of technologies either in isolation or jointly was found to improve calorie, protein, iron consumption and food diversity, and to reduce the prevalence of child stunting compared to non-adoption. The greatest impact was achieved when farmers jointly adopted practices. These results confirm the role of modern maize seeds and maize-legume cropping-system diversification in improving household nutrition, by providing important nutrients such as calories, protein and iron, suggesting that this cropping system can be considered a household nutrition-management strategy.

This study, combined with some recent studies that confirm the environmental-, income- and risk-protection effects (Teklewold et al., 2013; Kassie et al., 2015a; Manda et al., 2016), concludes that the adoption and diffusion of CSDs and improved seeds either individually and or jointly is a nutritionally-sensitive agricultural intervention which brings co-benefits to health and environment. The positive and significant effect of the adoption of CSDs and modern maize seeds on nutritional outcomes without any tradeoff, suggests that agricultural programs and policies aiming to have an impact on rural household nutrition and child under-nutrition should promote these practices rather than only increasing the total quantity of staple crops produced. Our results are a validation of the need to strengthen smallholder diversification in the face of subsistence production and weak food markets. In these scenarios, production of a diversified crop portfolio among low-income rural families should be encouraged, given the limited opportunities for specialization and constrained access to diversified diets through local food markets. In the long run, market access to diverse food types is likely to provide more sustainable dietary diversification because on-farm diversification has its limits, since few households can truly grow all the diversity of foods needed for a healthy diet.

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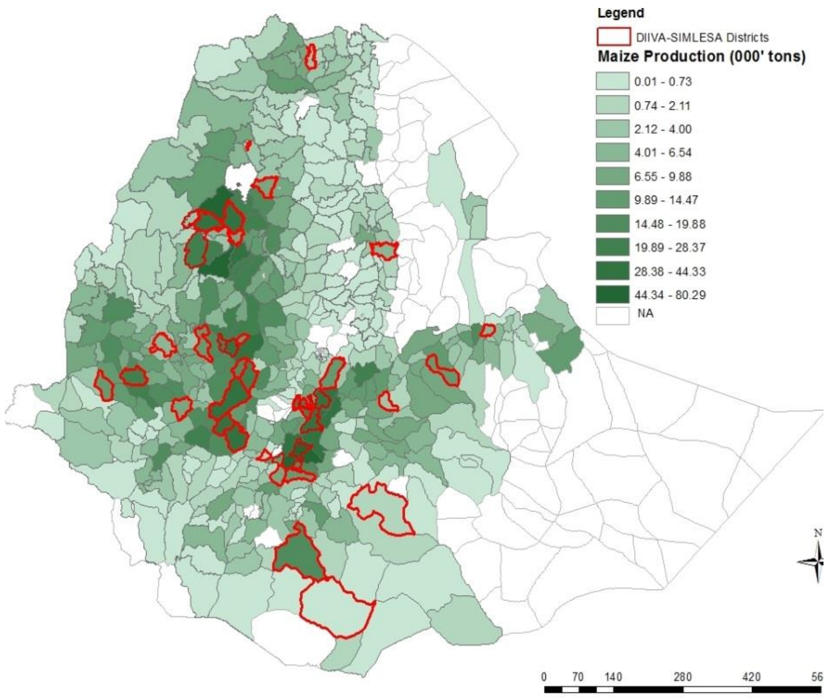


Figure 1: Study areas (red boxes show study villages)

