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An egg for an egg and a bean for a bean?

How production diversity determines dietary diversity of smallholder farmers in rural India

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Abstract

On-farm production diversity of smallholder farmers can improve the nutrition security of the household. The objective is to determine the significance and relevance of this relationship by considering the different degrees of separability between both the commercial and consumptive production of food. A household-level survey covering socioeconomic, agricultural and nutritional data was conducted in three regions of India from January to June 2017 including 1324 households in 119 villages. Various regression specifications (OLS, Poisson, Probit, IV / non-IV) were used to estimate the effect of production diversity on dietary diversity. Average yearly rainfall since 1981 is the excluded instrument. A positive association is estimated (ß: 0.417 / 0.016 | IV / non-IV). Access to markets improve dietary diversity on average by 0.5 food groups. The increase is significant only for a few food groups (dairy products, nuts and vegetable) and primarily, it is the higher income groups that benefit from market integration. In conclusion, production diversity does improve nutrition security, but the positive market effect is stronger for farming households that have a higher income.

Keywords: nutrition-sensitive agriculture, dietary diversity, agricultural production, India

JEL Classification: D13, Q12, C26

1 Introduction

Nutrition-sensitive agriculture is a buzzword that has attracted attention of development implementation and science alike since the global food crisis in 2007/08. Per Pinstrup-Andersen called for better research on how nutrition-sensitive food systems can effect nutrition security, because implementation up until this point was limited to small-scale projects such as kitchen gardens (2013). In a broader scale it is understood that biodiversity of the environment affects human nutrition (Frison, Cherfas, & Hodgkin, 2011). More specifically, the diversity of agricultural food production systems can affect food consumption. Hence, this study looks at the allegedly non-nutritional factors of smallholder farmers' food production and the household members' dietary consumption.

There are various pathways through which agricultural production can affect dietary intake of individuals and households. Prominently discussed is agriculture as a producer of food for the farming households, agriculture as an income generator through which food can be purchased, and agriculture as a vehicle for decision-making power on intra-household food allocation through women's participation and empowerment (Ruel & Alderman, 2013). Hence, the quality and quantity of diets depend on the agricultural production. The linkages are particularly strong in rural areas where agricultural production takes place in smallholder settings. The absolute yield is an approximation to the quantity of available food. Production diversity on the other hand can guide as a reflection of the diverse quality of production. Figure 1 presents a conceptual framework that indicates the possible pathways at the level of a farming household. On-farm production is divided into commercial and consumptive production. The decision on division is made based on factors such as commodity prices, market integration, value chain development and integration or storage capacities. Market-oriented production is primarily used for income generation, which again creates the option for possible food purchases. The decision on the extent of food purchases is influenced by individual preferences, food availability or food prices. Food expenditures are also influenced by subsistence food production e.g. in case certain items are produced instead of purchased. The final quality and diversity of the dietary intake is a result of intra-household food allocation choices. The future on-farm production diversity is again influenced by various factors, among these are consumption preferences and market demand considerations.

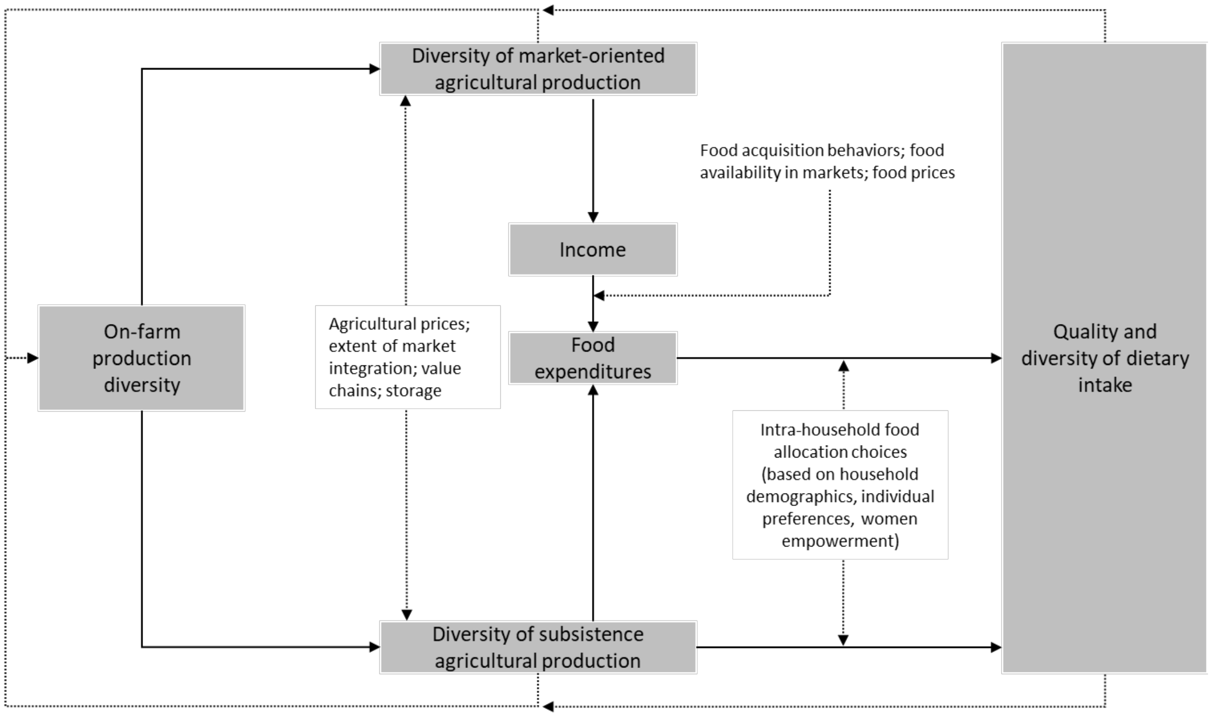

Figure 1: Conceptual framework for smallholder farming households. Source: Author's illustration based on Jones (2017)

This study focuses on the contribution of one research objective: to identify the effect of production diversity on nutrition security. The two research questions and associated hypotheses are:

- Do production choices affect nutrition choices of smallholder farmers?

  Hypothesis 1
  On farm production diversity as measured through the diversity of food groups produced has a positive effect on dietary diversity of the household and of individual household members.

- Does market access influence this relationship?

  Hypothesis 2
  With improving market access, the relationship between on farm production diversity and dietary diversity diminishes.

2 Empirical Evidence and Contribution

Links between production and consumption from a nutritional point of view have been quantitatively studied only quite recently. Robust results were produced with nationally representative data from Malawi (Jones, Shrinivas, & Bezner-Kerr, 2014), in which the effects of production diversity was positively estimated to affect the Household Dietary Diversity Score (HDDS) in agricultural households. Production diversity was measured through the Simpson's Index, an index that considers the number of crops as well as the distribution area on which these are cultivated. The Simpson's Index also accounts for permanent crops and tree crops that grow in the designated area. HDDS and Simpson's Index are suboptimal measures. The HDDS does not measure dietary diversity, but the access to food, hence the quantity (Swindale & Bilinsky, 2006). The Simpson's Index considers more crops than are considered in dietary diversity scores, a homogenization of measurements are necessary for a priori causality claims. Furthermore, given the non-separability condition of agricultural households, the linkage between agricultural production and consumption is further dependent on the access to markets (Singh, Squire, & Strauss, 1986).

