Child Malnutrition, Agricultural Diversification and Commercialization among Smallholders in Eastern Zambia

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EXECUTIVE SUMMARY

With only a few months remaining, Zambia still has a long way to achieving the millennium development goal of halving the number of stunted children by the end of 2015. Almost half of the children in Zambia remain undernourished and 40% of them have stunted growth, a long term malnutrition effect. This makes Zambia one of the countries with the highest levels of malnutrition in the world. The most vulnerable are the children from rural households which depend entirely on rainfed seasonal agricultural production and income, and survive on diets that are deficient in proteins and other important nutrients.

Applying the Generalized Propensity Score (GPS), which analyzes impact of particular interventions on a specific outcome and using Eastern province as a case study, this paper evaluates the impact of agricultural diversification (in terms of calorie and protein production) and commercialization on reducing malnutrition. The study uses two uniquely rich datasets which comprise social-economic, agriculture and anthropometric data observing 1,120 children from different farm households. We measured household agricultural diversification using the Simpson Index over production of major food groups including starchy foods, legumes-nuts-seeds, starchy vegetables, non-starchy vegetables, starchy fruits, non-starchy fruits, dairy, and eggs. Production is measured in two ways, firstly in terms of calorie production and secondly in terms of protein production. While commercialization is measured as an index derived from the share of agricultural sales in household's total value of agricultural production.

The following are the key findings from the study:

i.   With all factors remaining constant, increases in protein and calorie diversification (beyond 0.4 intensity level (40%)) reduces wasting and underweight significantly. This implies that high levels of diversification make the households more resilient to short-term agricultural production shocks due to their stable provision of a diverse set of nutrients that are correlated with calories from different agricultural products.

      The effect of agricultural diversification is nonlinear. Low levels of diversification (i.e., specialization) have marginal positive effects on stunting, while extreme levels of crop diversification have a negative effect on stunting. This implies that: a) specializing in very few crops results in a permanently less diverse diet with rising stunting rates; and b) extremely high calorie diversification levels, while delivering a wide variety of nutrients in the short term, could reduce longer term food security of children due to a less efficient production structure that delivers smaller amounts of nutrients than less diversified farms could produce.

ii.   All factors constant, the impact of the level of commercialization on stunting of children under five is non-linear with a U-shape impact curve. This implies that stunting is reduced when moving towards either low or high commercialization intensities. For most of the households, who already produce beyond the commercialization level of least favorable stunting outcomes, an increase in commercialization is therefore advisable.

iii. On the other hand, commercialization has a negative effect on underweight and wasting. Thus, in areas with less everyday access to a range of food items such as the rural parts of Eastern Province, capital accumulation through higher purchasing power may have less impact on short-term nutritional aims.

These results suggest that diversification strategies to deal with wasting and stunting of children under five would not be effective if they ignore the current diversification intensity of farmers and their differing impacts on wasting and stunting. Very high levels of diversification could improve the wasting and underweight status of children by delivering a high amount of nutrients, but may come at the cost of reducing the efficiency of the farm and thus, increasing the possibility of longer term stunting. Interventions focused on improving agricultural diversification and high degrees of commercialization may enhance adequate and diverse protein and calorie sources; while at the same time households will have excess production for the market to meet their income demands in the long-run. On the other hand, at low commercialization levels, it would be most favorable if households were more diversified.

These results, if substantiated by other studies point to two options: 1) promote more specialization in cash crops; or 2) promote more diversified subsistence farming to meet their nutritional needs while enhancing their off farm opportunities to earn income for other family needs.

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ACRONYMS

ATT	average treatment effect for the treated
CDIV	calorie diversification measured in terms of the Simpson index
CDIV	calorie production
CIA	conditional independence assumption
CSO	Central Statistical Office
DHS	Demographic Health Survey
DRF	dose response function
GLM	generalized linear model
GPS	Generalized Propensity Score
HAZ	height for age z-score
IAPRI	Indaba Agricultural Policy Research Institute
IFPRI	International Food Policy Research Institute
MAL	Ministry of Agriculture and Livestock
MDG	Millennium Development Goals
OLS	Ordinary Least Squares
PDIV	protein production
PSM	Propensity Score Matching
RALS	Rural Agricultural Livelihood Survey
SD	standard deviations
UNICEF	United Nations International Children's Fund
USAID	United States Agency for International Development
WHO	World Health Organization
WHZ	height for weight z-score
ZMK	Zambian Kwacha

1. INTRODUCTION

Malnutrition and nutrition related problems, especially among the children, remain high in Africa. Small children in particular remain vulnerable to malnutrition and nutrient-related health problems. Studies indicate that children that suffer from chronic malnutrition during the first two years of life tend to suffer from irreversible negative effects on brain and cognitive development (UNICEF 1990). This leads to reduced learning capacity in school and wage earning potential as adults.

Zambia has one of the highest rates of child malnutrition in the world. Most vulnerable are rural households, which highly depend on seasonal food production and survive on diets that are deficient in a variety of micronutrients. About 60.5% of the countries' population lives in rural areas (CSO 2010). According to the 2014 preliminary Demographic Health Survey (DHS) 40 % of the children in the country have stunted growth (z-score less than -2), 6% suffer from wasting and 15% are underweight (CSO 2014). Although the prevalence of underweight children has declined from 25.1% in 1992 to 15% in 2014, it remains a major concern as to whether Zambia will attain the Millennium Development Goals (MDG) target of 12.5% (Table 1) by the end of 2015. Wasting cases, which are relatively moderate, also remain worrisome, as the rates have increased from 3.1% in 1996 to 6% 2014 while the 2015 MDG target is 2.5%. With current stunting rates of 40%, it is unlikely that Zambia will have the MDG target of 20% by the end of 2015.

Considering that 70% of Zambia's population is dependent on agriculture for their livelihood and 90% of farmers are smallholders, understanding the impact of agriculture on nutrition becomes imperative. Rais, Pazderka, and Vanloon (2009) found that in India, most of the subsistence farms cannot provide for the entire household's food needs from production alone, often due to small landholdings and low productivity. Therefore, they have to generate income to purchase additional food. Intrinsically, agricultural diversification and commercialization provide alternative strategies for the rural households to improve diets (Hendrick and Msaki 2009; Khandker and Mahmud 2012), the former by yielding diverse food items for own consumption and the latter by increasing income and the household's ability to purchase a diverse range of food items. The growing of different groups of food crops contribute directly to a more diversified nutritional intake. At the same time, agricultural commercialization provides means of earning income that enables households to purchase goods and services like health-care, which are essential for sustaining their nutrition.

Table 1. Nutrition Status and Millennium Development Goals

Indicator	Value 1990	Value 2001/2	Value 2007	**Value 2014**	MDG target Value 2015
Percentage of underweight children (under 5 years of age)	25	23	15	**15**	12.5
Percentage of stunted children (under 5 years of age)	40	53	45	**40**	20
Percentage of wasted children (under 5 years of age)	5.1	6	5	**6**	2.5

Source: CSO (DHS) several years.

There is overwhelming evidence in recent literature showing that an increase in incomes during early childhood decreases stunting in the long-run (e.g., Zere and McIntyre 2003; Monteiro et al. 2010; Alderman et al. 2006).