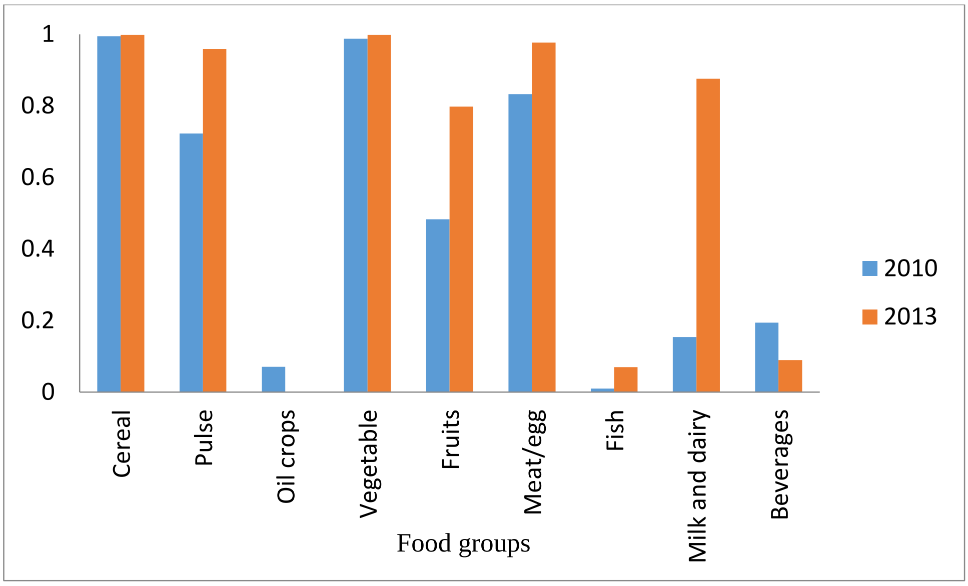
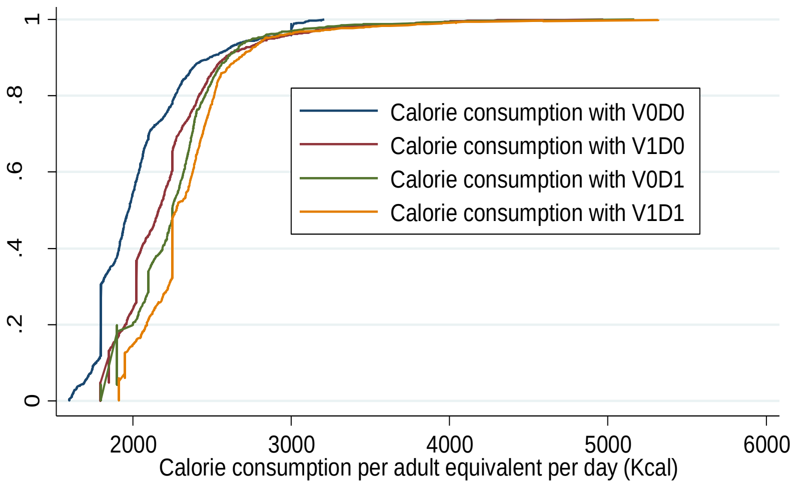
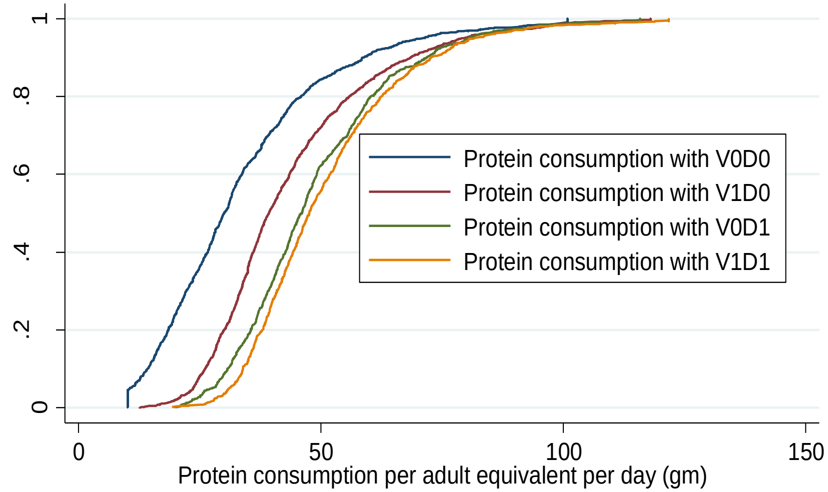


Figure 2: Frequency of distribution of consumption of the different food groups across years

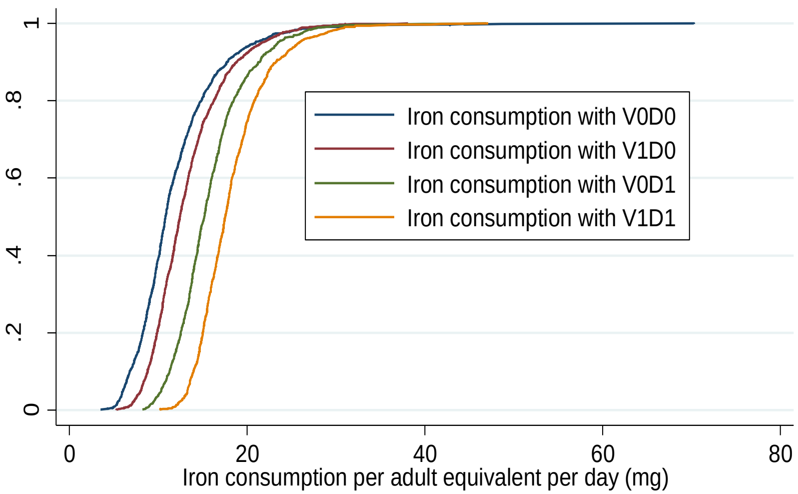
Figure 3: Cumulative density functions for the impact of cropping system diversifications and modern seeds on dietary intake and food diversity