In a cross-country comparison, Malawi, Kenya, Ethiopia and Indonesia were compared (Sibhatu, Krishna, & Qaim, 2015a). Market access was interacted with production diversity to measure the combined effect on dietary intake. The authors found a positive effect, however market access seems to negate the effect of production diversity on consumption diversity. Unfortunately, the methodological approach for measuring and comparing the questioned indicators were again insufficient (Berti, 2015; Remans, DeClerck, Kennedy, & Fanzo, 2015; Sibhatu, Krishna, & Qaim, 2015b). The most recent economist approach to unravel the relationship contains surprisingly a similar shortcoming, though with different indicators (again HDDS was used) (Koppmair, Kassie, & Qaim, 2016). The academic debate recognizes the need for a more careful selection of indicators, but also to take into account the infrastructural aspects such as market access (Koppmair & Qaim, 2017a, 2017b; Verger, Jones, Dop, & Martin-Prével, 2017). On the other hand, in a longitudinal set-up, Jones (Jones, 2017) confirms the effect on dietary diversity but finds no negating effect of market access in Malawi.

While most of the research is done in Sub-Saharan Africa, there are a few papers that particularly consider the South Asian setting. In India, one paper does not show any correlation between production diversity and household dietary diversity (Kavitha, Soumitra, & Padmaja, 2016). However, production diversity was measured with the Simpson's Index over one year, instead of considering the latest season. Also, the survey was conducted in an area that primarily applies mono-cropping. In Nepal a positive relation was found (Malapit, Kadiyala, Quisumbing, Cunningham, & Tyagi, 2015). However, this paper was more focused on the aspects of women empowerment and included production diversity as a control.

The presented literature is also limited in aspects of causality. The causal linkages are primarily based on theoretic considerations. Dillon et al. (2015) tried to overcome this shortcoming by using an IV approach, utilizing climate variability as an instrument for production. They conclude that climate variability could be a possible instrument, but their results indicate that climate variability is a better instrument for agricultural revenue in general, thus missing the point of reflecting production diversity. Hirvonen and Hoddinott (2017) propose temperature, altitude, the interaction of these and the slope of the farm land as an instrument. They find a positive effect on the diets of pre-school children in Ethiopia, and a particularly strong relation for households with partial access to markets. However, production diversity was calculated by considering the output of a full year, which is hard to justify for perishable goods in this particular context.

Accordingly, improvements to the research topic will be made in the following way. The robustness of results are still missing and needs to be considered (Hirvonen & Hoddinott, 2017, p. 11) as well as improvements to the identification strategy. The effect of market access needs to be clarified and most importantly, the correct indicators need to be used (see debates on Koppmair, Kassie, & Qaim, 2016; Sibhatu, Krishna, & Qaim, 2015a). The specific regional context is also important and as such, no information on South Asia is sufficiently provided (Jones, 2017, p. 94). Furthermore, this study looks particularly at smallholder households in India. Thereby, this study adds to the existing literature by using a homogenous data source from three different regions in India using cross-sectional surveys that were similarly conducted. The questionnaire design includes most of the indicators and information that were discussed by literature, which was previously not possible due to the recent developments in this field.

3 Data

3.1 Data description

This study relies on primary data that was collected in the states of Jharkhand, West Bengal and Karnataka in India between January and June 2017. Village-level data and market information complements the household-level survey. The used data is a subset of a larger dataset that was collected for an overall research objective. The sample size of the initial dataset consisted of 1324 households in 119 villages of the 3 regions. The regions were chosen to suite the overall research objective (i.e. rural areas that are prone to environmental shocks such as droughts and floods). We utilized a two-stage cluster sampling technique: the villages were randomly chosen from pre-identified districts and the households were also randomly chosen, partly on the basis of a random draw from current census data. If the census data was not up to date, we used the random walk technique for identification of the respondent households. The initial sample size was reduced to 811 households in 106 villages and 3 regions because of the focus on households with agricultural production. We have individual data for the household heads as well as for the spouse of one household. Nutrition information is available for the female household head/spouse and for at least one child below 2 years per household. The main variables to be used in this study are described in the following Table 1.

Table 1: Description of main variables

Variables	Description
Dietary Diversity Score	Number of food groups consumed by woman in past 24 hours on a scale of 10 food groups
Production diversity	Number of food groups produced by household in past season on a scale of 10 food groups
Age woman	Age of woman in years
Literacy of woman	Binary variable on literacy level of woman (1 = literate, 0 = illiterate)
Age of household head	Age of household head in years
Highest formal education among adult household members	Most years of formal education among household members >14
Female headed households	Binary variable if household is headed by female (1 = yes, 0 = no)
(log) Total value of liquidable assets	Value of liquidable assets
Religion	Categorical variable of household head's religion (1 = Muslim, 0 = Hindu)
Number of males 0-5 years	Count variable for number of males 0-5 years
Number of males 5-15 years	Count variable for number of males 5-15 years
Number of males 15-60 years	Count variable for number of males 15-60 years
Number of males 60+ years	Count variable for number of males 60+ years
Number of females 0-5 years	Count variable for number of females 0-5 years
Number of females 5-15 years	Count variable for number of females 5-15 years
Number of females 15-60 years	Count variable for number of females 15-60 years
Number of females 60+ years	Count variable for number of females 60+ years
Primary occupation of household is non-farm	Binary variable if primary occupation is non-farm (1 = yes, 0 = no)
Total land size	Total land available for agricultural production in hectares

Variables	Description
Number of government schemes that were used by household	Count variable of number of government schemes that the household was utilizing (counted if at least one member is using a scheme)
Distance to next market	Distance to the next available market in km
Household member visiting regularly next market	Binary variable if a member of the household is visiting the next available market regularly (1 = yes, 0 = no)
Village population	Population size of the household's village
No. of years that village is electrified	Number of years since the household's village received access to electricity
Regions	
Region: Jharkhand	Binary variable if household lives in region Jharkhand (1 = yes, 0 = no)
Region: West Bengal	Binary variable if household lives in region West Bengal (1 = yes, 0 = no)
Region: Karnataka	Binary variable if household lives in region Karnataka (1 = yes, 0 = no)
Average yearly rainfall since 1981	Average yearly rainfall calculated since 1981 in mm

The average household has 5.2 members, is male-headed and has a gender ratio of 0.48 women to men. The age of the household head is approximately 42 years, the age of the spouse is 33 years. The average household head has 6 years of formal education and 78% of the sample's household head are working primarily in agriculture-related activities either as a farmer or day laborer, however all households are producing food products either through livestock or through plots and gardens. The average income per capita is 1542 Rs. per month at adult equivalence (ca. 24 USD). Table 2 shows the summary statistics in detail.

Table 2: Summary statistics for variables

Variables	min	max	mean	sd
Dietary Diversity Score	1	7	3.64	1.20
Production diversity	1	8	3.05	1.17
Age in years of woman	18	80	33.57	12.36
Literacy of woman	0	1	0.54	0.50
Age of household head	20	90	42.38	13.65
Highest formal education among adult household members	0	17	5.96	4.30
Female headed households[ˠ]	0	1	0.00	0.07
(log) Total value of liquidable assets	6.68	15.58	11.24	1.71
Religion				
Hindu	0	1	0.91	0.29
Muslim	0	1	0.09	0.29
Number of males 0-5 years	0	3	0.45	0.67
Number of males 5-15 years	0	4	0.30	0.60
Number of males 15-60 years	0	5	1.67	0.87
Number of males 60+ years	0	2	0.22	0.42
Number of females 0-5 years	0	3	0.43	0.66
Number of females 5-15 years	0	4	0.37	0.70
Number of females 15-60 years	0	5	1.57	0.75
Number of females 60+ years	0	2	0.17	0.38
Primary occupation of Household is nonfarm (0 = yes, 1 = no)	0	1	0.12	0.33
Total land size (ha)	.01	24.58	0.84	1.23
Number of government schemes	0	7	3.10	1.42

Variables	min	max	mean	sd
that were used by household				
Distance to next market (km)	.07	20	4.96	4.65
Household member visiting regularly next market	0	1	0.75	0.43
Village population	75	12000	1314.85	1484.90
No. of years that village is electrified	1	67	27.63	20.67
Regions				
Region: Jharkhand	0	1	0.40	0.49
Region: West Bengal	0	1	0.08	0.27
Region: Karnataka	0	1	0.52	0.50
Average yearly rainfall since 1981 (mm)	734	1380	1094	217

