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Agricultural Production, Dietary Diversity and Climate Variability

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ABSTRACT *Nonseparable household modelsoutline the interlinkage between agricultural production and household consumption, yet empirical extensions to investigate the effect of production on dietary diversity and diet composition are limited. While a significant literature has investigated the calorie-income elasticity abstracting from production, this paper provides an empirical application of the nonseparable household model linking the effect of exogenous variation in planting season production decisions via climate variability on household dietary diversity. Using degree days, rainfall and agricultural capital stocks as instruments, the effect of production on household dietary diversity at harvest is estimated. The empirical specifications estimate production effects on dietary diversity using both agricultural revenue and crop production diversity. Significant effects of both agricultural revenue and crop production diversity on dietary diversity are estimated. The dietary diversity-production elasticities imply that a 10 per cent increase in agricultural revenue or crop diversity result in a 1.8 per cent or 2.4 per cent increase in dietary diversity respectively. These results illustrate that agricultural income growth or increased crop diversity may not be sufficient to ensure improved dietary diversity. Increases in agricultural revenue do change diet composition. Estimates of the effect of agricultural income on share of calories by food groups indicate relatively large changes in diet composition. On average, a 10 per cent increase in agricultural revenue makes households 7.2 per cent more likely to consume vegetables, 3.5 per cent more likely to consume fish, and increases the share of tubers consumed by 5.2 per cent.*

I. Introduction

Nonseparable household models outline the interlinkage between agricultural production and household consumption, yet empirical extensions to investigate the effect of production on nutrition are limited. An early, related literature investigated the calorie-income elasticity as part of a larger debate on whether households could grow their way out of poverty and malnutrition, but abstracted from agricultural production (see Strauss & Thomas, 1995 for a review). In current discussions about the role of agriculture in promoting nutrition, increased agricultural income and increased production diversity of nutrient rich food, especially among subsistence farmers, are two of the pathways through which agriculture might promote nutrition (Hoddinott, 2011). However, similar to the earlier calorie-income elasticity debates, we know little about whether agricultural income growth or production diversity is likely to have a larger effect on dietary diversity and diet composition. This paper provides an empirical application of the nonseparable household model to identify the effect of variation in planting season production via exogenous climate variability on household dietary diversity and diet composition.

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Household dietary diversity is strongly associated with household calorie availability (Ruel, 2003), an important component of nutritional status, while diet composition is associated with the consumption of particular micronutrients as well as diet quality. However, it should be noted that household nutrition measures fundamentally proxy for individual level food intakes. Intrahousehold distribution of calories and micronutrients is unlikely to be uniform across household members. Despite this important caveat, dietary diversity and diet composition are important nutritional indicators in rural subsistence populations (FAO, 2011; Ruel, 2003; Swindale & Bilinsky 2006). Dietary diversity is one method of measuring diet quality. The paper also uses the components of the household dietary diversity score to measure the effect of increased production on the share of total calories by food group.

The agricultural-nutrition mechanism explored in this paper is primarily the effect of agricultural revenue on dietary diversity. While we also address the potential link between production diversity and dietary diversity, our rural sample descriptive statistics illustrate that the average rural household specialises in only two crops. Hence production diversity is less relevant in this context than it may be in other studies. We therefore focus on examining the link between agricultural revenue and dietary diversity, while still reporting the production diversity-dietary diversity results. The pathways through which agricultural revenue could affect dietary diversity are multiple. Increases in agricultural production revenue may affect dietary diversity through increases in household purchasing power of nutritious foods and a wider variety of food in general, but specialisation by all producers in several staple crops may lower food prices and the revenue of producers. The effects of increased production and specialisation are not necessarily welfare increasing, given these general equilibrium effects. Increases in agricultural revenue may also lead to increased demand for nutrient rich foods by net producers, driving prices higher, and actually reducing consumption of nutrient rich foods. For these reasons, the mechanism between observed increases in agricultural revenue may not necessarily lead directly to increased household dietary diversity.

Using recent panel data from Nigeria which includes observations from both planting and harvest seasons within an agricultural season, our econometric strategy uses degree day and rainfall deviations from historical means as well as agricultural input prices and quasi fixed agricultural capital to instrument for production variables (agricultural revenue or crop production diversity) which are simultaneously determined with consumption. Degree days, a cumulative measure of optimal temperatures for plant growth, have been found to be correlated with reduced yields and agricultural income (Hatfield et al., 2008). We identify the effect of revenue variation on dietary diversity and diet composition in an empirical application of the nonseparable household model by using exogenous variation in rainfall and degree days that affect plant growth and agricultural revenue, but do not necessarily change market level prices at harvest which affect consumption patterns. This mechanism through which the exclusion restriction assumption could be violated can be tested in our data.

A small literature has investigated the effects of agricultural production on nutrition primarily via reduced form identification strategies. Muller (2009) found that production of food crops such as beans and certain tubers as well as a category composed of heterogeneous food of high quality had positive impacts on nutritional statuses, while the production of traditional beers and nonfood crops was found to have negative effects for nutrition. The authors also found production of other fruits and vegetables was associated with better health status. Although agriculture is primarily a rural activity in many developing nations, there has also been evidence that urban agricultural production has positive effects on nutrition. In their study of 15 developing countries, Zezza and Tasciotti (2010) found that urban agriculture does appear to be associated with greater dietary diversity and calorie availability after controlling for economic welfare and a set of household characteristics. Using a smaller set of countries Zezza and Tasciotti (2010) also found some evidence of a relationship between participation in urban agriculture and greater calorie consumption. Fruits and vegetables were the food groups more consistently found to contribute to the increase in calorie consumption.

Fewer studies have looked at both the linkage between income and nutrition and that between the diversity of crops produced and nutrition. Food prices, access to markets and credit can influence decisions on what type of crops households grow. For example, smallholder farmers are more likely to grow food crops to ensure food self-sufficiency rather than grow cash crops, and thus staple food expenditures have a low income elasticity (Fafchamps, 1992). Using a nationally representative household survey of India, Bhagowalia, Headey, and Kadiyala (2012) examine the relationship between agricultural income and nutrition (measured using children's anthropometric indicators), as well as agricultural production. They find a modest effect of income on nutritional status unless accompanied by improved health and education outcomes. However, they also find strong evidence that agricultural production conditions such as irrigation, crop diversity and ownership of livestock, substantially influence household dietary diversity. Jones, Shrinivas, and Bezner-Kerr (2014) also find a strong positive association between production diversity and household dietary diversity in Malawi.

There have been even fewer studies using data from Nigeria to examine the agriculture and nutrition linkage and the few papers that do exist are case studies or only use descriptive statistics (Babatunde, Adejobi, & Fakayode, 2010; Okezie & Nwosu, 2007). Babatunde et al. (2010) examines the relationship between income and calorie intake for farm households in rural Nigeria using household data from 40 villages in Kwara state. Although the authors found a significant positive relationship between income and calorie intake, the calorie-income elasticity was estimated as 0.181 suggesting that calorie intake does not increase substantially with income. They also found a positive relationship between farm size and calorie intake in Nigeria. Okezie and Nwosu (2007) examined the effect of agricultural commercialisation on nutritional status of children in Abia state in Nigeria and found that children in households that are more commercialised recorded a higher prevalence of underweight and stunting.