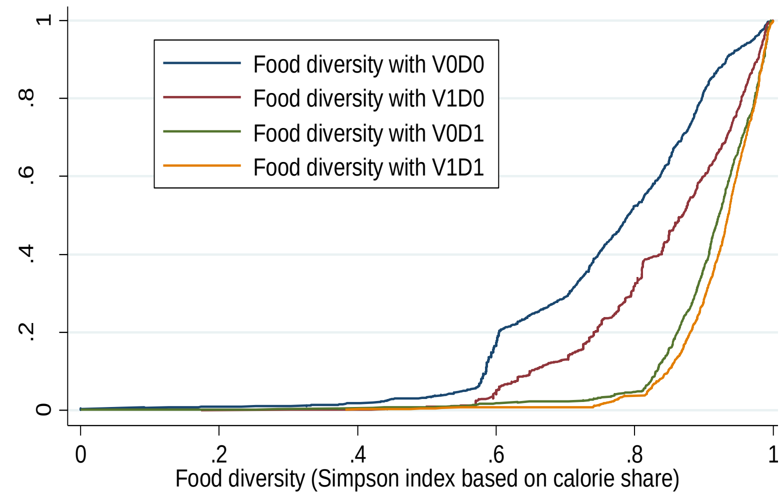
3a.Calorie



3b.Protein



3c. Iron



3d. Food diversity

Table 1: Definition of explanatory variables and summary statistics disaggregated by gender, adoption status and market participation

Variables	Description	None	Technology adoption: Improved maize variety	Technology adoption: Maize-legume diversification	Both	All
Gender	1=if gender of household head is male	0.916	0.953	0.934	0.954	0.941
Age	Age of household head (years)	42.373	42.139	42.435	42.017	42.221
Hhsize	Total family size (number)	6.795	6.829	6.803	7.106	6.866
Educhd	Education level of household head (years)	3.057	3.057	2.964	3.165	3.062
Totfarm size	Farm size, Ha	2.653	2.564	2.258	2.405	2.513
Prop cereal	Proportion of cereal crops area	0.710	0.639	0.569	0.587	0.638
Prop legum	Proportion of legume crops area	0.117	0.127	0.172	0.166	0.138
Prop oil	Proportion of oil crops area	0.037	0.040	0.114	0.096	0.060
Credit	1=if credit constraint (credit is needed but unable to get)	0.475	0.669	0.434	0.534	0.561
Tlu	Livestock size (in tropical livestock unit)	5.323	5.934	4.926	5.735	5.592
Asset val	Value of farm & household assets ('000 Birr)	24.304	21.762	20.364	28.000	23.313
Ox0	1=if household owns no oxen	0.211	0.125	0.266	0.193	0.180
Ox1	1=if household owns only one ox	0.198	0.195	0.261	0.226	0.211
Vilmkt dist	Walking distance to village markets. km	0.039	0.081	0.036	0.093	0.065
Manmkt dist	Walking distance to main markets. km	0.347	0.509	0.289	0.482	0.430
Distinput	Walking distance to input markets. km	0.993	1.669	0.983	1.665	1.393
Group	1=if member in input/marketing/group	0.224	0.255	0.185	0.290	0.243
Kinship	Number of close relatives living outside the village	6.181	7.746	7.626	9.534	7.646
Trader	Number of grain traders that farmers know and trust	2.015	2.479	1.942	2.113	2.215
Connec-tions	1=if household has relative in leadership position	0.557	0.551	0.547	0.555	0.553
Yearlived	Number of years the household has lived in the village	36.058	37.476	38.788	37.756	37.359
Distext	Walking distance to extension agents office. km	0.120	0.178	0.098	0.159	0.148
Extenskill	1=if confident with skills of extension workers	0.784	0.785	0.791	0.794	0.787
Govtsup	1=if believe in government support in case of crop failure	0.690	0.753	0.791	0.799	0.751