Note: Sample size is 811 households
ˈOnly 4 households are female headed

3.2 Dependent variables

This study examines nutrition security as a set of various nutrition intake variables by estimating multivariate regression models. Many various indicators exist to estimate the nutrition security of households and individuals. Concerning micronutrient deficiency, estimating the micronutrient content of human blood is the most exact approach, though also the most costly and time consuming. Proxy indicators are used instead (Martin-Prével et al., 2015). Food recalls for the past 24 hours, 7 days or even months are the most frequently used sources for proxy indicators. How to group the consumed food items and how to construct the indicators is the core debate in nutritional sciences about the measurement of micronutrient deficiencies. This study relies on the currently most investigated aggregation of food items, which presents the best possible proxy indicator . The Dietary Diversity of Women (DDW) is calculated as the number of food groups that have been consumed by woman between 15 to 49 years from a list of 10 defined food groups in the past 24 hours . The Minimum Dietary Diversity of Women (MDDW) is a dichotomous variable that takes the value 1 if at least 5 out of 10 defined food groups have been consumed by one individual in the past 24 hours (FAO & FHI 360, 2016). Whereas the DDW is a count variable that indicates also slight improvements in nutrition security, particularly for households in nutrition insecure settings, the MDDW aims to reflect a minimum requirement for micronutrient adequacy.

$$DDW_i = n$$

$$MDDW_i = \begin{cases} 1 \; if \; n \geq 5 \\ 0 \; if \; n < 5 \end{cases}$$

The food groups used for the indicators' construction are:

(1) Grains, roots, tubers
(2) Legumes
(3) Nuts, seeds
(4) Dairy products
(5) Meat, poultry, fish
(6) Eggs
(7) Dark leafy green vegetables
(8) Other Vitamin-A rich fruits and vegetables
(9) Other not Vitamin-A rich vegetables
(10) Other not Vitamin-A rich fruits

Figure 2 below shows the distribution of the WDDS within the sample of this study. The MDDW is met by 28.8% of the sample. It is apparent that the majority of the population consumes 3 to 4 food groups per day, which is an insufficient amount from a micronutrient point of view. Even lower consumption is an indication for severe malnutrition.

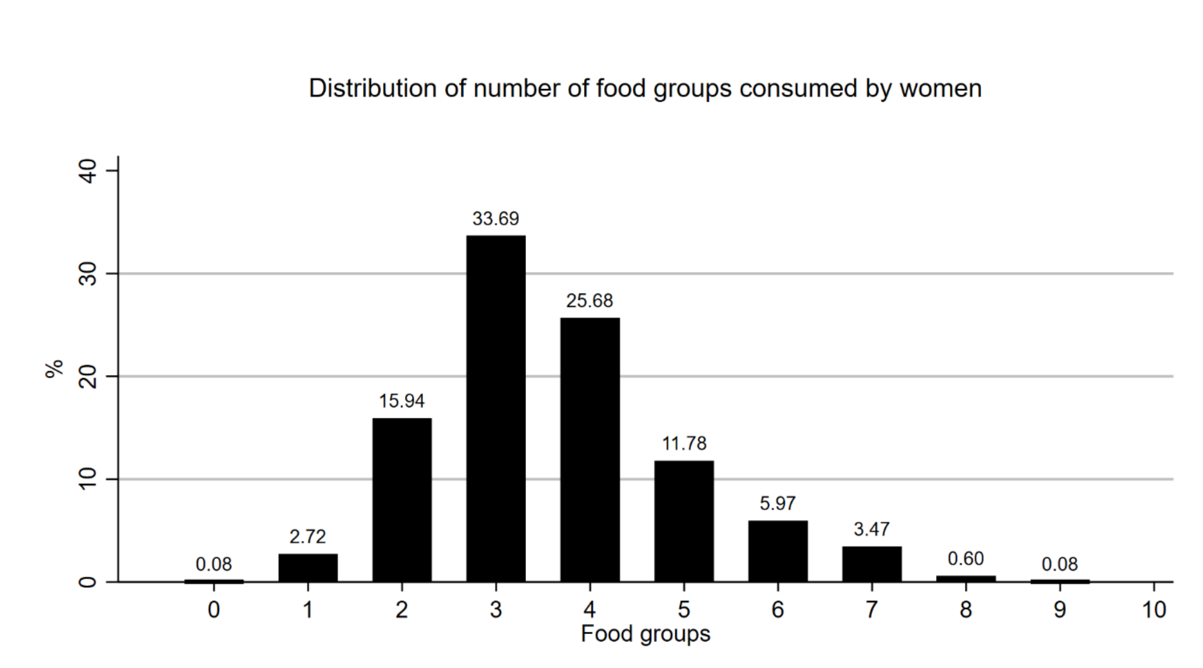

Figure 1: Dietary diversity scores of women

3.3 Main explanatory variables

Production diversity

The literature provides two distinct options to measure on-farm production diversity: either through a composite index or through a count of food groups. The composite indices reflect biodiversity in a certain area. Frequently used are the Simpson Index and the Shannon Index (see Keylock, 2005). The Simpson Index reflects the inverse probability to find within a defined area the same plant species that covers a part of the area. The Simpson Index converges towards the maximum of 1 if an indefinite number of distinct species are habituated in the defined area. Similarly, the Shannon Index uses the distribution of area for distinct species, though includes as well the distribution of area per species. The maximum value of the Shannon Index would be reached if all species cover the same area.

These indices are widely used for quantifying the biodiversity of various land uses in environmental systems. However, these lack the causal links to human nutrition diversity for the following reason: Looking at the example of a smallholder farm where wheat, barley and potatoes are grown, each on the same amount of area. This would reflect a low but existent diversity according to the Shannon and Simpson Indices. However, nutrition diversity would be 1 out of 10 (considering that nutrition security is represented by the number of food groups consumed on a scale of 10 different food groups as shown above for the dietary diversity scores). Clearly, a correlation cannot be hypothesized. Moreover, livestock or poultry production can only be accounted for by modifying the Indices, as no land area is attributed to livestock or poultry, which counteracts their intention. For instance, poultry might contribute to two food groups: eggs and meat. This increases there relevance for nutrition, but will not be reflected in the indices.

Therefore, we propose to construct an indicator for production diversity that is constructed exactly as the dependent variable for nutrition security, i.e. the count of produced food groups on the basis of 10 possible food groups (Berti, 2015; Jones, 2017). The similar aggregation ensures causal linkages if relations exist. We will only consider crops that have been cultivated in the last agricultural season before the survey took place, for which we collected information on the species level. Dairy, meat and egg production is considered if livestock and poultry ownership (any compared to none) was confirmed. Figure 3 below shows the distribution of produced food groups within the sample of this study.