This paper evaluates agricultural diversification and commercialization as critical rural strategies for increasing access to nutritious foods in the Eastern Province of Zambia. Specifically, this study answers two questions:

1) Does a diversified farm production system significantly affect the nutritional status of children?
2) Does participation in agricultural markets improve the nutritional status of the rural smallholder households?

2. AGRICULTURE AND NUTRITION IN EASTERN PROVINCE

The Eastern Province is one of Zambia's most productive regions in terms of agriculture. It ranks third in terms of maize production (the national staple food) and first in terms of groundnuts, the main source of protein in rural Zambia. In 2010/2011, the province produced 23% of the country's maize and 30% of the groundnuts (IAPRI/CSO/MAL 2012). As shown in Table 2, the Eastern Province is also well known for high crop diversification. The Simpson index for crop diversification of 0.47 is third highest out of ten provinces and above the national average of 0.42 (IAPRI/CSO/MAL 2012). [1]

While malnutrition levels are very high in the province, the Eastern Province has the second largest population of livestock produced by smallholders in the country. Similarly, the population of village chickens is highest in Eastern and Southern Provinces which produce 16.1% and 15.8% of the total smallholder village chickens in the country respectively. However, the number of livestock owned per household is much lower compared to other provinces. While, for instance, households in Southern and Luapula Provinces own an average of 10 and 16 cattle respectively, households in Eastern Province own an average of only five cattle per household (Lubungu and Mofya-Mukuka 2013). The smaller number of cattle owned per household could have implications on the level of protein source diversification and commercialization which may negatively affect child nutrition.

Despite the high and diversified crop production, diversified production of protein and calorie is relatively low (less than 0.3 Simpson Index of diversification). This could explain the shocking high levels of child malnutrition recorded in the province.

Table 2. Simpson Index of Crop Diversification per Province

	Mean	Specialized		Diversified
		Percentile 25th	Median	Percentile 75th
Central	0.41	0.2	0.48	0.61
Copperbelt	0.3	0	0.32	0.5
Eastern	0.47	0.38	0.5	0.63
Luapula	0.43	0.29	0.5	0.62
Lusaka	0.21	0	0.09	0.44
Muchinga	0.54	0.44	0.62	0.7
Northern	0.54	0.46	0.62	0.7
North Western	0.4	0.23	0.46	0.58
Southern	0.31	0.09	0.33	0.5
Western	0.42	0.32	0.49	0.59
Zambia	**0.42**	**0.24**	**0.49**	**0.63**

Source: Authors own computation based on the IAPRI/CSO/MAL RALS 2014 Survey.
Note: At 25th percentile, the households are moving to specialization while at 75th percentile the household moves to more specialization.

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[1] The Simpson Diversity Index measures the extent of diversity and is calculated as follows

$$DI = \sum_{i=1}^{n} Pi^2$$

Pi = Proportionate area of the ith crop in the Gross Cropped Area.

If $\sum Pi^2 = 1$ there will be complete specialization.

With 51.7%, the stunting rates in 2010 were second highest in the country, higher than the national average of 46.7%. Underweight rates stood at 12.3% while wasting rates were at 2.6% (Figure 1). Also, rural poverty rates in the province are very high (80%) which is the second highest in the country and remain above the national average of 75.5% (IAPRI/CSO/MAL 2012). The high rate of malnutrition amidst high and diversified agricultural production in the province is a paradox that requires evidence-based research drawing effective and sustainable solutions.

Figure 2. Incidence of Stunting, Underweight, and Wasting of Children (3-59 Months) in Zambia
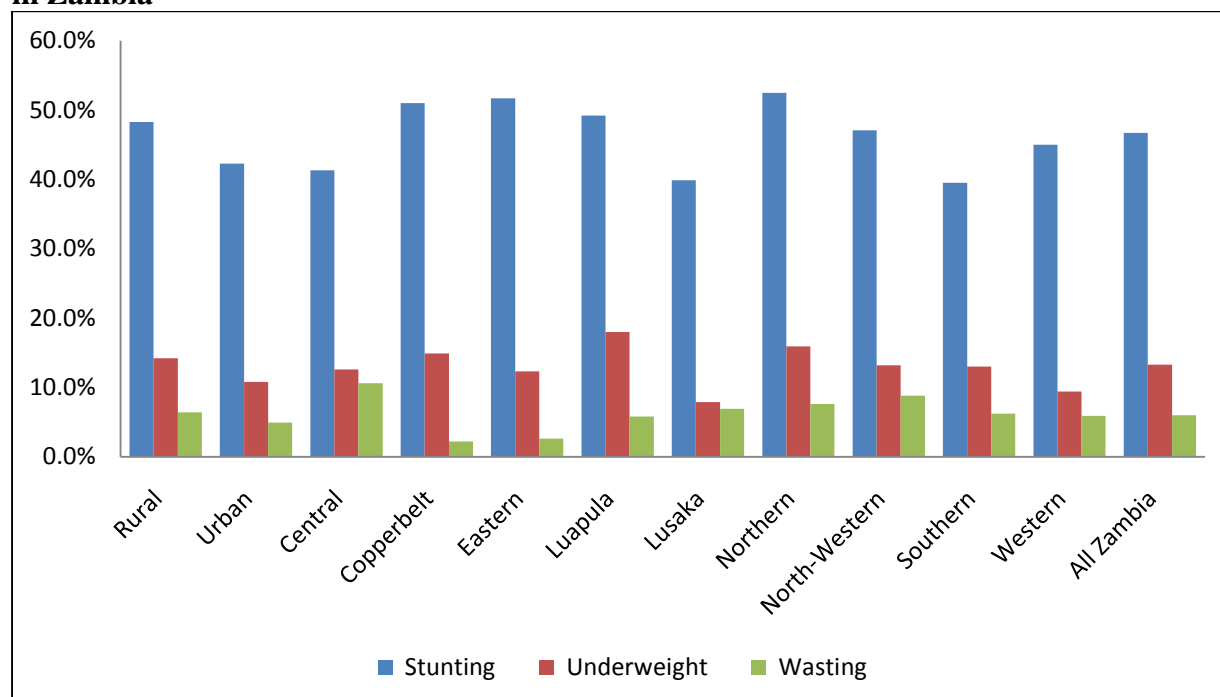
Source: Tembo and Sitko 2013.

3. AGRICULTURE AND NUTRITION LINKAGES

The conceptual framework developed by the United Nations International Children's Fund (UNICEF 1990) provides a fundamental basis for designing the analytical framework on the link between agriculture and nutrition. The interactions between agricultural and health conditions have implications on the utilization of food by the body. A lack of health services can lead to failure by the body to utilize the available food. At household level, the economic status of a household is an indicator of access to adequate food supplies, use of health services, availability of improved water sources, and sanitation facilities, which are prime determinants of child nutritional status (UNICEF 1990).