Given the existing gaps in the literature, the present study contributes to the literature by using nationally representative data from Nigeria that contains information on household consumption, agricultural production, and geospatial variables to examine the link between agriculture production and dietary diversity. The econometric strategy of the paper is based on the nonseparable household literature to estimate the causal effects of production diversity on dietary diversity rather than associations. In previous cross sectional studies, identification of the income and nutrition interlinkage may be confounded by the inability to distinguish the causal direction of the interlinkage, as higher income households may have increased nutrition, but households with better nutrition may also have higher productivity and higher incomes. By modelling this causal relationship using a nonseparable household model and using exogenous variation in degree days and rainfall and agricultural capital as instruments, the casual direction of the production-dietary diversity relationship is more clearly identified. The empirical estimates suggest significant effects of both agricultural revenue and crop production diversity on dietary diversity. A revenue-dietary diversity elasticity of 0.18 and a crop diversity-dietary diversity elasticity of 0.24 were estimated. We have most confidence in the revenue-dietary diversity estimates as this specification clearly passes all instrumental variable tests. Climate variability is also shown to have differing effects on revenue versus crop production diversity. Deviations from historical means of both rainfall and degree days has statistically significant effects on agricultural revenue while only deviations from rainfall means have statistically significant effects on crop production diversity.

The investigation below also reveals differential impacts of production variability on the likelihood of food group consumption and the share of calories consumed from separate food groups. A 10 per cent increase of agricultural revenue increases the likelihood of a household reporting consumption of vegetables by 7.2 per cent and fish by 3.5 per cent. Increased agricultural revenue is found to induce households to alter the composition of their diets by lowering the share of consumption from beverages and increasing tuber consumption shares. A 10 per cent increase in agricultural revenue results in a decrease in the consumption share of beverages by 5.9 per cent but increases the consumption share of tubers by 5.2 per cent. Estimates of changes in other food groups were either not statistically significant or did not pass all instrumental variables tests.

In the next section of the paper, the data is described including the construction of the climate variability and degree day variables. The third section outlines the econometric strategy of the paper, while the fourth section presents the paper's key results. The last section concludes.

II. Data Description

This study uses data from Wave 1 of the General Household Survey-Panel (GHS-Panel) conducted in 2010/2011 by the Nigeria National Bureau of Statistics (NBS) in collaboration with the World Bank Living Standard Measurement Study – Integrated Surveys on Agriculture (LSMS-ISA) project. The GHS-Panel survey is modelled after the Living Standard Measurement Study (LSMS) surveys and is representative at the national, zonal, and rural/urban levels. The total sample consists of about 5,000 households covering all 36 states in the country and the Federal Capital Territory, Abuja. One of the main objectives of the GHS-Panel is to improve agriculture data collection in Nigeria by collecting information at disaggregated levels (crop, plot, and household levels), and linking such data to nonagricultural aspects of livelihoods. All households were visited at two points in time: right after planting (post planting visit) and right after harvest (post harvest visit) and were administered multi topic household, agriculture and community questionnaires. Amongst a variety of topics, the household questionnaire gathered detailed information on food and nonfood consumption and expenditure of households. The survey covers over 100 food items commonly consumed in Nigeria and collected information on household consumption (quantity consumed) of the items in the past seven days before the survey. The use of handheld GPS devices to record coordinates of household plots allows the linkage of the data with geospatial variables such as rainfall and temperature data from other sources. Of the 5,000 households in the survey, about 3,000 were agricultural households in rural and urban areas producing a wide variety of crops. The study focuses on the rural agricultural households interviewed for the GHS-Panel 2010/2011 survey and all statistics are weighted to ensure representativeness at national, regional and rural/urban levels.

Using the consumption data from the GHS-Panel, dietary diversity indicators from the harvest round of the data are constructed. The indicator is constructed by classifying food items from the consumption module into 12 distinct food groups. The food groups are delineated according to guidelines from the Food and Agriculture Organization (Kennedy, Ballard, & Dop, 2011). Dietary diversity is an important nutritional indicator of household calorie availability. In a review of the nutritional literature on validation studies, Ruel (2003) documents a consistent set of results in developing countries that illustrate this positive correlation between dietary diversity measures and nutrient adequacy. For this reason, the present study uses household dietary diversity as its primary nutritional measure. In addition to dietary diversity, calorie intake from food groups is included in the descriptive analysis. Calorie intake and production was estimated using the consumption and agricultural production data in the GHS-Panel and applying calorie conversions for each item from the US Department of Agriculture's National Nutrient Database for Standard Reference.[1] The item level calorie estimates were then aggregated to the food/crop group and household levels for use in the analysis.

The two measures of production variability used in the analysis that follows are a count of the number of crop groups harvested and the value of agricultural output (agricultural revenue). Both measures are calculated using information from the post harvest round of the GHS-Panel. To construct the count of harvested crop groups, food crops were separated into five groups that correspond to five of the 15 groups that comprise the dietary diversity measure. Harvested nonfood crops were excluded. Agricultural revenue was calculated using farmer estimates of the total harvest value for each crop.

A major factor that could influence income (revenue) from production diversity is climate variability. The extensive literature on climate variability and agricultural production has established a strong relationship between climate and crop yields (Rowhani, Lobell, Linderman, & Ramankutty, 2011; Tao, Yokozawa, Liu, & Zhang, 2008). Rowhani et al. (2011) examined the relationship between seasonal climate and crop yields in Tanzania and found that both intra and inter seasonal changes in temperature and precipitation influence cereal (maize, sorghum and rice) yields in Tanzania. They found that seasonal temperature increases have the most important impact on yields. Tao et al. (2008) found that major crop yields were significantly related to growing season climate in the main production regions of China, and that growing season temperature had a generally significant warming trend. Using a panel dataset, Schlenker and Lobell (2010) examine the impact of changes in temperature and precipitation on crop yields of five main staple crops (maize, sorghum, millet, groundnuts and cassava) in sub-Saharan Africa and found that temperature changes have a much stronger impact on yields than precipitation changes.[2] Hatfield et al. (2008) establish that degree days, the number of days extreme temperatures affect optimal plant growth, have been found to be correlated with reduced yields and agricultural income. For this reason, the paper uses degree day and rainfall deviations as a source of exogenous variation in agricultural production. Daily temperature data from 1981–2010 and daily rainfall data from 2000–2010 was extrapolated from the Surface Meteorology and Solar Energy version 6.0 developed by the Atmospheric Sciences Data Center at NASA[3] and geo-referenced to the GHS-Panel. Historical averages for the number of degree days (1981–2009) and rainfall (2000–2009) during the planting season (April–June) were calculated for each household. The deviations from historical planting season degree day and rainfall averages were then calculated for the 2010 planting season.