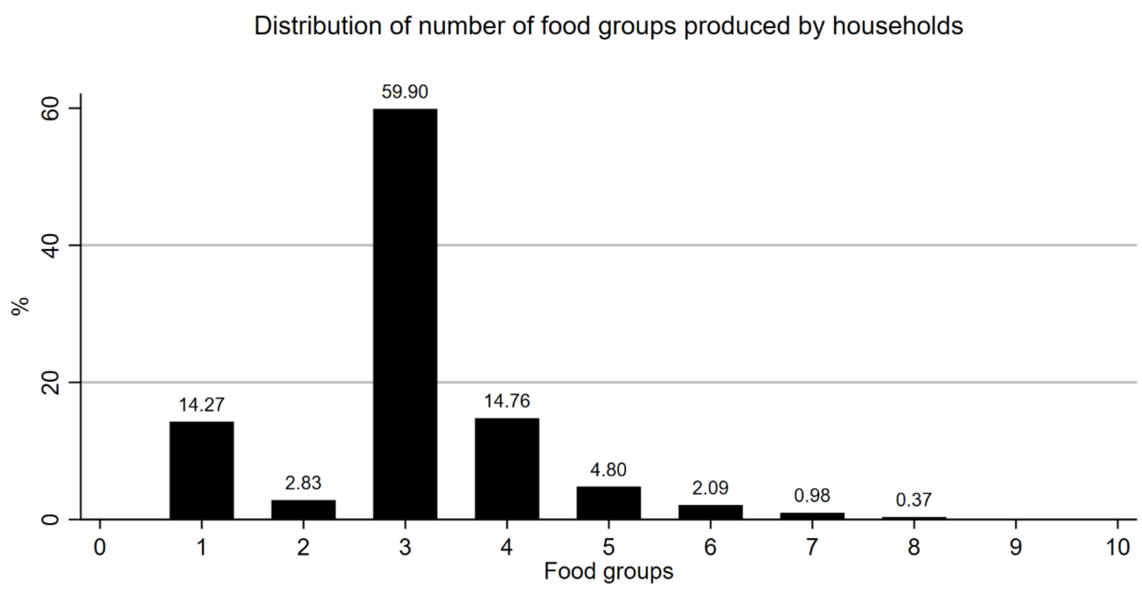

Figure 3: Production diversity of households

Market access

A market itself is here understood as a physical location at which food and non-food items are exchanged and which occurs regularly once a week. Access to markets contains two different connotations: an infrastructural aspect (availability and accessibility) as well as the behavioral aspect (usage). Availability and accessibility is estimated by measuring the time it takes to reach the market starting at the household. We inquired the time in walking distance. Additionally, a household's frequency of market usage is approximated by the inquiry of whether a member of the household is regularly visiting the next available market. The main explanatory variable is usage of the markets whereas the distance to the next market serves as control.

4 Methods

4.1 Estimation strategy

The dependent variable DDW can take only non-negative integer values as these present count data: {0,1,2,…}. Further from the descriptive statistics we can see that the dependent variables take only a few values with high probability (compare Figure 2). Accordingly, we use a Poisson regression model for which we use the following basic specification:

$$\log(\mathrm{DDW}_i) = \beta_0 + \beta_1 PD_h + \beta_2 X_{ihvr} + \epsilon_{ihvr}, \tag{1}$$

with r = 1,…,R, v = 1,…,V_r , h = 1,…,H_{vr} and i = 1,…,I_{hvr} . X_{ihvr} is a vector of explanatory variables and a set of control variables, β_2 is a vector with corresponding regression coefficients, and ϵ_{ihvr} is the error term. Of particular interest is the coefficient β_1 for PD_h representing production diversity on the household level.

As MDDW represents binary data taking only values of 0 or 1, we use a Probit regression estimation for the dichotomous variable as dependent variable, which basic equation is set as:

$$\Pr(MDDW_i = 1 | x_{ihvr}) = \Phi(\beta_0 + \beta_1 PD_h + \beta_3 X_{ihvr} + \epsilon_{ihvr}), \tag{2}$$

with r=1,…,R, v=1,…,V_r , and h=1,…,H_{vr} and i=1,…,I_{hvr} . $MDDW_i$ is equal 1 if the individual is consuming 5 or more food groups and 0 otherwise. The specifications are similar to the Poisson model: X_{ihvr} is a vector of explanatory variables and a set of control variables, β_3 is a vector with corresponding regression coefficients, and ϵ_{ihvr} is the error term. Of particular interest is the coefficient β_1 for PD_h representing production diversity on the household level.

In a second step, market access will be included in the equation (1) as an interaction term, in which the coefficient β_2 represents the effect of PD_h interacted with MA_h and β_3 represents the effect of MA_h alone:

$$\log(\mathrm{DDW}_i) = \beta_0 + \beta_1 PD_h + \beta_2 PD_h MA_h + \beta_3 MA_h + \beta_4 X_{ihvr} + \epsilon_{ihvr} \tag{3}$$

When estimating our main point of interest, the impact of production diversity on the various dietary indicators, we can assume to face various issues that limit the validity of the regressions. Given the cross-sectional data for the estimation, the following points should be of concern: (1) Ex ante it is likely that some of the control variables will affect production diversity such as assets. We assume further that perfect multicollinearity can be excluded. Yet multicollinearity will not reduce the predictability of our model, though we will not be able to claim with a sufficient validity the effect of the individual estimators such as the estimator of production diversity. (2) We are not able to completely comprehend all possible variables that effect diets. The claim that all variables are included in the model would be inadequate. Hence, unobserved characteristics that are correlated with either the dependent or the independent variables or with both are possible, creating the possibility for biased estimates. (3) Due to possible omitted variables, the model specification might also entail endogeneity issues, respectively the possibility that the main independent variables are correlated with the error term. Measurement errors[1] can emphasize these issues. (4) Reverse causality could theoretically be of concern. Following the conceptual framework and the included time dynamics, a diverse diet might lead to an improved nutritional status, hence to better suitability of the household for agricultural labor, which again might enhance the chances to diversify the household's agricultural production, particularly if market access is low (considering the non-separability condition). However, since we do not include any longitudinal data of the variables in question, we think the reverse causality issues can be safely ignored. Yet, the mentioned issues have to be addressed.

4.2 Identification strategy

In order to overcome the issues, we propose to use an instrument variable for production diversity. We know that 90% of all households have lived 22 years or longer in their respective villages (95% 12 years or longer, 50% 60 years or longer), hence permanent migration is uncommon. Therefore, we can assume that differences in production diversity cannot necessarily be explained by migrated households with a preference for high production diversity (or low). Moreover, production choices depend among others on agro-ecological factors, which are locally-specific. Agro-ecological zones comprise geographical areas that are similar in production opportunities. Differences are induced by climatic conditions that are usually characterized through rainfall, temperature and elevation. Whereas the zones are largescale, smaller clusters can also differ from surrounding zones in their characteristics. We propose to link the factors to local characteristics. Small-scale gridded data for rainfall, temperature and elevation is available either through the primary data collection or through secondary sources. Hirvonen and Hoddinott (2016) propose to use four similar instruments for an analysis in Ethiopia: temperature, altitude, their linkage and steep-sloping land. We propose to use rainfall as instrument, which is sufficiently strong for representing an agro-ecological zone and for explaining biodiversity differences in general.

[1] In this case it is more likely to encounter underreporting for the main variables of interest due to recall gaps.

For using the instrument variable approach, the instrument needs to fulfill certain conditions (Wooldridge, 2013). Following equation (1), the proposed instrument variable (z_h) needs to be uncorrelated to the error term in (ϵ_{ihvr}) and sufficiently correlated to production diversity (PD_h):

$$Cov(z_h, \epsilon_{ihvr}) = 0$$

and

$$Cov(z_h, PD_h) \neq 0$$

If these conditions are fulfilled, we can claim that the instrument is exogenous in equation (1) and the instrument is relevant for explaining production diversity. Rainfall affects production choices in terms of food items (e.g. wheat needs less rainfall than rice), but in general there is no effect on food groups as these are defined for the dependent variables of dietary diversity (e.g. wheat and rice are both cereals). Hence, the instrument exogeneity in regard to the outcome variable, dietary diversity can be claimed.