Based on the UNICEF (1990) framework, Gillespie, Harris, and Kadiyala (2012) developed a framework that reaffirms agricultural initiatives alone cannot solve the nutrition crisis but can make a much bigger contribution than those currently in place. The Gillespie, Harris, and Kadiyala (2012) framework highlights seven key pathways between agriculture and nutrition:

   i. Agriculture as a *source of food*, the most direct pathway in which the household translates agricultural production into consumption (via crops cultivated by the household);
  ii. Agriculture as a *source of income*, either through wages earned by agricultural workers or through the marketed farm-products;
 iii. The link between agricultural policy and *food prices*, involving a range of supply-and-demand factors that affect the prices of various marketed food and nonfood crops, which, in turn, affect the incomes of net sellers and the ability to ensure household food security (including diet quality) of net buyers;
  iv. Income derived from agriculture and *how it is actually spent*, especially the degree to which nonfood expenditures are allocated to nutrition-relevant activities (for example, expenditures for health, education, and social welfare);
   v. Women's *socioeconomic status* and their ability to influence household decision making and intra-household allocations of food, health, and care;
  vi. Women's *ability to manage* the care, feeding, and health of young children; and
 vii. Women's *own nutritional status*, if their work-related energy expenditure exceeds their intakes, their dietary diversity is compromised, or their agricultural practices are hazardous to their health (which, in turn, may affect their nutritional status).

Yet, empirical evidence of the impacts of agricultural interventions on nutrition remains scanty. A review of ten studies by Webb and Kennedy (2014) shows that although there are differences in the methods and focus of the studies, empirical evidence for plausible and significant impacts of agricultural interventions on specific nutrition outcomes remain scarce. However, the absence of evidence should not be mistaken for evidence of no impact. Weakness in methods and general study design may explain the weak results of some studies. They suggest that future investigations on the impact of agriculture on nutrition must be set rationally, based on well-defined mechanisms and pathways.

Gillespie, Harris, and Kadiyala (2012) review 26 studies on the links between agriculture-derived income and household food expenditure or individual nutrition status. The analysis finds that in some studies (e.g., Headey, Chiu, and Kadiyala 2011) agricultural growth rates are significantly associated with improvements in women's BMI but weakly associated with child stunting at the national level. However, Gillespie, Harris, and Kadiyala (2012) conclude that if one looks at heterogeneity across communities, it seems clear that in some areas agricultural growth is associated with improvements in stunting, while in other cases there is a total disconnection.

4. DATA AND METHODS

4.1. Data

We use a uniquely rich dataset that comprises socioeconomic, agricultural, and anthropometric data. The study covers 1,120 children from the Eastern Province of Zambia with data collected in two rounds. The first dataset is based on the 2012 Rural Agricultural Livelihood Survey (RALS), a nationally representative dataset covering 8,839 households. The RALS, which was conducted by the Indaba Agricultural Policy Research Institute (IAPRI) in partnership with the Central Statistical Office (CSO) and the Ministry of Agriculture and Livestock (MAL), provides information for calculating crop diversification and agricultural commercialization.

The second dataset is anthropometric data collected from the same households and is used to calculate stunting (measured by height for age z-score (haz)), wasting (measured by height for weight z-score (whz)), and underweight (measured by weight for age z-score (waz)) in children. This dataset also provides variables related to the health environment. The data was collected in December 2012 which gives almost two years from January 2011 when the household begin to consume the produce from the 2010/11 farming season, to the time of collection of Anthropometric data. This period was very important to examine height-for-age cumulative effects of past nutrition deprivations. The Anthropometric data included only children (0 – 59 months) from the 1,120 households in five districts in Eastern Province.

We calculate diversification using the Simpson Index for production of major food groups: starchy foods, legumes-nuts-seeds, starchy vegetables, non-starchy vegetables, starchy fruits, non-starchy fruits, dairy, and eggs. Table 3 shows the food groups and the produce that fall in the groups.

Table 3. Food Groups and Agricultural Produce

Food Group	Agricultural Produce
Starchy Foods	Maize, Sorghum, Rice, Millet,
Legumes-nuts and Seeds	Sunflower, Groundnuts, Soybeans, Mixed beans, Bambara nuts, Cowpeas
Starchy Vegetables	Green maize, Sweet potatoes, Irish potatoes, Cassava
Non-Starchy Vegetables	Cabbage, Carrots, Rape, Spinach, Tomato, Onion, Okra, Eggplant, Chilies, Pumpkin, Chomolia, Lettuce, Green beans, Impwa, Pumpkin leaves, Sweet potato leaves, Cassava leaves, Beans/Cowpea leaves, Chinese Cabbage, Bondwe
Starchy Fruit	Bananas, Avocado
Non-Starchy Fruit	Oranges, Pineapples, Guavas, Pawpaw, Watermelon, Mangos, Tangerine, Lemons, Grapefruit, Sugarcane, Sweet Sorghum
Dairy	Milk
Eggs	Eggs

Source: Authors.

Meat and meat products could not be added to the list because these were consumed very rarely. We measure production in two ways; firstly in terms of protein production (PDIV) and secondly in terms of calorie production (CDIV).

$$PDIV = 1 - \sum_{i=1}^{S} p_i^2 \qquad (1)$$

$$CDIV = 1 - \sum_{i=1}^{S} c_i^2 \qquad (2)$$

where S is the number of food groups and p and c are protein and calorie content for food group i respectively. Commercialization was measured as an index derived from the share of agricultural sales in household's total value of agricultural production. Descriptive statistics for these variables, as well as other household characteristics variable that were controlled are presented in Table 4.

Table 4. Descriptive Statistics of Balancing Variables

Variable	Description	Mean	Std. Dev.
Nutritional outcome variables			
Stunting (haz)	Length/height-for-age z-score	-1.86	1.69
Underweight (waz)	Weight-for-age z-score	-0.86	1.18
Wasting (whz)	Weight-for-length/height z-score	0.26	1.51
Treatment variables			
Calorie Simpson Index	index "=1-sum of squared calorie shares of the produce.	0.26	0.19
Protein Simpson Index	index "=1-sum of squared crop protein shares of the produce.	0.28	0.18
Commercialization	household commercialization index	0.50	0.27
Farm characteristics			
FHHdefacto	=1 if de facto female-headed HH	0.12	0.33
noformaled	=1 if HH head has no formal education	0.18	0.39
grade1_4	=1 if HH head completed lower primary (grades 1 to 4)	0.18	0.39
grade5_7	=1 if HH head completed upper primary (grades 5 to 7)	0.34	0.47
agehead	Age of the HH head	40.48	12.51
ftesum	Full-time equivalent HH members	6.19	2.57
shareAgeun~5	Share of household members aged below 5	0.20	0.14
shareAge5_14	Share of household members aged 5 to 14	0.30	0.19
shareAbove60	Share of household members aged 60	0.04	0.12
deathinfam~y	=1 if the household experienced death of a member within the reference perion	0.05	0.23
landholdsz12	Total land holding size less rented in and borrowed in	3.58	3.09
landother	sum of land borrowed in and rented in	0.16	0.81
landtitled	land with title deeds	0.28	1.56
deflstock	Value of livestock (real ZMK, 2007/08=100) [2]	2,781,176.00	4,534,321.00
defvalequip	Value of farm equipment (ZMK/10,000; 2007/08=100)	43.07	88.94
fisphh	=1 if HH acquired FISP fertilizer	0.47	0.50
remit_c	Cash remittances received	139,725.90	808,848.70

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[2] At the time of the RALS, the Kwacha-dollar rate was $1 = ZMK5,012.