In the next section, the econometric strategy for the paper is described, building on the socio-economic, geo-referenced climate data, and dietary diversity indicators.

III. Econometric Strategy

In a nonseparable household model, production and consumption decisions are jointly determined (Benjamin 1992; Bardhan & Udry 1999; LaFave & Thomas 2013; Strauss, 1984). Identification of the direction of causality is potentially confounded by cross sectional correlation. In our empirical strategy, a reduced form regression of climate variables on dietary diversity would also be mis-specified due to omitted production variables. Behrman et al. (1997) addressed these econometric challenges by developing a dynamic nonseparable household model which motivated using planting and harvest season data to improve the identification of calorie-income elasticity estimates. Our strategy builds on this approach and the post planting and post harvest data structure of the Nigeria LSMS-ISA by distinguishing between the timing of seasonal production decisions to understand the effect of planting period production decisions on post harvest dietary diversity within a full agricultural season, *t*.

In the dynamic formulation of the agricultural household model, households maximise expected utility given the production function (Q_t), time endowment (E^L) and intertemporal budget constraint (Equation 4) (LaFave et al., 2013). The household's problem is to choose produced agricultural goods (x_{at}), purchased market goods (x_{mt}), agricultural inputs (V_t) and leisure (l_t) to maximise utility given observed (μ_t) and unobserved household characteristics (ε_t) such that:

$$\max E\left[\sum_{t=0}^{\infty} \beta^t u(x_{at}x_{mt}, l_t; \mu_t, \varepsilon_t)\right] \tag{1}$$

subject to the constraints:

$$Q_t = Q_t(L_t, V_t, A_t; \theta) \tag{2}$$

$$E^L = l_t + L_t^F + L_t^O \tag{3}$$

$$W_{t+1} = (1 + r_{t+1})\left[W_t + w_t\left(E^L - l_t\right) + \pi - p_{at}x_{at} - p_{mt}x_{mt}\right] \tag{4}$$

where $\pi_t = p_{at}Q_t(L_t, V_t, A_t; \theta) - w_tL_t - p_{Vt}V_t - p_AA_t$ is the profit function over season *t*. Equation (2) represents the production function which depends on vectors of farm labour (L_t), variable inputs (V_t), fixed assets (A_t) such as land and capital, and seasonal climate variability (θ). The household's time endowment (Equation 3) is divided between leisure, on farm (L_t^F) and off farm labour (L_t^O). A standard dynamic household budget constraint is represented in Equation (4).

In a separable household model, demand for consumption of good c in period t is:

$$x_{ct} = x_{ct}(p_{mv}, p_{av}, w_v, r_{t+1}, \pi_t(p_{vV}, p_{aV}, p_V, p_{At}; \theta), y_V, \lambda_V; \mu_t, \varepsilon_t) \tag{5}$$

where good c consumption depends on market (p_{mv}) and agricultural prices (p_{av}), the price of variable inputs (p_v) such as agricultural labour, fertiliser, pesticides or herbicides, interest rates (r_{t+1}), farm profits (π_t) conditional on climate variability (θ), exogenous income (y_V) and future prices via the marginal utility of wealth (λ_V). Consumption also depends on observed (size and composition) and unobservable household characteristics (food preferences). The problem can be disaggregated into a recursive two period problem where household first maximise profits and then choose consumption levels if we assume separability (Bardhan & Udry 1999; Singh, Squire, & Strauss, 1986).

In our nonseparable formulation, production factors such as input prices influence the household's consumption choices such that:

$$x_{ct} = x_{ct}(p_{mv}, p_{av}, w_v, r_{t+1}, \pi_t(p_{vV}, p_{aV}, p_V, p_A; \theta), p_{vV}, p_{aV}, p_V, p_A, y_V, \lambda_V; \mu_t, \varepsilon_t) \tag{6}$$

Input prices affect household consumption when markets are incomplete and we cannot assume that only income affects household consumption demand. Therefore, the consumption demand equation includes not only variables that affect household income, but also those variables that affect production decisions. The identification strategy to disentangle the joint production and consumption decision by the household is to model the production-climate variability relationship as a first stage regression controlling for other production variables including labour availability and agricultural capital while also controlling for prices and including state level fixed effects. The state fixed effects control for potentially omitted variables that are unobserved in our data set including interest rate and price expectations which we assume are similar across rural areas within states. In the second stage, exogenous climate deviations from long term means provide identification for the effect of agricultural production variables (agricultural revenue and crop diversity) on dietary diversity. The demand for a consumption good is generalisable to a dietary diversity indicator or a share of calories consumed by food group after converting food quantities into calories.

More precisely, the first stage relationship between production (Y), which is determined by input prices (p_v), the value of agricultural capital (p_A), climate variability (θ_{hs}), and household characteristics including household size and composition (X):

$$\ln Y_{hvs} = \beta^{pv} p_v + \beta^A p_A + \beta^\theta \theta_{hvs} + \beta^x X_{hvs} + \lambda_s + \varepsilon_{hvs} \tag{7}$$

In our empirical analysis, the relationship between production and climate variability includes the specification of Y_{hs} as either a crop group count index in a first set of regressions or agricultural revenue[4] in a second set of regressions. Farm capital is a quasi-fixed stock over the agricultural season considered in the analysis. The motivation for including agricultural capital is clear from the agricultural production function: agricultural capital along with inputs are posited to directly affect production and hence agricultural revenue. As agricultural capital is a stock, we argue that this stock does not change within season, though it may change across season.[5] Agricultural capital likely satisfies the exclusion restriction because investments in capital occur before post harvest consumption measurement and are unlikely to be correlated with post harvest consumption. The value of agricultural capital is uniformly low in our sample, while consumption diversity is more variable. In direct tests, we find that agricultural capital is not strongly correlated with current period consumption. Climate variables including the degree day and rainfall deviations from historical trends are included in the above first stage equation. State fixed effects (λ) are also included in this regression to control for agricultural market integration that may affect either access to inputs or marketing opportunities for farmers.

The second stage equation establishes the relationship between production and dietary diversity at the household level and is given by:

$$\ln N_{hvs} = \beta^{Y} \ln Y_{hvs} + \beta^{pm} p_m + \beta^{pv} p_v + \beta^{x} X_{vhs} + \lambda_s + \varepsilon_{hvs} \quad (8)$$

where N_{hs} is dietary diversity for household h in village v in state s. Dietary diversity is determined by agricultural production Y, market prices (p_m) during the post harvest period, variable input prices (p_v), and household characteristics X including household composition which may affect household consumption. Y is endogenously determined so we instrument with local climate variables and agricultural capital that are correlated with production variables, but uncorrelated with dietary diversity. The plausibility of the excludability condition depends on the spatial intensity of climate shocks and market integration. While climate shocks could have an effect on dietary diversity via price variation, the econometric specification includes market prices in the second stage. Further, rural Nigerian markets seem to be sufficiently integrated that local climate variability causes reduction in yields for local farmers, but these climate induced yield variations have small effects on equilibrium prices. Hence, the pathway through which climate variation affects dietary diversity is through the quantity of crops available for the household's own consumption or in our second specification through the agricultural income generated from production, but not via local climate variability induced price changes.