Rainfall has been used as an instrument for income or economic growth (Brückner & Ciccone, 2011; prominently Miguel, Satyanath, & Sergenti, 2004) and also in the Indian context (Sarsons, 2015), which can be argued for each application separately. This paper considers rainfall from an agricultural perspective in that we understand rainfall as reflecting agro-ecological zones, hence reflecting biodiversity on farmland in specific regions. Nevertheless, one might argue that in a rural setting where the main source of income depends on agriculture, variation in rainfall affects agricultural output, hence, income. Income on the other hand has an effect on access to food and under certain conditions can enable households and individuals to consume more diverse foods (e.g. the likelihood of meat consumption increases). In settings with a minimal dietary diversity due to a missing purchasing power, this argument might hold true. To satisfy the exclusion restriction, it would not be an option to include a measure of income as a control variable due to the argued violation. Therefore, we propose to include a measurement of liquidable assets in the estimation. Liquidable assets are a reflection of wealth over a period of time, which might be caused by income but not necessarily (Carter & Barrett, 2006). It is definitely not a reflection of current cash flow as is income. It can be argued that the effect of rainfall on asset accumulation over time is marginal in comparison to income if not insignificant; therefore, it can be included as a control variable without violating the exclusion restriction.

Data for precipitation is taken from Climate Hazard Group InfraRed Precipitation (CHIRPS) (Funk et al., 2015). It is a rainfall dataset that incorporates 0.05° (roughly 5km x 5km) resolution satellite imagery with station data. Daily data from 1.1.1981 to 31.12.2016 is used. The coordinates are matched with the household-level GPS coordinates that were taken during the surveys. Various ways to measure rainfall were tried (e.g. average yearly rainfall from 2006 to 2016, standard deviation of rainfall over the average of the period between 1981 to 2016), but the strongest correlation and reliable F-tests between rainfall and production diversity in the first stage regression was found in the average yearly rainfall from 1981 to 2016.

We use an OLS specification for estimating the correlation between the instrument and production diversity. The relevance is displayed by the Sanderson-Windmeijer F-test of excluded instruments (Sanderson & Windmeijer, 2016). On the basis of included covariates, which are the same as in the regression set up, average yearly rainfall since 1981 is highly significant and positively correlated with production diversity. The F-test of 11.61 shows that the instrument is sufficiently strong. As the endogenous variable is exactly identified, no over-identification test is presented. Furthermore, testing on significant correlation between the residuals of the first stage regression and on the dietary diversity with included instruments results in high significance at .99 level, thus indicating that endogeneity is indeed a problem in this model specification and adding further strength to the conclusion that the applied identification approach is appropriate. *Table 3* shows the results of the first stage estimation.

Table 3: First stage regression results based on the linear model

Dependent variable: Production diversity	(1)
Excluded instrument:	
Average yearly rainfall since 1981 (mm)	0.001***
	(0.000)
Included instruments:[ˠ]	Yes
R-squared	0.218
Weak-identification test	
Sanderson-Windmeijer F-statistic	11.61
Observations	777

Robust standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1
ˠ Coefficients omitted to preserve space

5 Results

5.1 Primary results

Dietary diversity of women

Table 4 below shows the results of the regression, in which dietary diversity of the woman is the dependent variable and production diversity (PD) is the main explanatory variable with controls on individual, household and regional levels. PD is significantly correlated at the 0.1 level with DDW in the main Poisson specification. The effect size indicates a 1.6% increase of DDW per additional food group produced on the farm. The OLS specification confirms these results as robust (using the log of DDW for comparative purposes with Poisson).

In comparison to other studies, we can see that the effect sizes are in an expected range. An estimated coefficient for production diversity pooled over four countries (Indonesia, Kenya, Ethiopia and Malawi) reflects an 0.9% increase of dietary diversity ranging from 5.4% in Indonesia to 0.2% in Ethiopia[2] (Sibhatu, Krishna, & Qaim, 2015). In Malawi, agricultural biodiversity is associated with an increase in dietary diversity ranging from 8% to 13%[3] (Jones, 2017).

Using the instrumented approach, the results of the Poisson IV (GMM) regression show still a significant effect of PD on DDW at the 0.1 level but with a higher relevance, indicating an increase of DDW by 40% per additional food group produced. Again, the 2SLS with log DDW confirm the results by using another estimation specification[4].

The increase in the effect size might seem surprising at first sight, however, conceptually an increase in the effect size should expected when using the instrument approach. Furthermore, looking at the other study that included an IV approach can bring the results in perspective. Hirvonen and Hoddinott estimated the effect of production diversity on child dietary diversity (2016), finding a positive effect of 9.2% for a Poisson specification and 49% for a Poisson IV (GMM) specification. Thus, the presented results in Table 4 seem to be in line with previous findings and not suprising.

Significant covariates vary between Poisson and Poisson IV (GMM) equations. Looking at the significant Poisson results, literacy of the women – a dummy variable if the woman of whom the dietary diversity score is generated can read and write or not – is positively correlated to DDW as could be expected. The number of males in the household who are between 14 and

[2] The effect sizes seem to be coinciding, yet the previously mentioned flaws in the methodology of calculating production diversity and dietary diversity need to be kept in mind (see Section **Fehler! Verweisquelle konnte nicht gefunden werden.**).

[3] Jones concludes his results based on relatively few covariates. This does not necessarily entail a methodological issue, yet the probability that the coefficients are overestimated is increased. Hence, Jones' results might be more in line with Sibhatu, Krishna and Qaim (2015) and with the results presented here.

[4] 2SLS is used as a more efficient estimation given only one excluded instrument.

59 years old is negatively correlated, indicating a lower relative empowerment of the women in more male-dominated households. Total land size, visits to markets and government support are positively correlated. On the basis of literature, these results can be expected. Particularly, the positive and significant effects of market visits already indicate that this variable is a relevant channel as we will further examine it below. On the other hand, significant Poisson IV results indicate that female-headed households are negatively correlated and supporting government policies are confirmed to be positively correlated to DDW. Female-headed household are mostly found due to deaths of the male spouse that used to be the household head, thus a household that is likely to experience a reduced economic access to foods.

Table 4: Impact of production diversity on dietary diversity of women

	OLS	**Poisson**	**Linear IV (2SLS)**	**Poisson IV (GMM)**
Dependent variable: dietary diversity score of women	**(log) DDW**	**DDW**	**(log) DDW**	**DDW**
Production diversity	0.018*	0.016*	0.316**	0.417*
	(0.010)	(0.010)	(0.139)	(0.227)
Individual characteristics:				
(log) Age in years	-0.016	0.024	-0.189	-0.158
	(0.067)	(0.060)	(0.120)	(0.153)
Literacy of woman	0.091***	0.073***	0.058	0.055
	(0.031)	(0.027)	(0.046)	(0.053)
Household characteristics:				
Age of household head	0.002*	0.001	0.003	0.003
	(0.001)	(0.001)	(0.002)	(0.003)
Highest education among adult household members	0.008	0.006	0.012*	0.010
	(0.005)	(0.004)	(0.006)	(0.008)
Female headed household	-0.037	-0.116	-0.310*	-0.413*
	(0.099)	(0.095)	(0.186)	(0.244)
(log) Total value of liquidable assets	-0.003	0.008	-0.084**	-0.104
	(0.011)	(0.010)	(0.043)	(0.069)
Religion (0 = Hindu, 1 = Muslim)	-0.003	-0.006	-0.028	-0.061
	(0.061)	(0.062)	(0.110)	(0.151)
Number of males 0-5 years	0.001	-0.002	-0.032	-0.031
	(0.023)	(0.022)	(0.036)	(0.044)
Number of males 5-14 years	0.019	0.007	-0.013	-0.049
	(0.020)	(0.018)	(0.032)	(0.062)
Number of males 15-59 years	-0.033*	-0.033**	-0.032	-0.021
	(0.018)	(0.016)	(0.026)	(0.032)
Number of males 60+ years	-0.009	-0.030	-0.004	-0.018
	(0.036)	(0.032)	(0.048)	(0.056)
Number of females 0-5 years	-0.007	0.003	-0.032	-0.021
	(0.024)	(0.022)	(0.037)	(0.048)
Number of females 5-14 years	-0.011	-0.009	-0.028	-0.049
	(0.020)	(0.016)	(0.029)	(0.044)
Number of females 15-59	0.011	0.006	0.008	0.003
	(0.019)	(0.017)	(0.028)	(0.032)
Number of females 60+ years	-0.050	-0.025	-0.043	-0.035