Variable	Description	Mean	Std. Dev.
remit_m	Value of maize received	7,527.23	32,657.21
remit_o	Value of other commodities received	15,975.00	110,869.80
bomai	Km from the homestead to the nearest boma	31.20	20.74
feedroadi	Km from the homestead to the nearest feeder road	1.81	5.07
agrodealeri	Km from the homestead to the nearest agro-dealer	24.99	20.84
clinic_max	distance to the nearest clinic	6.49	5.97
district2	dist==Katete	0.22	0.42
district3	dist==Lundazi	0.25	0.43
district4	dist==Nyimba	0.10	0.30
district5	dist==Petauke	0.19	0.39

4.2. Method

As indicated before, diversification as well as commercialization can potentially help improving the nutritional status of children. To quantify the effect of both measures, it is possible to employ the typical impact evaluation framework, in which diversification (commercialization) is seen as a treatment, and the nutritional status is the observed outcome. In the following section, we explain the econometric method by focusing on diversification as the treatment, but all the explanations also hold for commercialization.

In a first step, we use a simplified model in which treatment A is a binary variable, i.e., the farmer chooses to diversify (A=1) or not (A=0). This is the conventional impact assessment scenario, and we will later on consider a more flexible approach. The expected treatment effect for the treated population is of primary significance. This effect is given as

$$\tau\mid_{A=1} = E(\tau \mid A=1) = E(O_1 \mid A=1) - E(O_0 \mid A=1)$$

(3)

where τ is the average treatment effect for the treated (ATT), A is a dummy for diversification decision, O_1 denotes the value of the outcome when the household diversified its production, and O_0 indicates the value of outcome in case the household did not diversify its production.

The measurement of the ATT is not trivial. The estimation problem arises due to the fact that it cannot be observed how a diversified household would have performed if it had not diversified its production, i.e., $E(O_0 \mid A=1)$ cannot be observed. Although the difference $[\tau^e = E(O_1 \mid A=1) - E(O_0 \mid A=0)]$ could be estimated, it would potentially be a biased estimator of the ATT, because the groups compared are likely to be different in their characteristics. This is because of self-selection of households, which is likely to occur when farm characteristics affect the utility that a farm derives from diversification or commercialization. To formalize the effect of farm characteristics on the treatment variable, we assume the following relationship between utility U and farm and household characteristics Z of farm household i:

$$U = \alpha' Z_i + \eta_i$$

(4)

8

where η_i indicates the residual. Given that the farmer maximizes utility by choosing whether to diversify or not to diversify, the probability of employing the diversification strategy is shown by the following equation:

$$\Pr(A_i = 1) = \Pr(U_{A,i} > U_{NA,i}) = \Pr(\eta_i > -\alpha'Z_i) = 1 - \Phi(-\alpha'Z_i)$$ (5)

Where $U_{A,i}$ is the maximum utility gained from choosing the treatment while $U_{NA,i}$ is the maximum utility derived from being in the control group. Φ indicates the distribution of the residual, which is logistic in the case of the Logit model we apply in our later analysis. Results of outcome comparisons between groups are biased even if farm characteristics are controlled for in simple regression analyses. To show this, consider a reduced-form relationship between the technology choice and the outcome variable such as

$$O_i = \alpha_0 + \alpha_1 A_i + \alpha_2 Z_i + \mu_i$$ (6)

Where O_i represents a vector of outcome variables for household i such as demand for inputs, A_i denotes a binary choice variable of diversification as defined above, Z_i represents farm level and household characteristics, and μ_i is an error term with $\mu_i \sim N(0,\sigma)$. The issue of selection bias arises if the error term of the technology choice η_i in equation (4) and the error term of the outcome specification μ_i in equation (6) are influenced by similar variables in Z_i. This results in a non-zero correlation between the two error terms, which would in turn lead to biased regression estimates if equation (6) is estimated with conventional OLS techniques. In particular, α_1 would not be a valid estimator of the ATT.

Several econometric techniques exist to re-establish a randomized setting in the case of self-selection. The difference-in-differences method is not applicable, as it requires panel data from several time periods, which are not provided by RALS data. The instrumental variables technique relies on parametric assumptions regarding the functional form of the relationship between the outcomes and predictors of the outcome, as well as on the exogeneity of the instruments used. Since this approach is quite sensitive to violations of these strict assumptions, we follow the matching approach, in which households of the group of diversified farmers are matched to households in the control group which are similar in their observable characteristics.

4.2.1. Generalized Propensity Score

It is common to treat diversification and commercialization as a binary decision variable. The most common method applied is the propensity Score Matching (PSM) which we explain in detail in the appendix. The PSM is, however, an oversimplification, since households produce at different intensity levels of diversification and commercialization. These various levels may have different effects on the nutritional status. In this paper, we change this econometric setup, and measure the impact of different levels of diversification and commercialization. For this, we use the method proposed by Hirano and Imbens (2004) and employ the Generalized Propensity Score (GPS) to balance the differences among farms of different intensity levels. The unbiased heterogeneous impact of different intensities of diversification and commercialization on health outcomes can then be illustrated with dose response functions.

For each household i, we observe the vector of pre-treatment variables X_i, the actual level of treatment received, T_i, and the outcome variable associated with this treatment level $O_i = O_i(T_i)$. Of interest is the dose response function (DRF), which relates to each possible production intensity level t_i, the potential welfare outcome $O(t)$ of farm household i:

$$\theta(t) = \mathrm{E}[O_i(t)] \quad \forall\ t \in \mathcal{T} \quad \text{where}\ \mathcal{T} = (0, \dots, 1] \tag{7}$$

where θ represents the DRF, and t is the treatment level, which is measured as a diversification index (the Simpson index) or as the share of crops sold in total crop revenues (commercialization index). Similar to the conditional independence assumption (CIA) in the PSM setting for dichotomous treatment variables, we presume weak unconfoundedness.[3] In order to adjust for a large number of observable characteristics, Hirano and Imbens (2004) suggest estimating the generalized propensity score (GPS), which is defined as the conditional density of the actual treatment given the observed covariates. Formally, let $r(t,x) = f_{T|X}(t|x)$ be the conditional density of potential treatment levels given specific covariates. Then the GPS of a household i is given as $R_i = r(T_i, X)$. The GPS is a balancing score, i.e., within strata with the same value of $r(t, X)$, the probability that $T = t$ does not depend on the covariates X_i. Due to its balancing property, the GPS can be used to derive unbiased estimates of the DRF (Hirano and Imbens 2004). For this, the conditional expectation of the outcome first needs to be calculated as $\gamma(t,r) = E[O_i|T_i = t, R_i = r]$. The average DRF of equation (7) can then be estimated at particular levels of treatment as follows:

$$\theta(t) = \mathrm{E}[\gamma(t, r(t, X_i))] \tag{8}$$

The GPS is estimated with a generalized linear model (GLM) with covariates X_i and a fractional logit (Flogit) specification, which takes into account that both of the analyzed treatment variables (diversification and commercialization) range between 0 and 1.[4]

The common support condition is imposed by applying the method suggested by Flores and Flores-Lagunes (2009).[5] We test the balancing property of the estimated GPS by employing the method proposed by Kluve et al. (2012).[6] The conditional expectation of the outcome for each farm is estimated using a flexible polynomial function, with quadratic approximations of the treatment variable and the GPS, and interaction terms (Hirano and Imbens 2004). The specification is estimated using OLS regression for continuous welfare outcomes. Then the DRF of equation (8) is evaluated at 10 evenly distributed levels of agricultural diversification

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[3] This assumption essentially postulates that once all observable characteristics are controlled for, there is no systematic selection into specific levels of diversification/commercialization intensity left that is based on unobservable characteristics (Flores and Flores-Lagunes 2009).