Testing the Exclusion Restriction

The validity of the exclusion restriction potentially invalidates the identification of the effect of production variables on the nutritional outcomes. The primary concern is that climate variation may be correlated with dietary diversity or calorie shares by food group. This would be the case if climate variation produced general equilibrium price changes that in turn affect consumption through market prices independently of their effect on production.

One approach to test this mechanism and find evidence that the exclusion restriction is indeed invalid would be to estimate the effect of climate directly on market level prices. Any potential general equilibrium effects of climate variation on market prices, either through deviation from historical averages of degree days or rainfall, can be estimated directly. As a test of one potential mechanism that would violate the exclusion restriction, the climate-price specification is estimated at the enumeration area level, the unit of analysis that most closely correlates to local markets in our data. If strong correlations exist between the climate shocks and market prices, the exclusion restriction would be clearly violated.

IV. Results

Tables 1–4 examine the descriptive linkages between production, climate, and nutrition. In Tables 1–3, households are separated into degree day and rainfall deviation quartiles where deviations are with respect to the historical mean of the climate variable. Those households in the first quartile experienced larger negative deviations (for example below average rainfall, fewer degree days) while those in the fourth experienced larger positive deviations (for example higher rainfall and more degree days). Increased degree days have negative effects on crop yields and agricultural income for a variety of crops (Hatfield et al. 2008; Schlenker & Lobell 2010).

Table 1 provides descriptive estimates for total production across degree day and rainfall shock quartiles. For both degree day and rainfall shocks, an inverted-U relationship is observed whereby agricultural revenue is highest when there is a small deviation from average weather but smallest when there are large positive or negative shocks. Negative rainfall shocks and positive degree days

Table 1. Total production and climate shocks

	Degree Day Shock Quartiles				Rainfall Shock Quartiles				
	– Shock		+ Shock		– Shock		+ Shock		
	1	2	3	4	1	2	3	4	Total
Total harvest value									
Harvest Value (Naira)	139,269	170,005	190,035	133,172	118,777	186,447	164,381	162,866	158,114
Households that grew crop groups (per cent of quartile):									
Grains or flours	60.0	41.8	87.4	99.6	98.7	95.2	60.1	34.8	72.2
Starchy roots, tubers, and plantains	62.3	86.7	29.2	6.6	4.2	19.3	75.3	86.0	46.2
Pulses, nuts, or seeds	29.1	8.7	56.0	81.0	82.5	56.5	27.9	7.8	43.7
Fruits	12.9	10.7	2.6	0.8	0.7	3.0	11.1	12.3	6.7
Oil plants	6.9	12.8	1.0	0.0	0.0	0.2	4.6	15.9	5.2
Vegetables	20.3	21.8	7.8	10.9	3.7	13.9	16.2	27.0	15.2
Other crops	9.4	1.0	2.2	3.7	2.4	5.7	7.9	0.2	4.1
Share of harvest value from crop group:									
Grains or flours	32.9	17.2	59.9	67.4	68.6	65.3	29.5	13.8	44.3
Starchy roots, tubers, and plantains	41.6	69.9	18.2	1.1	0.8	9.3	51.2	69.6	32.7
Pulses, nuts, or seeds	8.4	1.7	19.0	25.9	27.9	18.4	7.2	1.7	13.8
Fruits	3.4	2.9	0.8	0.2	0.3	0.8	2.6	3.7	1.8
Oil plants	2.6	3.9	0.5	0.0	0.0	0.0	1.4	5.6	1.8
Vegetables	5.5	3.7	1.1	3.7	1.5	3.4	3.5	5.5	3.5
Other crops	5.7	0.6	0.5	1.6	0.9	2.7	4.7	0.1	2.1
Share of total calories produced from crop group:									
Grains or flours	35.6	18.1	60.2	73.7	74.9	67.4	30.0	15.2	46.9
Starchy roots, tubers, and plantains	43.3	67.8	17.2	0.8	0.5	10.4	51.5	66.8	32.3
Pulses, nuts, or seeds	8.3	2.4	21.2	24.8	24.0	20.5	9.9	2.3	14.2
Fruits	4.9	2.1	0.5	0.0	0.0	1.0	3.9	2.7	1.9
Oil plants	4.2	7.3	0.5	0.0	0.0	0.1	2.4	9.5	3.0
Vegetables	3.7	2.3	0.2	0.7	0.6	0.6	2.3	3.4	1.7
Other crops	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0

Notes: Degree day and rainfall shocks are deviations from historical mean values. A positive shock indicates above average degree days or rainfall while a negative shock indicates below average.

Table 2. Production diversity and climate shocks

	Degree Day Shock Quartiles				Rainfall Shock Quartiles				
	– Shock		+ Shock		– Shock		+ Shock		
	1	2	3	4	1	2	3	4	Total
Number of crops and crop groups harvested by household:									
# of crop groups harvested	1.92	1.82	1.84	1.99	1.90	1.88	1.95	1.84	1.89
# of crops harvested	2.69	2.46	2.84	3.40	3.07	3.15	2.77	2.41	2.85
Share of cultivated land devoted to crop group:									
Grains or flours	36.6	20.6	61.9	66.1	64.3	70.1	34.9	15.8	46.3
Starchy roots, tubers, and plantains	36.6	67.4	13.9	1.2	0.7	6.4	42.8	69.3	29.8
Pulses, nuts, or seeds	10.0	2.2	21.1	29.4	33.1	17.4	10.1	2.1	15.7
Fruits	4.3	2.6	0.5	0.1	0.1	0.5	2.7	4.2	1.9
Oil plants	0.7	1.6	0.3	–	–	–	0.8	1.9	0.7
Vegetables	5.9	4.9	1.6	2.5	1.2	3.0	4.1	6.6	3.7
Other crops	5.8	0.7	0.6	0.8	0.5	2.6	4.7	0.0	2.0

Notes: Degree day and rainfall shocks are deviations from historical mean values. A positive shock indicates above average degree days or rainfall while a negative shock indicates below average.