	OLS	Poisson	Linear IV (2SLS)	Poisson IV (GMM)
	(0.041)	(0.035)	(0.055)	(0.067)
Primary occupation of household is nonfarm (0 = yes, 1 = no)	0.010	0.041	-0.035	-0.042
	(0.044)	(0.041)	(0.066)	(0.098)
(log) Total land size	0.036**	0.033**	0.006	-0.036
	(0.016)	(0.015)	(0.029)	(0.063)
Distance to next market (in km)	0.007*	0.003	0.015**	0.013
	(0.004)	(0.003)	(0.007)	(0.009)
A household member is regularly visiting the next available market (0 = no, 1 = yes)	0.029	0.050*	0.014	0.031
	(0.028)	(0.026)	(0.041)	(0.053)
Number of government schemes that were used	0.024**	0.027***	0.041***	0.053**
	(0.010)	(0.009)	(0.015)	(0.024)
Village characteristics:				
(log) Village population	-0.015	-0.034*	0.049	0.044
	(0.020)	(0.018)	(0.038)	(0.052)
Years that village is electrified	0.002	0.002	0.004	0.005
	(0.002)	(0.002)	(0.002)	(0.003)
Region dummies	Yes	Yes	Yes	Yes
Number of observations	810	811	760	761
Adjusted R-squared	0.269			
Pearson goodness-of-fit test		302.1		
p-value		1.00		
Sanderson-Windmeijer F-test			11.61	
p-value			0.0007	

Note: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Minimum Dietary Diversity of Women

Table 5 below shows the results of the regression, in which the minimum dietary diversity of the woman is the dependent variable and PD is the main explanatory variable with controls on individual, household and regional levels. First of all, Probit and Probit IV (GMM) indicate that an increase in PD increases the probability that the minimum dietary diversity is met at the 0.05 and 0.01 level respectively. The relevance of PD is increased in the Probit IV (GMM) estimation, increasing the marginal effects of production diversity from 3.5% to 82.7%. Hence, the probability of meeting the minimum adequate diet rises by 82.7% if the production diversity changes by an infinitesimal amount considering the presented model with all covariates. Looking again first at the Probit estimation, the age of the woman, number of females below 5 years in the household, government support and visits to the markets are increasing the probability and are significant. A higher number of adult males in the household (15 years and above) reduces the probability. The Probit IV (GMM) indicates contrarily that the total value of liquidable assets reduced the probability, and market distance increases the probability. On the other hand, positive effects of visits to markets and government support are restated.

Table 5: Impact of production diversity on minimum dietary diversity of women

	Probit	**Probit IV (GMM)**
Dependent variable: minimum adequate diet of women met (0 = no, 1 = yes)	**MDDW**	**MDDW**
Production diversity	0.035**	0.827***
	(0.014)	(0.098)
Individual characteristics:		
(log) Age in years	0.138*	-0.192
	(0.080)	(0.271)
Literacy of woman	0.045	-0.012
	(0.036)	(0.118)
Household characteristics:		
Age of household head	-0.000	0.004
	(0.002)	(0.005)
Highest formal education among adult household members	0.003	0.024
	(0.005)	(0.017)
(log) Total value of liquidable assets	0.014	-0.181***
	(0.013)	(0.059)
Religion (0 = Hindu, 1 = Muslim)	-0.125	-0.249
	(0.108)	(0.309)
Number of males 0-5 years	0.007	-0.059
	(0.036)	(0.107)
Number of males 5-15 years	0.013	-0.061
	(0.026)	(0.083)
Number of males 15-60 years	-0.054**	-0.110
	(0.021)	(0.076)
Number of males 60+ years	-0.088**	-0.206
	(0.039)	(0.127)
Number of females 0-5 years	0.066**	0.121
	(0.033)	(0.115)
Number of females 5-15 years	-0.001	-0.016
	(0.024)	(0.074)
Number of females 15-60 years	0.017	0.010
	(0.023)	(0.071)
Number of females 60+ years	0.012	0.034
	(0.041)	(0.127)
Primary occupation of household is nonfarm (0 = yes, 1 = no)	0.120*	0.062
	(0.067)	(0.210)
(log) Total land size	0.037	0.004
	(0.023)	(0.077)
Market distance (in km)	0.004	0.027**
	(0.004)	(0.013)
A household member is regularly visiting the next available market (0 = no, 1 = yes)	0.132***	0.256*
	(0.038)	(0.145)
Number of government schemes that were used	0.035***	0.132***
	(0.013)	(0.048)
Village characteristics:		
(log) Village population	-0.027	0.110
	(0.023)	(0.083)

	Probit	Probit IV (GMM)
Years that village is electrified	0.002	0.008
	(0.002)	(0.005)
Region dummies	Yes	Yes
Number of observations	807	757
Pseudo R-squared	0.2962	
Wald F-test		11.34

Note: Marginal effects at means. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1
Variable "Female headed households" omitted due to insufficient variance.

5.2 Secondary results

OLS, Poisson, Linear IV (SLS) and Poisson IV (GMM) for estimating the market effect are presented in

Table 6. All specifications use the same covariates, but only the relevant interaction terms are presented. The approach for the IV estimations is that PD and the interaction term PDxMarket_visits are instrumented by Rainfall and RainfallxMarket_visits, thus the model is exactly identified. However, the F-tests indicate that the instruments are not sufficiently strong. We therefore do not include the IV regressions in the interpretation of the results, but merely use these as robustness checks. The main focus of the discussion is put on the Poisson specification as the theoretically best fitting model.

First of all, we can recognize that PD (A), PDxMarket_visits (B) and Market_visits (C) have similar direction of effects independent from the model specification. Only the Linear IV (2SLS) estimation does not indicate any significance of (B) and (C). However, the effect sizes of (A), (B), and (C) are relative to each other within each model specification of similar magnitude. We see that the interaction has a relatively small but still positive effect on DDW if the household is not regularly visiting the next available market. Considering Poisson IV (GMM), the increase of PD by one food group will result in an approximate 4.4% increase in the DDW[5]. That is a larger result than in the Poisson IV (GMM) specification of *Table 4* by a magnitude of 3 percentage points. If a household member is visiting the next available market regularly, the effect size of the interaction is an approximate 17.3% increase in the

[5] Calculate: (0.044) x 1 + (-0.039) x 0 + (0.168) x 0 = 0.044 resulting in 4.4% considering the Poisson model.

DDW[6]. We can also infer from these results that PD has a higher singular positive effect on DDW if markets are not visited, keeping all other things equal.

Table 6: Impact of market access

	OLS	**Poisson**	**Linear IV (2SLS)**	**Poisson IV (GMM)**
Dependent variable: dietary diversity score of women	**(log) DDW**	**DDW**	**(log) DDW**	**DDW**
Production diversity (A)	0.049***	0.044***	0.701**	0.521***
	(0.017)	(0.017)	(0.353)	(0.165)
Production diversity X Market visit (B)	-0.045**	-0.039**	-0.589	-0.323**
	(0.020)	(0.019)	(0.413)	(0.160)
A household member is regularly visiting the next available market (0 = no, 1 = yes) (C)	0.168**	0.168***	1.782	1.122**
	(0.066)	(0.063)	(1.232)	(0.552)
Other control variables:	Yes	Yes	Yes	Yes
Number of observations	806	807	756	756
Adjusted R-squared	0.265			
Pearson goodness-of-fit test		300.5		
p-value		1.00		
Sanderson-Windmeijer F-test (A)			10.17	
p-value			0.0015	
Sanderson-Windmeijer F-test (B)			4.92	
p-value			0.0268	

Note: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

The result that market visits have a positive effect on DDW and the interaction with PD is presented visually in

[6] Calculate: (0.044) x 1 + (-0.039) x 1 + (0.168) x 1 = 0.173 resulting in 17.3% considering the Poisson model.