[4] The fractional logit model is implemented as a GLM with Bernoulli distribution and a logit link-function.

[5] We thank Helmut Fryges and Joachim Wagner for granting us access to a modified Stata program that allows the imposition of common support.

[6] For the calorie index, six variables are significant at the 1% level before the GPS is included. After the GPS was introduced into all regressions, there is no variable with significant effect on the treatment intensity anymore. In case of the protein index and before the incorporation of the GPS into the regression, seven variables were significant at 1% level, two were significant at 5% level and one was significant at 10% level. After the inclusion of the GPS in the PDIV equations, one variable remains significant, however at a low 10% significance level. For commercialization, the test shows that before the inclusion of GPS, six variables are significant at 1% level and four are significant at 10% level, while none is significant when the GPS is included. We therefore conclude that the variables used for balancing fairly well balance the differences in farm characteristics and go on with the analysis of the treatment effect.

or commercialization. Confidence bounds at 95% level are estimated using the bootstrapping procedure with 1,000 replications.

5. RESULTS

5.1. Results of Treatment with Diversification of Calorie Production

Figure 2 depicts the effects of different intensities of calorie diversification on the nutritional status of children. In each of the three diagrams a), b) and c), the x-axis indicates the intensity of calorie diversification measured in terms of the Simpson index (CDIV), and the y-axis measures the expected effects on a) stunting b) underweight and c) wasting at the a given level of diversification. Diagram d) is a simple histogram that shows how farmers are distributed over the intensity levels of calorie diversification. Once the continuous nature of diversification is taken into account, trends can be observed in terms of how calorie diversification affects the nutritional status of children.

5.1.1. Stunting Effects of Diversification of Calorie Production

The stunting indicator shows that the long term nutritional effect of calorie diversification tends to be positive at low diversification levels (i.e., high specialization), however at a relatively marginal rate. As shown in Figure 2, the dose response function (DRF) depicted in diagram a) has a maximum at roughly 0.3, and becomes negative at high levels of diversification.

Figure 2. Nutritional Status and Calorie Production Diversification (Simpson Index)
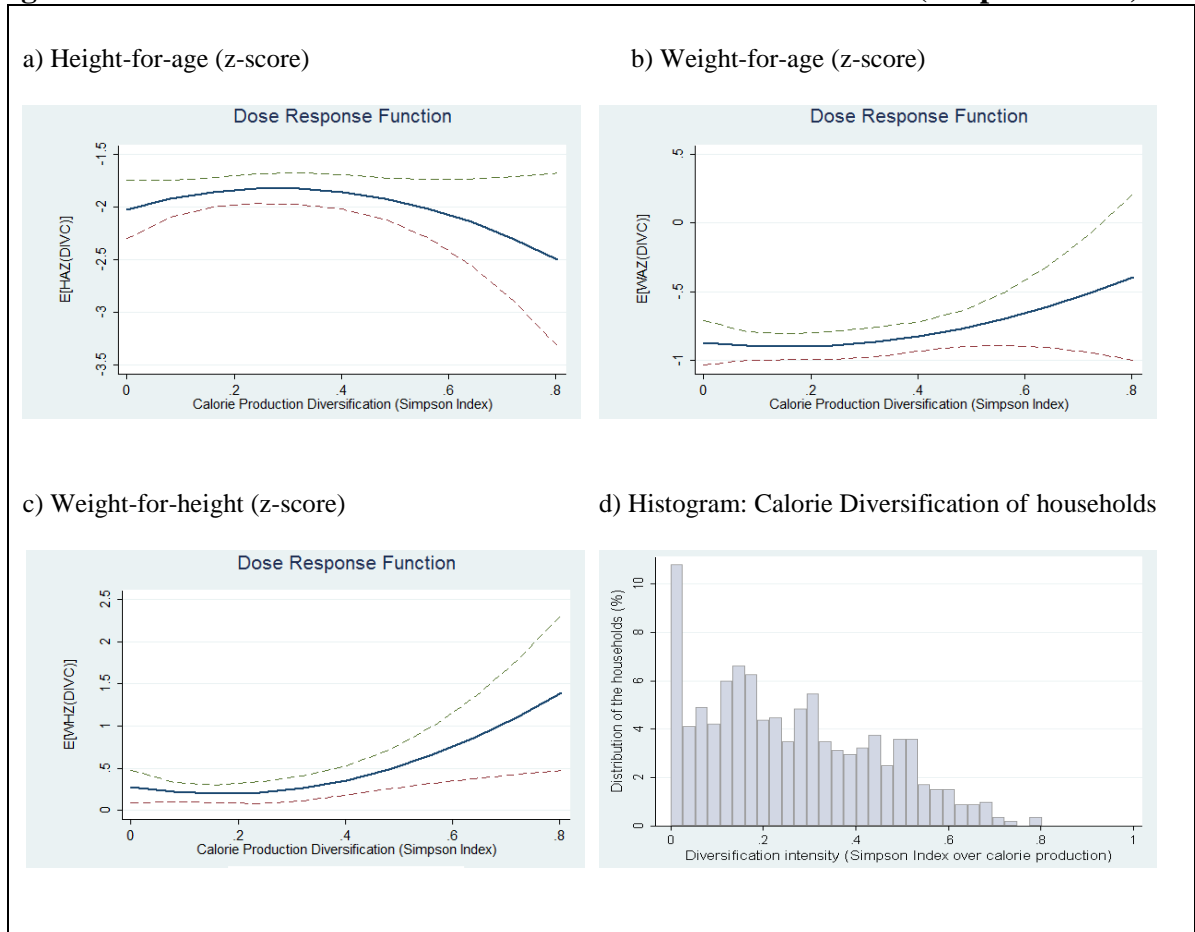
a) Height-for-age (z-score)

b) Weight-for-age (z-score)

c) Weight-for-height (z-score)

d) Histogram: Calorie Diversification of households

Source: Authors.
Note: the straight line is the dose response function and dashed lines indicate the 95% confidence interval.

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An explanation for this non-linear relationship might be that on the one hand, specialization in very few crops results in a permanently less diverse diet with quickly arising long-term consequences for nutritional status of the child. On the other hand, extremely high diversification levels could reduce food security of children due to a less efficient production structure that delivers fewer amounts of nutrients than less diversified farms could produce. The histogram (d) and a median of calorie diversification at 0.23 indicate that for most farmers a moderately increased diversification of food production would be beneficial with respect to long-term nutritional outcomes.

5.1.2. Underweight and Wasting Effects of Diversification of Calorie Production

The DRFs for the effect of calorie diversification on underweight (graph b of Figure 2) and wasting (graph c of Figure 2) are similar, but show a very different shape than the stunting function. Both graphs show a positive relationship between calorie diversification and the children's nutritional status. High levels of diversifications may prevent households from short term shock situations due to their stable provision of diverse set of nutrients that are correlated with calories from different agricultural products.

It has to be kept in mind however, that very few farms have actually reached diversification levels above 0.5, as the histogram shows. In these very high intensities of calorie diversification, the estimations of all three DRFs are, therefore, based on few treatment units and should therefore be interpreted with caution. This is also seen by the spread of the confidence interval at that point of intensity in all study graphs. Thus, although the average effect has a clear trend, statistical predictions become shakier.