Variables	Description	None	Improved maize variety	Maize-legume diversification	Both	All
		Technology adoption				
Pests	1=if pest is a key problem	0.046	0.034	0.066	0.067	0.048
Disease	1=if disease is a key problem	0.043	0.040	0.080	0.065	0.051
Waterlog	1=if waterloging is a key problem	0.047	0.033	0.031	0.039	0.037
Drought	1=if drought is a key problem	0.180	0.105	0.129	0.126	0.131
Plotdist	Plot distance from home. minutes	10.918	11.285	7.815	9.610	10.376
Tenure	1=if owned and cultivated by the household	0.812	0.816	0.923	0.877	0.841
Shalwdepplt[a]	1=if plot has shallow depth soil	0.165	0.222	0.228	0.229	0.210
Moddepplt[a]	1=if plot has moderately deep soil	0.367	0.283	0.305	0.228	0.298
Godfertplt[b]	1=if plot has good fertile soil	0.436	0.513	0.507	0.553	0.499
Modfertplt[b]	1=if plot has moderately fertile soil	0.480	0.420	0.426	0.384	0.429
Flatslop[c]	1=if plot has flat slop	0.663	0.680	0.644	0.721	0.677
Modslpplt[c]	1=if plot has moderately steep slop	0.293	0.287	0.301	0.241	0.283
Manureuse	1=if manure use	0.324	0.290	0.462	0.375	0.339
Altitude	Altitude (meter above sea level)	1723.93	1802.24	1772.42	1782.03	1774.19

[a]Reference group is plot with deep depth soil; [b]Reference group is plot with poor fertile soil: [c]Reference group is plot with steep slope.

Table 2: Mean household dietary intake, food diversity and stunting across years

	year		
	2010	2014	Total
Calorie intake per adult equivalent, Kcal per day	2165.19_a (412.78)	2246.09_b (430.93)	2204.05 (423.49)
Protein intake per adult equivalent, gm per day	38.33_a (19.96)	45.50_b (19.57)	41.78 (20.09)
Iron intake per adult equivalent, mg per day	12.03_a (5.54)	14.02_b (5.76)	12.98 (5.73)
Simpson index* (based on calorie share)	0.80_a (0.14)	0.87_b (0.12)	0.84 (0.14)
Height-for-age Z-score (HAZ)	-	-1.12 (2.59)	-1.12 (2.59)
Stunted (%) [Height-for-age Z-score <-2]	-	40.2	40.2
Number of households	2400	2289	

Note: Values in the same row not sharing the same subscript are significantly different at p<0.05 in the two-sided test of equality for column means. Tests assume equal variances.

Table 3: Adoption rates for cropping system diversification and modern seeds at plot level (%)

Choice (j)	Combination	Modern maize variety (V)		Cropping system diversification (D)		Year		Average
		V_0	V_1	D_0	D_1	2010	2014	
A	B	C	D	E	F	G	H	I
1	V_0D_0	√		√		36.63	12.97	25.56
2	V_1D_0		√	√		46.06	36.84	41.74
3	V_0D_1	√			√	9.01	21.60	14.90
4	V_1D_1		√		√	8.30	28.59	17.80

Note: Each element in the combination is a binary variable for a modern maize seeds (V) and cropping system diversification (D), where the subscript refers 1= if adopted and 0=otherwise; Number of plot observations are 4354 in 2010 and 3907 in 2013.

Table 4: Transition matrix on the adoption of CSDs and modern maize varieties between 2010 and 2013

Adoption category in2010	Adoption category in 2013 (%)[A,B]				Total (%)
	None	Maize variety only	Maize-legume diversification	Both	
A	B	C	D	E	F
None	153 (18.5%)	365 (44.1%)	91 (11.0%)	218 (26.4%)	827 (6.5%)
Maize variety only	109 (12.3%)	123 (13.9%)	215 (24.3%)	439 (49.5%)	886 (9.7%)
Maize-legume diversification	21 (7.3%)	82 (28.4%)	27 (9.3%)	159 (55.0%)	289 (2.7%)
Both	19 (7.1%)	30 (11.3%)	50 (18.8%)	167 (62.8%)	266 (11.7%)
Total	302 (13.3%)	600 (26.5%)	383 (16.9%)	983 (43.3%)	N=2268

Note: [A] Number in parenthesis shows proportion of plots of the total number of plots (column F).