Table 3. Harvest value, dietary diversity and climate shocks

	Degree Day Shock Quartiles				Rainfall Shock Quartiles				
	– Shock		+ Shock		– Shock		+ Shock		
	1	2	3	4	1	2	3	4	Total
Dietary diversity:									
Dietary Diversity (food group count)	8.04	8.18	7.04	6.94	6.65	7.24	7.72	8.59	7.55
Per cent of total calories consumed from food group:									
Grains and flours	39.6	31.3	55.2	66.6	68.9	57.8	38.2	27.8	48.2
Roots and tubers	21.2	25.2	11.2	2.0	1.8	7.7	23.7	26.4	14.9
Pulses, nuts, and seeds	9.2	11.9	10.5	9.9	10.3	10.5	9.8	10.9	10.4
Oils and fats	16.8	18.1	14.2	13.7	11.9	15.2	17.1	18.7	15.7
Fruits	1.9	1.1	0.5	0.2	0.2	0.4	1.5	1.6	0.9
Vegetables	1.6	2.4	1.2	1.3	1.2	1.1	1.5	2.7	1.6
Eggs	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.0
Meat and poultry	2.5	2.1	2.3	1.8	1.7	2.2	2.2	2.7	2.2
Fish and seafood	2.2	3.8	1.7	0.6	0.6	1.4	2.3	4.0	2.1
Milk and milk products	1.1	1.6	0.3	0.6	0.4	0.4	0.7	2.0	0.9
Sweets and confections	1.8	1.0	2.0	2.8	2.8	2.2	1.7	0.9	1.9
Condiments and beverages	1.9	1.4	0.9	0.4	0.1	1.0	1.3	2.3	1.2
Per cent of food group consumption from own production*:									
Grains and flours	33.6	19.3	56.7	61.4	57.2	63.6	36.0	13.7	43.0
Roots and tubers	49.0	65.5	35.6	12.2	8.0	27.4	52.5	65.8	46.1
Pulses, nuts, and seeds	14.5	7.7	38.0	58.8	57.9	42.9	11.3	6.9	29.2
Oils and fats	11.4	25.4	2.9	1.5	1.7	2.5	7.4	29.5	10.3
Fruits	36.1	29.3	11.5	0.4	1.0	11.6	35.0	30.3	24.0
Vegetables	9.4	7.3	6.2	9.4	9.1	7.6	9.6	6.1	8.1
Eggs	14.4	2.6	4.8	36.9	0.0	4.4	7.3	14.7	9.1
Meat and poultry	8.6	6.3	7.3	2.9	2.2	7.4	8.3	6.8	6.2
Fish and seafood	1.1	0.7	2.6	7.8	7.4	2.0	1.5	0.8	2.0
Milk and milk products	6.7	4.2	14.2	4.0	5.2	11.5	13.5	1.0	6.8
Sweets and confections	2.4	0.3	0.2	0.0	0.1	0.2	2.0	0.8	0.7
Condiments and beverages	0.9	2.1	1.9	0.0	0.0	1.3	1.0	2.2	1.4

Notes: Degree day and rainfall shocks are deviations from historical mean values. A positive shock indicates above average degree days or rainfall while a negative shock indicates below average. *Calculated as: calories produced of group x/total calories consumed of group x

Table 4. Dietary diversity and harvest value quartiles

	Harvest Value Quartiles				
	1	2	3	4	Total
Dietary Diversity (food group count)	8.16	7.19	7.30	7.54	7.54
Distribution:					
Consumed 3 or fewer food groups (% of quartile)	1.1	2.7	2.5	1.7	2.0
Consumed 4–6 food groups (% of quartile)	22.4	33.2	30.4	24.2	27.5
Consumed 7–9 food groups (% of quartile)	45.7	50.1	55.9	59.8	52.9
Consumed 10 or more food groups (% of quartile)	30.8	14.0	11.2	14.3	17.7

Notes: The sample is divided into quartiles based upon total harvest value. Quartile 1 contains households with the lowest harvest value while quartile 4 contains those with the highest.

shocks appear to have the greatest effect on agricultural revenue. Table 1 suggests there is a strong relationship between degree day and rainfall variability and the type of crops harvested by the household. Grains and flours as well as pulses, nuts, and seeds were more likely to be harvested by households that experienced above average temperatures (degree days) and below average rainfall during the planting season. This may be because grains and pulses are generally more drought and heat tolerant than other crops. For all other crop groups, the reverse descriptive trend is observed. The middle panels of Table 1 present the shares of total production in terms of both agricultural revenue and the calories produced of each crop group. Variations in the production shares across the climate shock quartiles are nearly identical to those for the production indicators in the top panel.

Table 2 examines the descriptive relationship between crop diversity and climate deviations. In contrast to agricultural revenue, the number of crop groups harvested exhibits a weakly positive relationship with degree day shocks and a weakly negative relationship with rainfall shocks. Positive rainfall deviations potentially reduce production uncertainty in the early planting period that results in less need to diversify planting. Increased degree days imply higher temperatures during the agricultural season and increased production uncertainty which may increase farmer's crop diversification. The bottom panel of Table 2 presents the share of cultivated land devoted to each crop group. In general, the land shares follow the same pattern as production shares in Table 1. Overall, the descriptive results highlight an important linkage between climate variability and agricultural production.

The relationship between climate variations and both dietary diversity and food group consumption is explored in Table 3. The estimates in the top panel suggest that wetter weather is associated with higher dietary diversity. Rainfall conditions that are more favourable to agricultural production are associated with improved dietary diversity, while there is a negative association between degree day shocks and dietary diversity. The middle panel of Table 3 presents calorie consumption shares of each food group. Variations across climate shock quintiles are similar to the production patterns shown in Table 1. The consumption share of grains and flours as well as pulses, nuts, and seeds is higher on average in households that experience above average temperatures and below average rainfall while the opposite is largely true for all remaining categories. A similar pattern is found in the bottom panel of Table 3 where the calorie consumption share from own production is presented.

Table 4 examines the relationship between agricultural revenue and dietary diversity. The estimates in the top panel of Table 4 do not suggest a clear trend between the number of food groups consumed and agricultural revenue. Curiously, households with the lowest agricultural revenue consumed the most food groups on average. These may be the farmers who consume primarily out of own production. Further, wealthier rural households may engage in agriculture as a side activity with a nonfarm activity as their main source of income. Such households will probably fall in the lower agricultural revenue quartile but have sufficient means to acquire a wider variety of food. The bottom panel of the table looks at the distribution of the number of food groups consumed by agricultural revenue quartile. The distribution remains relatively stable across agriculture revenue though the proportion of households consuming 7–9 food groups does consistently increase with agricultural revenue.

The summary statistics for variables used in the analysis are presented in Table 5. According to the table, an average household consumed food from 7.5 of the 12 food groups included in the dietary diversity measure. An average household in the sample had agricultural revenue of 158,000 Naira (about $980) though there was considerable variation within the sample. Households grew 2.8 different crops across 1.9 different crop groups. Around half of all households grew two crop groups but a significant number only grew a single crop group or three groups.[6] The 2010 planting season average degree day deviation was positive while the rainfall deviation was negative. This suggests that the 2010 planting season was hotter as well as drier than average.