5.2. Treatment with Diversification of Protein Production

Figure 3 presents the heterogeneous effect of protein diversification on the nutritional outcomes. As in Figure 1, graphs a), b), c) indicate the dose response on Stunting, underweight and wasting, respectively, and graph d) shows the distribution of farmers on protein diversification levels. The effects are very similar to the calorie diversification, but have one major difference.

5.2.1. Stunting Effects of Diversification of Protein Production

The stunting dose response function remains flat over the whole range of treatment levels, therefore indicating that for stunting levels there are in fact no significant effects to expect from a diversification in protein sources (Graph a of Figure 3). This is not surprising, given that the data used for calculating the treatment variable did not provide enough timeframe to establish impact on long-term nutritional status.

5.2.2. Underweight and Wasting Effects of Diversification of Protein Production

However, the protein effect on underweight and wasting are clearly positive and significant at quite high levels of diversification (Graph b and c of Figure 3 respectively).

Figure 3. Nutritional Status and Protein Diversification (Simpson Index)
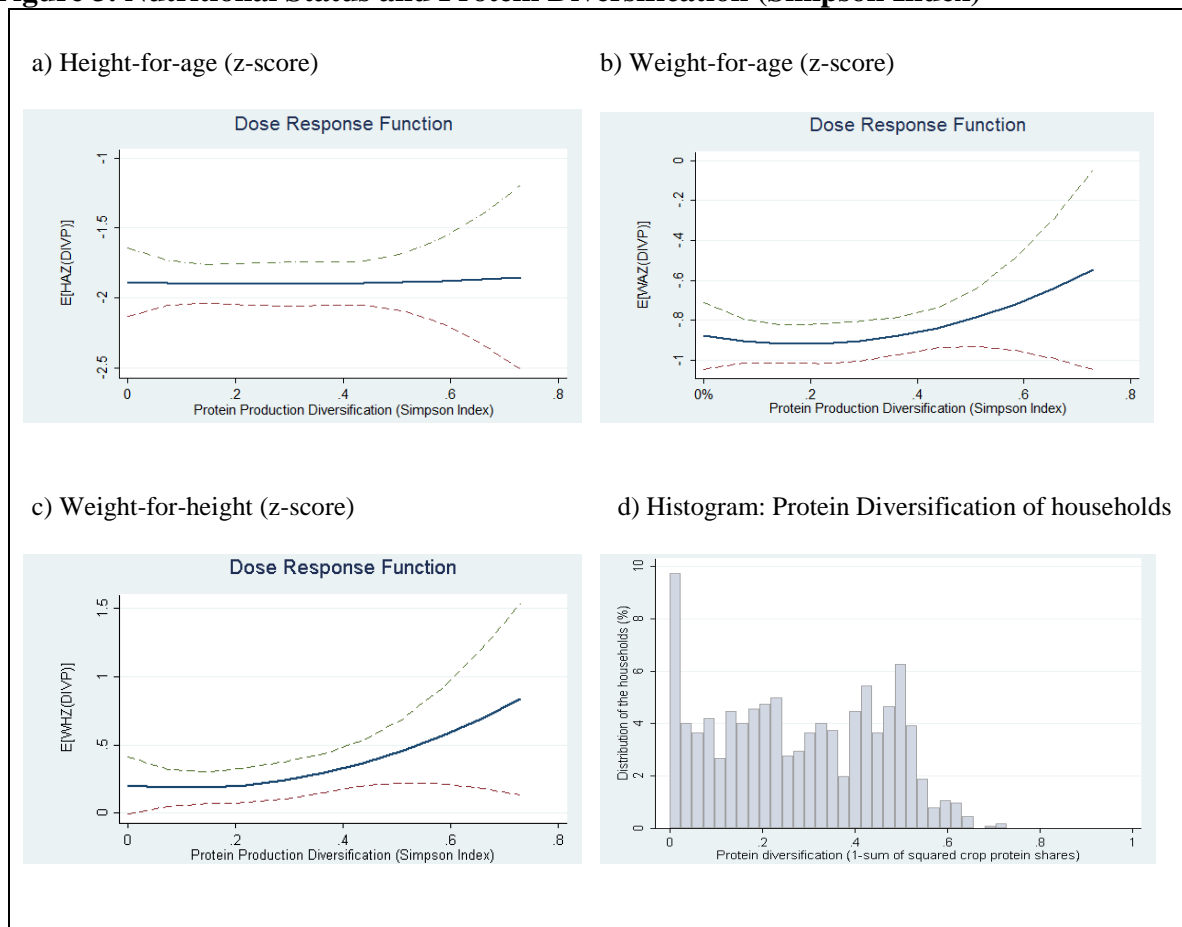
a) Height-for-age (z-score)

b) Weight-for-age (z-score)

c) Weight-for-height (z-score)

d) Histogram: Protein Diversification of households

Source: Authors.
Note: the straight line is the dose response function and dashed lines indicate the 95% confidence interval.

Since animal products contribute quite significantly to protein supply, and that products like milk and eggs deliver protein continuously over the time, it seems that their stabilizing effect contributes to the short- and middle-term nutritional outcomes of children.

As with calorie diversification, the histogram d) shows very few farms at protein diversification levels above 0.5. Therefore, results should be interpreted with care, but there is nevertheless a quite clear upward trend at high levels of protein diversification.

5.3. Treatment with Agricultural Commercialization

Figure 4 presents the effect of commercialization on the nutritional outcomes, and the histogram of commercialization. Unlike the diversification curves, commercialization seems to have a negative slope for underweight and wasting, and also for most intensity levels of stunting. However, at higher intensities of commercialization, commercialization seems to become more beneficial for the nutritional long-term status (reducing stunting), but it only reaches similar levels as those households with no commercialization at all. There might be two strategies to tackle the large problem of stunting in Zambia, either specializing in cash crops, or going into a subsistence farm, which maybe has other income sources than agriculture. While farmers might not want to fully go into either of both strategies, the graphs indicate that commercialization at medium levels does not, in general, result in more

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beneficial stunting outcomes. The histogram seems to confirm the finding of two commercialization strategies, as it is clearly bimodal with a considerable numbers of households producing near subsistence levels, but the largest fraction of households at intensities beyond 40%.