. This figure shows the effect of PD on DDW for each possible production choice of the farming households. The y-axis reflects DDW. Two trend lines are displayed, one without regular market visits ("No") and one with regular market visits ("Yes"). The shaded areas represent the 95% confidence interval for each estimated point. The increasing lines reflect the overall positive effect of PD keeping all other things equal. With market visits, the line is higher overall, showing the positive effect of market visits. We can further see that the differences between both lines is significant whenever the confidence interval is not touching the other line's points, which is the case for each PD level besides the PD equal to eight.

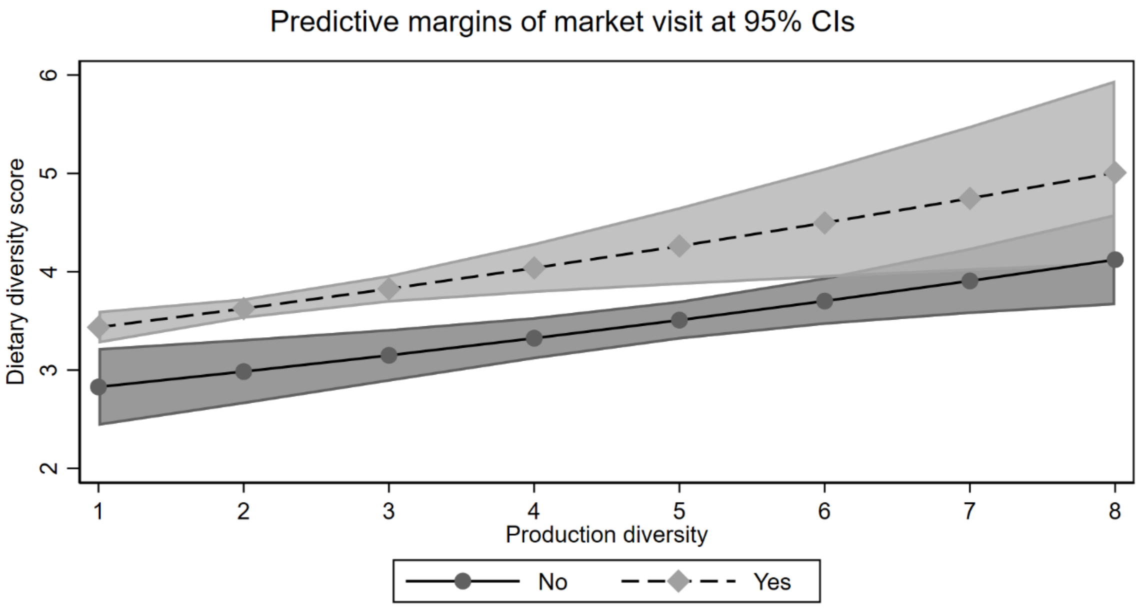

Figure 2: Predictive margins of market visits

After inferring that market visits in interaction with production diversity have a positive and significant effect on dietary diversity, it is useful to understand in which food group this effect is relevant. *Table 7* shows the various food groups that form dietary diversity and production diversity respectively (compare with Section ***Fehler! Verweisquelle konnte nicht gefunden werden.***). This table shows the percentage of the sampled households whose women have consumed the according food group. The χ2 p-value indicates if the difference between market visits is significant[7]. The food groups "nuts, seeds", "dairy products", and "Other (not Vitamin-A rich) vegetables" are the food groups that are more frequently consumed if households visit markets, indicating that these food products are more likely purchased than produced on-farm.

Table 7: Consumption of food groups by market visits

Food group	Consumption of food groups by regular market visits (in %)		χ^2 p-value
	no	yes	
Grains, roots, tubers	99.51	99.67	0.737
Legumes	68.47	70.16	0.650
Nuts, seeds	**6.90**	**14.92**	**0.003**
Dairy products	**16.26**	**33.11**	**0.000**
Meat, poultry, fish	8.87	5.90	0.142
Eggs	3.45	2.79	0.630
Dark leafy green vegetables	61.08	61.80	0.855
Other Vitamin-A rich fruits and vegetables	7.88	8.20	0.887
Other vegetables	**73.40**	**82.79**	**0.003**
Other fruits	10.34	13.93	0.188

As the next step, we wanted to understand if the consumption increase of the food groups is distributed equally over the population or if certain groups benefit more from market visits and according consumption increases. In the following, three figures are presented (*Figures 5-7*) that display the change of consumption according to market access for each of the above identified food groups per income quintile[8]. The χ2 p-value is indicating if the changes are significant, where we consider a p-value below 0.1 as significant.

[7] The significance has been also estimated by using Probit regressions, having a food group as dependent variable and using all control variables as in the previous regressions of this paper. Therefore, it is sufficient to indicate only the χ2 p-values at this point.

[8] Income is calculated from expenditures and weighted based on an adult equivalence scale (AE) per household. The weighting is defined as follows, where age is in years: AE = 0.5 if age < 5, AE = 0.7 if 5 =< age < 15, AE = 1 if age >= 15.