The value of agriculture capital for the average rural households is relatively low with a value of 4,600 Naira (about $28) while the average size of total land holdings is 1 hectare. The average household has about three persons in the 15–65 age group who are primarily the labour pool for the household and about three persons in the 0–14 age group while less than one person on average fell in the above 65 age group. As expected, most household heads are male (about 90%) and have an average of four years of schooling.

The last two panels in Table 5 present the average prices for agricultural inputs and composite prices for the dietary diversity food groups. The average daily male agricultural wage was just under 1900

Table 5. Summary statistics

	Mean	Std Dev
Dietary diversity		
Count of food groups consumed	7.55	1.97
Production characteristics:		
Harvest value	158,114	324,928
Number of crops grown by the household	2.85	1.38
Number of crop groups grown by the household	1.89	0.78
Distribution of number of crop groups:		
Grew crops from 1 group	0.32	0.47
Grew crops from 2 groups	0.51	0.50
Grew crops from 3 groups	0.13	0.34
Grew crops from 4 groups	0.04	0.19
Grew crops from 5 groups	0.00	0.05
Climate shocks:		
Deviation from mean planting season (April–June) degree days	48.9	54.0
Deviation from mean planting season (April–June) rainfall	−30.9	49.5
Other agricultural characteristics:		
Value of household agricultural capital	4,581	25,717
Total household land holdings (hectares)	1.0	1.6
Household characteristics:		
Number of persons aged 15–65 in the household	3.1	1.8
Number of persons aged 0–14 in the household	3.0	2.3
Number of persons aged 66 and over in the household	0.2	0.5
Male Head of household	0.9	0.3
Age of head	50.0	15.2
Head years of education	4.4	4.8
Local agricultural input prices (various geographic levels)		
Local male adult agricultural wage	1855.8	3677.1
Local fertiliser price per kg	122.8	329.0
Local pesticide price per kg	827.7	667.8
Local herbicide price per kg	964.6	665.3
Local food prices (various geographic levels):		
Market price of grains/flour	118.9	42.9
Market price of roots/tubers	77.4	17.6
Market price of pulses, nuts, seeds	142.1	67.8
Market price of oils and fats	248.6	97.6
Market price of fruits	98.8	16.7
Market price of vegetables	167.7	82.0
Market price of eggs	494.6	133.9
Market price of meat and poultry	476.2	116.3
Market price of fish and seafood	421.0	179.0
Market price of milk and products	491.7	207.1
Market price of sweets and confections	277.0	116.5
Market price of condiments and beverages	246.6	123.6
Observations	2154	2154

Notes: Weighted sample mean and standard deviation estimates presented.

Naira (about $12). The average local per kilogram prices for fertiliser, pesticide, and herbicide were 120, 830, and 960 Naira respectively. Fertiliser is significantly cheaper than pesticide or herbicide because the majority of fertiliser used was organic and not chemically based. Local food prices follow a predictable pattern whereby staples such as grains and tubers are relatively expensive while proteins (eggs, meat, and fish) are more expensive.

The descriptive trends presented in Tables 1–5 outline the key variables in our econometric analysis. Tables 6 and 7 present the paper's primary results from estimation of the relationship between agricultural revenue and dietary diversity as well as production variability and dietary diversity,

Table 6. Agricultural revenue and dietary diversity

	OLS	IV: 1st Stage	IV: 2nd Stage
Agricultural Revenue:			
Log of agricultural revenue	0.014**		0.18***
	(0.0061)		(0.056)
Instrumental variables:			
Deviation from mean planting season (April–June) degree days		−0.0015***	
		(0.00049)	
Deviation from mean planting season (April–June) rainfall		0.0022***	
		(0.00083)	
Interaction of rainfall and degree day deviation (April-June)		−0.00001	
		(0.000011)	
Log value of agricultural capital		0.11***	
		(0.019)	
Local input prices (various geopolitical levels):			
Log male adult agricultural wage	−0.0081	0.11***	−0.026**
	(0.0081)	(0.030)	(0.011)
Log fertiliser price per kg	−0.0019	0.0055	−0.0040
	(0.0072)	(0.042)	(0.0089)
Log pesticide price per kg	−0.0050*	−0.034**	0.00085
	(0.0030)	(0.016)	(0.0039)
Log herbicide price per kg	−0.016*	0.012	−0.018*
	(0.0081)	(0.028)	(0.0093)
Household characteristics:			
Number of persons aged 15–65 in the household	0.0041	0.081***	−0.010
	(0.0034)	(0.013)	(0.0062)
Number of persons aged 0–14 in the household	0.0074***	0.049***	−0.0014
	(0.0025)	(0.011)	(0.0043)
Number of persons aged 66 and over in the household	0.0023	0.0076	0.00047
	(0.016)	(0.055)	(0.018)
Male Head of household	0.00089	0.43***	−0.077**
	(0.019)	(0.092)	(0.036)
Age of head	−0.00088	0.0026	−0.0013**
	(0.00057)	(0.0021)	(0.00066)
Head years of education	0.0058***	−0.0011	0.0060***
	(0.0013)	(0.0053)	(0.0015)
Constant	5.65***	4.82	4.69**
	(1.57)	(8.29)	(2.15)
Durbin-Wu-Hausman χ^2		10.91***	
F-Statistic		12.64***	
Sargan and Basmann overidentification χ^2		4.4	

Note: Standard errors clustered at the enumeration area in parentheses. Estimates for local food group prices omitted for brevity. Significance denoted: ***p < 0.01, **p < 0.05, *p < 0.1.

respectively from Equation (8). In both tables, the first column shows the results of an OLS specification. The OLS results are included for comparison and show a positive and significant correlation between dietary diversity and both agricultural revenue and production diversity. The second column in Tables 6 and 7 shows the first stage results establishing the relationship between the instrumental variables (climate variability and quasi fixed agricultural capital) and production. The results from the first stage estimations suggest that a higher than average number of degree days and lower than average rainfall in a planting season are associated with lower agricultural revenue as expected.