Figure 4. Nutritional Status and Agricultural Commercialization Index
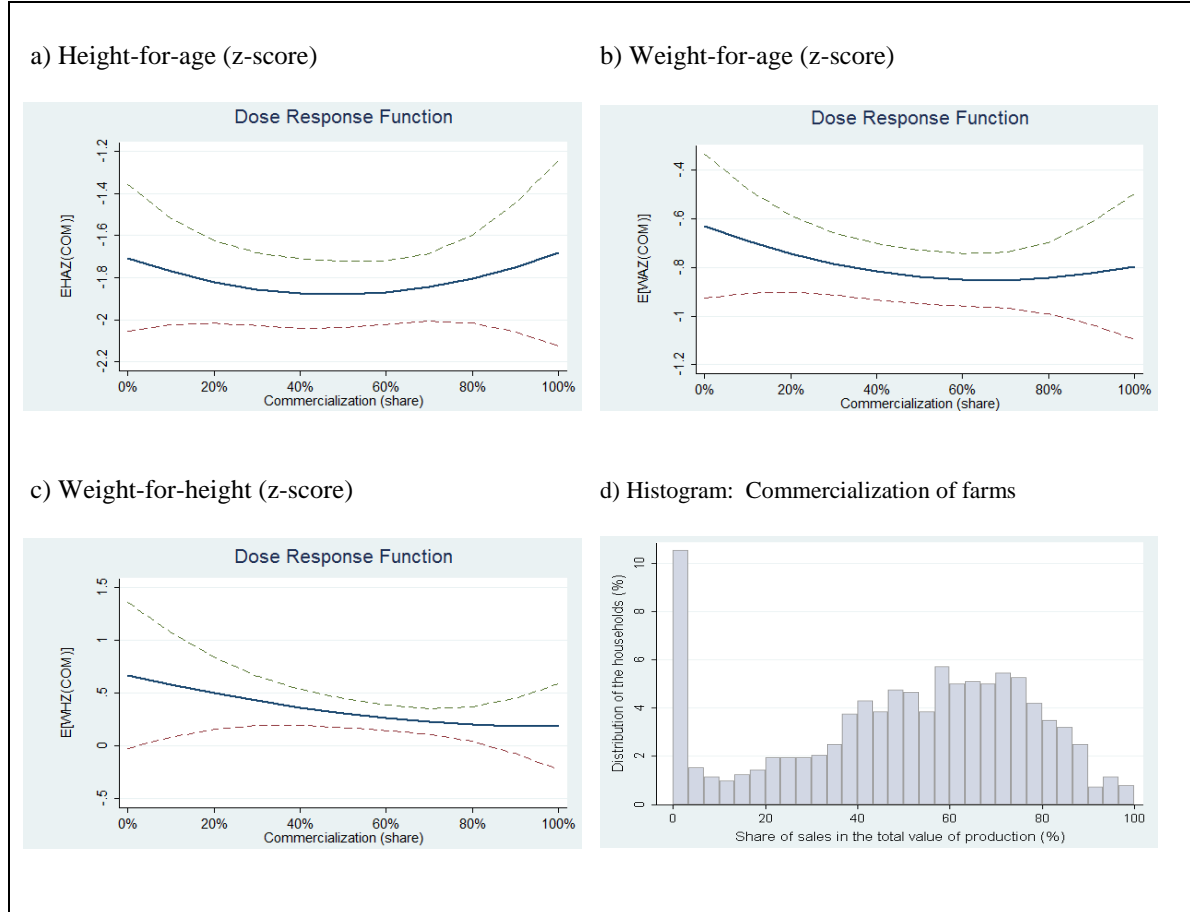
a) Height-for-age (z-score)

b) Weight-for-age (z-score)

c) Weight-for-height (z-score)

d) Histogram: Commercialization of farms

Source: Authors.
Note: the straight line is the dose response function and dashed lines indicate the 95% confidence interval.

6. CONCLUSION AND POLICY RECOMMENDATIONS

Agricultural diversification and commercialization remain critical for improving the nutrition status of children. However, there are important aspects of improving nutritional status of children with the two agricultural strategies that need to be taken into account. First, the results in this paper have shown that intensity of treatment (crop diversification and commercialization) at household level matters in the nutrition status of the children. Very high levels of diversification can improve nutritional status while smaller levels do not have significant impacts.

Second, it is important to promote agricultural production diversification according to the food groups because different food groups have varying impact on different forms of malnutrition. The impact of protein production diversification has a positive and significant effect at high levels of diversification for short and medium term malnutrition effects. However, the impact on long term malnutrition is not significant even with increasing intensity of diversification. Also, the impact of calorie diversification is non-linear, an indication that specialization in very few crops results in a permanently less diverse diet with quickly arising long-term consequences for nutritional status of the child. This is consistent with food production and consumption patterns in rural Zambia which is mainly based on calorie consumption. These results explain why stunting is high despite a diversified calorie production.

Third, commercialization has a significant but negative effect on improving the short-term malnutrition status of children. Referring to the high commercialization index of 0.5 (50 percent of production is sold), the results imply that most households sell most of their agricultural produce, regardless of the quantities produced, leaving very little for home consumption. It can further be concluded that the revenue realized from these sales, is not being spent on purchasing nutritious food.

Policies need to consider the current diversification intensity of households and the different consequences on wasting and stunting when implementing diversification strategies. High levels of diversification could improve the wasting and underweight status of children by delivering a high amount of nutrients, but may come at the cost of reducing the production efficiency of the households and thus increasing the possibility of longer term stunting. Interventions, such as outgrower schemes, focused on improving agricultural diversification and high degrees of commercialization may enhance adequate and diverse protein and calorie sources, while at the same time providing households with the opportunity to sell their agricultural products on the market to meet their other income demands.

APPENDICES

APPENDIX A: NUTRITION AND ANTHROPOMETRY MEASURES

Nutrition explains how food nourishes the body. Sizer and Whitney (2000) describe the human body as dynamic in that it renews its structures continuously, building muscle, bone, skin, and blood, and replacing old tissues with new. The body requires good quality water, and food that is rich in energy and sufficient nutrients such as carbohydrates, fats, protein, vitamins, and minerals. In broader terms, nutrition security is defined as "combining secure access to highly nutritive and quality food within a sanitary environment, adequate health services, and knowledgeable care to ensure a healthy life for all household members across time and space" (Gillespie 2006).

In the year 2000 at a United Nations millennium development summit, the need to develop progress monitoring tools of the MDGs was emphasized such that it was necessary to adopt specific indicators for the goals. Among such indicators were the nutrition indicators which become critical for assessing progress of the nutritional status of the population and monitor government policies achievement. Anthropometric measurements, defined as body dimensions and composition, have become increasingly useful tools for examining an individual's body parameters to indicate nutritional status or even the extent and severity of malnutrition in a given population. The most widely used measurements are the weight and height which may be combined to examine nutritional status.

In some cases, birth weight is used to assess nutritional status of new-borns as well as of the mother during pregnancy (See Chevassus-Agnès 1999). Ideally, anthropometry measures show the response of the body dimensions, composition, and growth to the quantity and composition of food intake (Table A1). The measures provide insights into whether an individual or a population needs nutrition interventions.

Each of the indices, the height-for-age, weight-for-height, and weight-for-age provide different nutritional information. The height-for-age index is explains the linear growth of a child. A Z-score of below minus two standard deviations (<-2 SD) from the median of the reference population indicates stunted. Children falling in this category are considered short for their height, an indication of chronically malnourished and recurrent illness. Below minus three (<-3 SD) from the median of the reference population is an indication of severely stunted. Therefore, the height-for-age indicator does not only explain the current status but also the future risks, as the effect is chronic. In that case, policy interventions should be directed towards long-term solutions.

Weight-for-height explains acute malnutrition and therefore requires speedy interventions. Similarly, a Z-score of <-2SD from the median of the reference population means the child is thin for the height, a condition referred to as being wasted. Children whose Z-score falls below minus three (<3SD) a considered severely wasted. Inadequate nutrition prior to the survey or acute illness leading to sudden loss of weight may be the cause of wasted children. Studies show that height-for-age has greater sensitivity[7] than height-for-weight in identifying children that are likely to die in the next two years (WHO 1995).