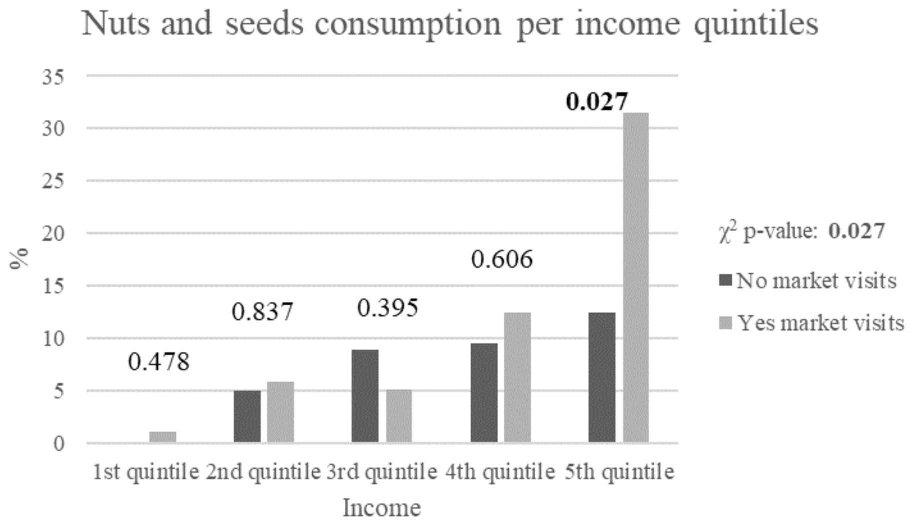

Figure 3: Nuts and seeds consumption per income quintiles

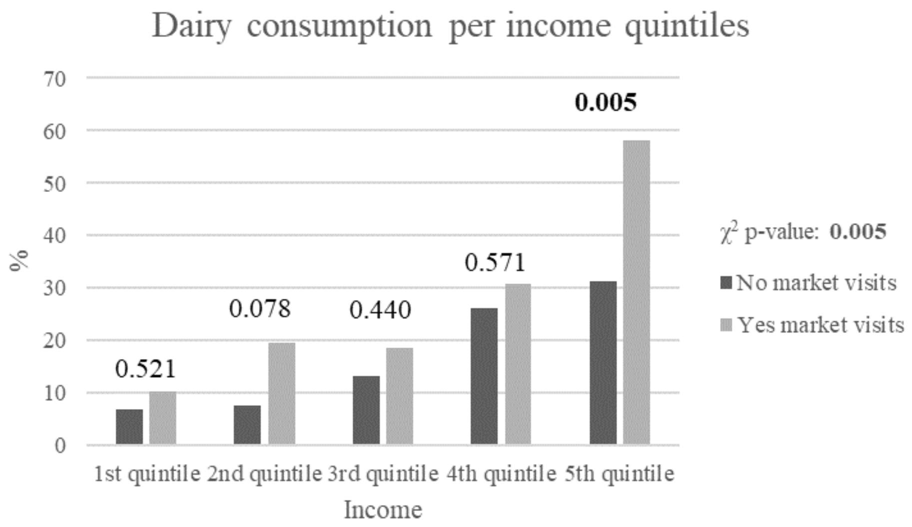

Figure 4: Dairy consumption per income quintiles

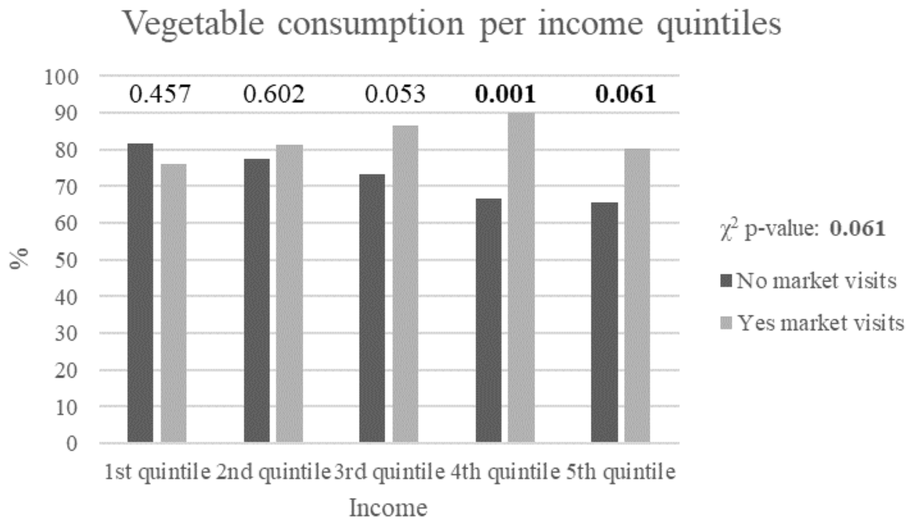

Figure 5: Vegetable consumption per income quintiles

For the food groups "Nuts and seeds" and "Dairy products", we can see an increase of the consumption with higher income quintiles independent from market access. However, the consumption by the 5th quintile – i.e. the richest 20% of the sample – benefit the most from market access, where nuts and seeds and dairy products are consumed by an additional 20%. Vegetable consumption shows a different picture. We see that vegetable consumption is decreasing with higher income groups if markets are not visited regularly. Market access is inverting this trend so that also higher income groups continue to consume vegetables.

5.2 Robustness checks

Dietary diversity is influenced by a magnitude of different determinants. This paper is focusing on production diversity and market access. In order to control for possible correlation between production diversity and the other factors, we include a sufficiently strong instrument variable. Further, we included model specifications different from our main Poisson model, an OLS model and a 2SLS model. The results indicate different magnitudes, however, similar direction of effects of the covariates were included. In a second set of estimations we use Minimum Dietary Diversity Score, a binary variable, as a dependent variable and as a different measurement for nutrition security. A Probit model uses the same covariates and again displays results with different magnitudes, but with the same effect direction. Finally, the interaction is included that once again produces similar results in the effect directions and partially also in effect size. Thus, having included a set of model specifications, variations in the dependent variable and other robustness measures such as regional effects, robust standard errors and a prior tested set of covariates, we interpret the presented results as sufficiently robust.

6 Discussion

In the context of the Indian subcontinent it is obvious: large parts of the population suffer from food and nutrition insecurity, particularly women and children are at risk. The majority of the food insecure people live in rural areas and are smallholder farmers producing a significant share of their food themselves. This study shows that the diversity of production has a positive effect on the diversity of consumption of women in smallholder farmer households. This is by no means the only channel that affects dietary diversity. The results indicate that the effects of government programs have a positive effect. Individual characteristics such as the literacy of women play an important role as well. Household demographics are important in the sense of the household structure; the more male adults that are present, the worse female nutrition becomes. This study cannot make any profound claim on the importance of women empowerment, however, we think that literacy and the number of males can reflect the bargaining power of women within the household, which again represents one additional channel for nutrition improvements.

Market access changes the picture. We understand market access not as a mere infrastructural variable as it is often observed e.g. by measuring the distance to markets. Rather market visits are included, which represents the behavior of whether markets are visited regularly. We show that market access improves nutrition primarily in regard to food groups that are not necessarily produced on-farm. We cannot infer if market access leads to a certain specialization of on-farm production and thus to a reduction of production diversity, which might explain the results as well. However, we can state that primarily higher income groups benefit from market access. Accordingly, the agricultural household model's separability condition – production choices are independent from consumption choices if households are integrated in markets – does partly hold. Households of various income groups do not differ in mean distance to markets nor in the average behavior of visiting markets, but still the effects of the markets on nutrition choices differ. Poorer households have a stronger non-separability than wealthier households in our context.

We would like to conclude that production diversity increases dietary diversity, but that the positive effect of market access can outdo the positive effect of production diversity, though only for higher income groups and only for some food groups. Accordingly, we deduct policy recommendations as follows:

- Policies and programs for increasing production diversity have the potential to be effective for improving nutrition security, though these might not be the most efficient policies. These policies and programs should have a different primary goal such as income generation or women empowerment.
- Intensifying the market access can be a viable policy objective for improving the nutrition security if higher income groups are targeted.

- Lower income groups are certainly supported by governmental support programs as these are already existent in India.
- Women empowerment through education policies can have a positive effect on the nutrition status of women.

7 Conclusion

This study contributes to existing studies on production diversity by answering the research hypotheses and by utilizing a robust methodology. The first hypothesis of this study can be verified: On farm production diversity as measured through the diversity of food groups produced *does have* a positive effect on dietary diversity of individual household members, namely women. It is not a food group for a food group. But, if production diversity is increased by 1 food group it can be said with a high probability that the dietary diversity of women increases around 40%.

The second hypothesis of this study needs to be falsified: Market access is *not* the channel for this relationship. We see that with market access, the effect size of production diversity decreases, yet remains positive. The effect size of market access is much larger and in interaction with production diversity, is overall positive. However, market access is primarily benefitting the top income groups, whereas for lower income groups on-farm production diversity remains more relevant.

This study has certain limitations. One, we see representative results for three distinct rural regions of India, we can by no means extrapolate the results for all of India as the characteristics are too manifold. Two, this study uses a cross-sectional survey, which is sufficient to respond to the research questions. Panel data would be superior in controlling for unobserved heterogeneity and for causality claims. Panel data could also shed light on possible seasonality effects and on nutrition variability due to shocks. Three, dietary diversity is the best possible approximation to measuring nutrition security. However, there is still an error margin between dietary diversity scores and actual micronutrient status.

Accordingly, we would like to make the following suggestions for future research. Despite its relevance towards global economics, its population size and its issues with food and nutrition insecurity, India still has a comparatively low level of research results in the research domain of this study. Therefore, we would like to encourage further research activities that include comparative surveys across India. These surveys would be preferably of longitudinal character and designed as a panel, particularly to control for intra-household effects. We highly recommend to utilize human tissue analysis to precisely determine the micronutrient status. The role of markets has been studied extensively, however, in regard to food and nutrition security, the depth of analysis is partially lacking. For example, markets can be of different shape: size, degree of formality, geographical outreach, accessibility etc. Most of the literature, including this study, differentiates only marginally. Given the results of differing market effects by income groups and food groups, we see it as relevant to further investigate if informal markets or possible barter trading is of higher importance for the food and nutrition security level of lower income groups in rural areas.

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