The first stage results also suggest that a higher than average rainfall is positively associated with increased harvested crop diversity. Though the results show a negative relationship between degree

Table 7. Crop diversity and dietary diversity

	OLS	IV: 1st Stage	IV: 2nd Stage
Production diversity:			
Log count of food groups grown	0.037** (0.015)		0.24* (0.13)
Instrumental variables:			
Deviation from mean planting season (April–June) degree days		−0.00014 (0.00034)	
Deviation from mean planting season (April–June) rainfall		0.0018*** (0.00048)	
Interaction of rainfall and degree day deviation (April–June)		−0.000017** (0.00001)	
Log value of agricultural capital		0.027*** (0.0068)	
Local input prices (various geopolitical levels):			
Log male adult agricultural wage	−0.0060 (0.0082)	−0.0096 (0.013)	−0.0027 (0.0093)
Log fertiliser price per kg	−0.0014 (0.0073)	−0.011 (0.011)	0.00090 (0.0075)
Log pesticide price per kg	−0.0049 (0.0030)	−0.013** (0.0053)	−0.0019 (0.0036)
Log herbicide price per kg	−0.016** (0.0080)	0.016 (0.012)	−0.021*** (0.0079)
Household characteristics:			
Number of persons aged 15–65 in the household	0.0051 (0.0034)	0.0056 (0.0056)	0.0040 (0.0037)
Number of persons aged 0–14 in the household	0.0079*** (0.0025)	0.0058 (0.0042)	0.0065** (0.0026)
Number of persons aged 66 and over in the household	0.0032 (0.016)	−0.021 (0.024)	0.0078 (0.017)
Male Head of household	0.0059 (0.018)	0.018 (0.035)	−0.0017 (0.020)
Age of head	−0.00088 (0.00056)	0.00091 (0.00075)	−0.0011* (0.00058)
Head years of education	0.0058*** (0.0013)	0.0019 (0.0022)	0.0055*** (0.0013)
Constant	5.82*** (1.58)	−2.15 (2.77)	6.28*** (1.75)
Durbin-Wu-Hausman χ^2		3.27*	
F-Statistic		7.6***	
Sargan and Basmann overidentification χ^2		20.67***	

Note: Standard errors clustered at the enumeration area in parentheses. Estimates for local food group prices omitted for brevity. Significance denoted: ***p < 0.01, **p < 0.05, *p < 0.1.

days and crop diversity, this relationship was not significant. The interaction of degree day and rainfall deviations was a significant determinant of crop group diversity. The first stage results also provide some evidence that the other instrumental variable, agricultural capital, is relevant to explaining production variables. The household's value of agricultural capital equipment was positively associated with both crop group diversity and agricultural revenue.

The third column of Tables 6 and 7 present the main results from the second stage of the IV estimation. According to the results, agricultural revenue has a positive and statistically significant effect on dietary diversity. The set of instruments in Table 6 is strongly correlated with the endogenous variable with an F-statistic of 12.6. The specification also passes two benchmark tests for endogeneity (Durbin-Wu-Hausman) and overidentification (Sargan and Bassmann) whose results are shown at the bottom of Table 6.[7] The estimates suggest that a 10 per cent increase in agricultural revenue will increase dietary diversity by 1.8 per cent, a relatively small effect that is precisely estimated.

The results also indicate that both the agricultural wage and herbicide price have a negative effect on dietary diversity. Other household characteristics also have an association with dietary diversity. Gender of the household head is found to have a significant effect on dietary diversity. Households with male heads are less likely to have a diverse diet compared to those with female heads. The results also show that households with better-educated heads had more diverse diets while households with older heads had less diverse diets.

Production diversity was found to have a positive and statistically significant effect on dietary diversity as shown in Table 7. The set of instruments are correlated with the number of crop groups grown with a first stage F-statistic of 7.6. This F-statistic falls slightly below the standard cut-off value of 10 established by Staiger and Stock (1997) which indicate that this specification could suffer from relatively weak instruments. As for the agricultural revenue specification, the Durbin-Wu-Hausman test result indicates that the correction for endogeneity of production diversity is justified. The production diversity specification does not pass the Sargan-Bassman overidentification test. This casts some doubt on the validity of the instruments in the production diversity specification and thus the results should be interpreted with this caveat in mind. One potential reason the specification does not pass the IV tests is found in our descriptive statistics. Low production diversity is noted across the rural subsample in Table 2 with both a low mean and standard deviation. Farmers specialise in fewer crops, so the probable agricultural-nutrition linkage results from increased revenue due to specialisation. For these reasons, our preferred specification is found in Table 6, which includes agricultural revenue as the production variable. The point estimate suggests that a 10 per cent increase in production diversity (as measured by crop groups[8]) will increase dietary diversity by 2.4 per cent, all else equal. This elasticity is larger than that found for agricultural revenue, but the overall magnitude is relatively small.[9]

Significant dietary diversity relationships are also found for the number of persons aged 0–14 and for the age and education of the household head. The results indicate that households with more persons in the 0–14 age group are more likely to have a diverse diet. Similar to agricultural revenue, the production diversity results indicate that households with older heads are less likely to consume a diverse diet while having a more highly educated head is associated with a more diverse household diet.

Testing the Exclusion Restriction

If climate variations impact dietary diversity through climate induced price fluctuations, then the instrument exclusion restriction is violated and our IV results will be biased. Table 8 contains the results from a direct test of the relationship between climate deviations and local (enumeration area) composite prices for each food group. This is one mechanism through which the exclusion restriction would be violated if production shocks affected harvest period prices and the consumption choices of households. If markets are relatively integrated or production shocks are relatively minor then localised production shocks should have no effect on market prices.

For the majority of food groups, there is no significant relationship between climate deviations during the agricultural season and local prices after harvest. In addition, most estimates of the effect are relatively small. Although for a few items climate deviations appear to have had a weak effect on prices, the lack of a measured effect for most food items lends support that the exclusion restriction is not violated through the transmission of production shocks on post harvest food prices.

Differential Effects Across Food Groups

The agricultural revenue estimation results found in Table 6 indicate a small but significant effect of increased agricultural revenue on dietary diversity. Dietary diversity measures may coarsely measure

Table 8. Local market prices and climate shocks

	Median EA Market Prices											
	Grains	Tubers	Pulses	Oils	Fruit	Vegetables	Eggs	Meat	Fish	Milk	Sweets	Condiments & Beverages
Village median degree day deviation	0.015**	0.0030	0.0017	−0.0018	−0.0062	−0.0070	−0.014	−0.0026	−0.019	0.0079	0.035	−0.034
	(0.0072)	(0.0041)	(0.0099)	(0.020)	(0.0055)	(0.015)	(0.020)	(0.016)	(0.027)	(0.021)	(0.024)	(0.031)
Village median rainfall deviation	0.022	−0.0031	0.016	0.054*	−0.012	0.0078	0.031	0.050*	0.088*	0.057	0.0062	−0.0059
	(0.017)	(0.0058)	(0.021)	(0.031)	(0.011)	(0.041)	(0.047)	(0.026)	(0.049)	(0.050)	(0.027)	(0.029)
Interaction of rainfall and degree day deviation	−0.000062	0.000066	0.00024	−0.000075	0.00019	0.00021	0.000086	−0.00015	−0.0010**	−0.00043	0.00046	0.00080
	(0.00016)	(0.000068)	(0.00020)	(0.00042)	(0.00012)	(0.00041)	(0.00034)	(0.00036)	(0.00042)	(0.00048)	(0.00052)	(0.00088)
Village median agricultural wage	1.34**	0.16	1.48**	−0.46	−0.30	1.23	2.05	−0.35	1.28	2.84	1.04	0.035
	(0.67)	(0.27)	(0.67)	(1.41)	(0.31)	(1.13)	(1.57)	(1.06)	(1.95)	(1.91)	(1.56)	(1.09)
Village median fertiliser price	0.52	0.13	−0.57	0.50	−0.27	1.69	−0.41	−0.53	−0.14	−1.08	−2.62	−0.18
	(0.49)	(0.21)	(0.79)	(0.86)	(0.33)	(1.41)	(1.47)	(1.06)	(1.28)	(2.00)	(2.96)	(1.01)
Village median pesticide price	−0.0045	0.28*	0.53	1.22**	0.075	1.62**	0.10	−0.080	−0.21	2.26	0.37	0.12
	(0.25)	(0.15)	(0.45)	(0.48)	(0.056)	(0.73)	(0.41)	(0.51)	(0.55)	(1.50)	(0.34)	(0.56)
Village median herbicide price	−0.73	0.060	1.64*	1.58	0.069	0.34	1.31	−0.32	−1.92	0.83	0.13	1.53
	(0.60)	(0.28)	(0.96)	(1.84)	(0.24)	(1.08)	(1.13)	(1.55)	(1.51)	(2.71)	(0.95)	(1.32)
Constant	66.0***	73.3***	41.1***	139***	129***	215***	564***	409***	344***	449***	160***	157***
	(6.38)	(2.79)	(8.61)	(15.9)	(3.27)	(13.1)	(12.7)	(13.4)	(14.9)	(25.6)	(11.3)	(8.85)
Observations	294	294	294	294	294	294	294	294	294	294	294	294
R-squared	0.986	0.976	0.985	0.988	0.976	0.952	0.955	0.993	0.994	0.986	0.988	0.990