The weight-for-age indicates underweight, a condition resulting from both chronic and acute malnutrition. A Z-score of below minus two standard deviation (<-2 SD) from the reference population indicates underweight while <-3 SD indicates severe underweight.

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[7] Sensitivity explains the anthropology indicator in relation to death. However it is beyond the scope of this study to get into detailed sensitivity calculation.

Table A1. Anthropometry Index and Challenge Measured

Index	Nutritional challenges measured
Weight-for-height	Acute malnutrition (wasting)
Height-for-age	Chronic malnutrition(Stunting)
Weight-for-age	Any protein-energy malnutrition (Underweight)
BMI	Under or over nutrition
Birth weight	Maternal nutrition and baby survival chances at birth.

Source: WHO 1995.

It is therefore important to select the anthropometry indicator according to the objective of the intended policy intervention. Decisions as to what nutritional or agricultural interventions are required, for which population, how soon, and how the intervention should be carried out. Table A1 shows the index and the national challenges that are measured.

The severity of malnutrition is measured by prevalence rate and differs across the indicators as seen in Table A2. For stunting, a prevalence rate of 40% is considered very high while for underweight very high is anything above 30%. Wasting is considered very high if more than 15% of the children in a given population have a z-score of <2 SD. The classification for assessing the severity of malnutrition in a given population is presented in Table A2.

Table A2. Classification for Assessing Severity of Malnutrition

	Indicator Severity of malnutrition by prevalence ranges (%)			
	Low	Medium	High	Very high
Stunting	<20	20-29	30-39	>=40
Underweight	<10	10-19	20-29	>=30
Wasting	< 5	5-9	10-14	>=15

Source: CSO 2012.

APPENDIX B: PROPENSITY SCORE MATCHING APPROACH

Given the multitude of factors potentially influencing the adoption decision, it is hardly possible to match each household of the group of adopters with an adequately similar household in the group of non-adopters. As a solution to this problem, Rosenbaum and Rubin (1983) have shown that it is possible to use the propensity of adoption as a single indicator for similarity, making it a balancing score in the matching process. The propensity score is defined as the conditional probability that a farmer is diversified, given pre-adoption characteristics (Rosenbaum and Rubin 1983). To create the condition of a randomized experiment, the PSM employs the unconfounded assumption also known as conditional independence assumption (CIA), which implies that once X is controlled for, participation is random and uncorrelated with the outcome variables. The PSM can be expressed as,

$$p(X) = \Pr\{P = 1 \mid X\} = E\{P \mid X\} \tag{A1}$$

where P = {0,1} is the indicator for being diversified and X is the vector of household and farm characteristics. Given CIA, the conditional distribution of X, given p(X) is similar in both groups of participation and non-participation, so the effect measured after balancing with the propensity-score is like in a randomized experiment.

The CIA is a strong assumption. If selection into treatment is based on unmeasured characteristics, there may still be systematic differences between outcomes of diversified and non-diversified households even after conditioning on the propensity score (Smith and Todd 2005). However, Jalan and Ravallion (2003) pointed out that the CIA assumption is no more restrictive than those of the IV approach employed in cross-sectional data analysis.

In our study, we match on the odds ratio, since Leuven and Sianesi (2003) indicated it to be the general suggestion for household survey data. These odds ratio is calculated with a Logit model of equation (3). The empirical analysis is then carried out by employing the approach suggested by Rosenbaum and Rubin (1983).

After having computed the balancing score for each household, the average treatment effect for the treated (ATT) is estimated by the average differences of matched pairs with similar score values. This can be stated as

$$\begin{aligned}\tau &= E\{O_1 - O_0 \mid A = 1, p(X)\} \\ &= E\{E\{O_1 \mid A = 1, p(X)\} - E\{O_0 \mid A = 0, p(X)\} \mid A = 1\}\end{aligned} \tag{A2}$$

Several techniques have been developed to match adopters with non-adopters. In the current paper the Nearest Neighbour Matching (NNM) method is employed.

Results from the Propensity Score Matching

We used the variables of Table B1 to calculate the odd ratios with a logit model. For the sake of brevity, we do not show the results of the propensity-score calculation, since this model is not for interpretational purposes but just for deriving a sample of matched households that are well balanced in their characteristics.[8] The estimation results of the PSM method are shown in Tables B1, B2, and B3.

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[8] The results can be obtained from the authors by request.

Table B1. ATT with Calorie Diversification Index Greatment Variable

Variable	Sample	Treated	Controls	Difference	S.E.	T-stat
waz	Unmatched	-.8609319	-.862720721	.001788821	.070863297	0.03
	ATT	-.8609319	-.913154122	.052222222	.12039295	0.43
haz	Unmatched	-1.84740143	-1.81327928	-.034122154	.097209559	-0.35
	ATT	-1.84740143	-1.93446237	.087060932	.155240961	0.56
whz	Unmatched	.292903226	.217063063	.075840163	.090368959	0.84
	ATT	.292903226	.225716846	.06718638	.144038334	0.47

Table B2 shows results from treatment with protein production diversification Simpson index. Unlike the treatment with calorie production diversification, the treatment with protein diversification has significant impact on the reduction of stunting (by 0.30 Simpson index), but not on the reduction of wasting and underweight. The impact is positive in consideration of the fact that children from more protein production diversified households (0.26 and above Simpson Index), have a higher stunting rate than those from less diversified households. However, the difference of 0.30 is too small if children are severely stunted. As mentioned above, PSM does not account for different intensity levels of protein production diversification, such that child nutritional status is affected differently at different intensities.

Table B3 shows the results when treatment is commercialization index. The results show no significant impact on all the three malnutrition measures.

The insignificance of all these measures could however indicate that the application of the PSM method is not appropriate, as it requires the somewhat arbitrary categorization in diversified and non-diversified farmers and commercialized and non-commercialized farmers, respectively. Households however produce at different intensity levels of diversification and commercialization, which could have different effects on child nutrition. Since PSM cannot capture such heterogeneous effects of different intensity levels, we employ the GPS approach in the following section.

Table B2. ATT with Protein Diversification Index as Treatment Variable

Variable	Sample	Treated	Controls	Difference	S.E.	T-stat
waz	Unmatched	-.812468694	-.911624549	.099155855	.070801306	1.40
	ATT	-.810752688	-.877741935	.066989247	.10514265	0.64
haz	Unmatched	-1.79872987	-1.86232852	.063598645	.09719685	0.65
	ATT	-1.79587814	-2.10082437	.304946237	.139056961	2.19
whz	Unmatched	.323255814	.186299639	.136956175	.090304752	1.52
	ATT	.323405018	.420125448	-.09672043	.132186981	-0.73

Table B3. ATT with Commercialization Index as Treatment Variable

Variable	Sample	Treated	Controls	Difference	S.E.	T-stat
waz	Unmatched	-.85099278	-.87255814	.02156536	.070860821	0.30
	ATT	-.861797753	-.937827715	.076029963	.126946814	0.60
haz	Unmatched	-1.76144404	-1.89871199	.137267942	.097128309	1.41
	ATT	-1.75303371	-1.93011236	.177078652	.18571376	0.95
whz	Unmatched	.200794224	.308890877	-.108096653	.09033999	-1.20
	ATT	.178651685	.298370787	-.119719101	.183225724	-0.65

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