[B] The cells in columns B-F show the number (percent) of 2010 plots that transitioned to the 2013 adoption category

Table 5: Household nutrition and food diversity by adoption status

	Consumption per adult equivalent per day			Food diversity (Simpson index)
Practices	Calorie (Kcal)	Protein (gm)	Iron (mg)	
V_0D_0	2049.71(7.042)	33.76 (0.403)	11.88 (0.112)	0.77 (0.003)
V_1D_0	2220.17 (6.247)	43.81 (0.298)	13.26(0.072)	0.84 (0.002)
V0D1	2271.37 (9.969)	48.91 (0.469)	15.80 (0.118)	0.91 (0.002)
V1D1	2349.59(9.493)	51.10(0.429)	18.23 (0.105)	0.92 (0.002)
Average	2207.73 (4.047)	43.33 (0.203)	14.18 (0.055)	0.85 (0.001)

Note: Numbers in parenthesis are standard errors.

Table 6: Average adoption effects on nutrition indicators for all samples

Nutrition Indicator	Outcome	Adoption status		Average adoption effects
		Adopting (Actual)	Non-adopting (counterfactual)	
A	B	C	D	E
Calorie(C) consumption per adult equivalent (Kcal/day)	$E(C_j \| j=2)$	2188.05 (1.36)	1995.03 (1.18)	193.02 (1.79)***
	$E(C_j \| j=3)$	2250.02 (3.35)	2038.29 (1.75)	211.72 (3.78)***
	$E(C_j \| j=4)$	2300.96 (2.61)	2031.89 (1.76)	269.06 (3.15)***
Protein(P) consumption per adult equivalent (gm/day)	$E(P_j \| j=2)$	40.24 (0 .094)	32.85 (0 .134)	7.39 (0.163)***
	$E(P_j \| j=3)$	43.66 (0.209)	34.72 (0.189)	8.93 (0.282)***
	$E(P_j \| j=4)$	45.64 (0.145)	36.09 (0.190)	9.55 (0.237)***
Iron(I) consumption per adult equivalent (mg/day)	$E(I_j \| j=2)$	13.03 (0.023)	11.67 (0.028)	1.36 (0.036)***
	$E(I_j \| j=3)$	14.71 (0.047)	12.34 (0.041)	2.37 (0.062)***
	$E(I_j \| j=4)$	15.99 (0.049)	12.45 (0.041)	3.55 (0.064)***
Food diversity (Simposn index-S)	$E(S_j \| j=2)$	0.85 (0.001)	0.78 (0.001)	0.065 (0.001)***
	$E(S_j \| j=3)$	0.90 (0.001)	0.81 (0.001)	0.097 (0.002)***
	$E(S_j \| j=4)$	0.92 (0.001)	0.81 (0.001)	0.104 (0.002)***

Note: figures in parenthesis are standard errors; *, ** and *** indicate statistical significance at 10%, 5% and 1% level; For numbers on column B refer to column B of Table 3.

Table 7: Impacts of adoption on child malnutrition (stunting)

Nutrition indicator	outcome	Adoption status		Average adoption effects
		Adopting (Actual)	Non-adopting (Counterfactual)	
A	C	D	E	F
Stunting-ST (%)	$E(ST_j \mid j=2)$	0.215 (0.004)	0.334 (0.008)	-0.119 (0.009)***
	$E(ST_j \mid j=3)$	0.252 (0.007)	0.236 (0.013)	0.016 (0.015)
	$E(ST_j \mid j=4)$	0.158 (0.004)	0.308 (0.011)	-0.150 (0.011)***
Height-for-age Z-score	$E(HAZ_j \mid j=2)$	-1.004 (0.028)	-1.074 (0.078)	0.070 (0.083)
	$E(HAZ_j \mid j=3)$	-1.288 (0.038)	-1.858 (0.112)	0.570 (0.118)***
	$E(HAZ_j \mid j=4)$	-0.859 (0.023)	-1.077 (0.094)	0.217 (0.097)**

Note: figures in parenthesis are standard errors; *, ** and *** indicate statistical significance at 10%, 5% and 1% level.

Table 8: Impacts of adoption on mother's dietary diversity (MDD) score

Nutrition Indicator	Outcome	Adoption status		Average adoption effects
		Adopting (Actual)	Non-adopting (Counterfactual)	
A	C	D	E	F
Mothers dietary diversity	$E(MDD_j \| j = 2)$	1.783 (0.002)	1.769 (0.003)	0.014(0.002)***
	$E(MDD_j \| j = 3)$	1.748(0.002)	1.771(0.003)	-0.023(0.005)***
	$E(MDD_j \| j = 4)$	1.794(0.001)	1.783(0.002)	0.011(0.002)***

Note: figures in parenthesis are standard errors; *, ** and *** indicate statistical significance at 10%, 5% and 1% level.