Notes: Robust standard errors in parentheses. Significance denoted: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

diet composition changes due to exogenous changes in agricultural revenue because the dietary diversity measure aggregates changes in consumption patterns across all food groups in a single index. To examine the effects of agricultural revenue changes on diet composition, two additional variations of the IV models used above are estimated. The first is a probit version with food group consumption indicators as the dependent variable. This specification estimates how exogenous changes in agricultural revenue affect the likelihood that a household consumes a particular food group. The second specification estimates how exogenous changes in agricultural revenue through production shocks affect the share of a food group a household consumes. In this version, the calorie consumption shares from each food group are the dependent variables. We focus on the effects of agricultural revenue on the probability of food group consumption and the share of total calories by food group as only the agricultural revenue specification passed all instrumental variable tests.

The marginal effect estimates from the item consumption probit specifications are presented in the top panel of Table 9. In addition to the IV results, the results from a standard probit (without IV) are included for reference. The IV marginal effect estimates suggest that higher agricultural revenue is associated with a higher probability that a household will consume tubers, fruits, vegetables, fish, and meat and poultry. However, only the specifications for vegetables and fish pass all three IV tests. The estimated effect for the other food groups must therefore be viewed with some caution. The standard probit results support the positive finding for tubers and meat, but does not establish causality. The results suggest that as agricultural revenue increases, large effects on diet composition are unlikely as the probability of eating any single food group increases with similar likelihood.

Diet composition could also change with respect to the share of calories consumed from any single food group. The results from the food group calorie consumption shares are presented in the bottom panel of Table 9. Again, we include both the OLS and IV results. The IV results suggest that increased agricultural revenue was associated with a greater share of tubers being consumed but a lower share of fish, beverages, and grains. However, only the tuber and beverage specifications pass all three IV tests. The estimates indicate that a 10 per cent increase in agricultural revenue will result in the household consuming 5.2 per cent more tuber calories and 5.9 per cent fewer beverage calories as a share of total calories consumed. This could suggest that as households increase agricultural revenue, beverage consumption is replaced by healthier tuber consumption.

V. Conclusion

In recent discussions of the agriculture-nutrition relationship (Hoddinott, 2011), agricultural pathways to increase nutrition are likely to occur through two mechanisms: either through income effects or increased consumption of own produced foods. The paper's main results presented in Tables 6 and 7 test the potential effect of each of these pathways. Our preferred specification investigates the agriculture-nutrition relationship between increased agricultural revenue and dietary diversity, primarily because we observe low production diversity in our rural sample. It is probable that with increased revenue from production, households may be able to purchase more nutritious food as well as a wider variety of food beyond what could be grown locally given inputs and geographic restrictions. We use variation in rainfall and degree days and agricultural capital to instrument for the effect of agricultural revenue and crop diversity on dietary diversity – our preferred measure of nutrition. Climate variability is shown to have differing effects on revenue versus crop production diversity. Deviations from historical rainfall means have statistically significant effects on agricultural revenue and crop diversity while deviations from degree day seems to only have statistically significant effects on agricultural revenue.

The estimated dietary diversity-production elasticities imply that a 10 per cent increase in agricultural revenue or crop diversity result in a 1.8 per cent or 2.4 per cent increase in dietary diversity respectively. Both specifications illustrate a statistically significant, but small, effect of production on

Table 9. Agricultural revenue and consumption of food groups

	Food Groups											
	Grains	Tubers	Pulses	Oils	Fruit	Vegetables	Eggs	Meat & Poultry	Fish	Milk Products	Sweets	Beverages
	Consumption indicators (Probit)*											
Probit												
Log agricultural revenue	0.002	0.021**	0.011	−0.017**	0.008	0.001	0.001	0.021**	−0.008	0.011	0.001	0.003
	(0.002)	(0.009)	(0.008)	(0.007)	(0.009)	(0.005)	(0.004)	(0.010)	(0.009)	(0.009)	(0.010)	(0.009)
IV Probit												
Log agricultural revenue	0.301	0.981***	0.242	0.172	0.339**	0.729**	0.095	0.305*	0.355**	−0.026	0.127	0.157
	(0.494)	(0.212)	(0.174)	(0.223)	(0.173)	(0.311)	(0.353)	(0.161)	(0.176)	(0.171)	(0.161)	(0.180)
Wald exogeneity χ^2	0.16	26.88***	1.36	1.59	3.57*	6.19**	0.02	2.49	5.42**	0.12	0.65	0.74
F-Statistic	17.34***	17.34***	17.34***	17.34***	17.34***	17.34***	17.34***	17.34***	17.34***	17.34***	17.34***	17.34***
Amemiya-Lee-Newey overidentification χ^2	3.05	13.79***	2.21	2.67	16.52***	1.81	18.28***	14.55***	5.07	17.24***	13.26***	26.6***
	Log share of total calorie consumption											
OLS												
Log agricultural revenue	0.026	0.062***	0.063**	−0.061**	0.013	0.030	0.014	−0.0055	0.038	0.00068	0.016	0.00083
	(0.021)	(0.024)	(0.030)	(0.026)	(0.025)	(0.034)	(0.017)	(0.021)	(0.028)	(0.020)	(0.023)	(0.038)
IV												
Log agricultural revenue	−0.18*	0.52***	0.099	−0.20	−0.054	−0.038	−0.015	0.14	−0.36*	0.14	0.27	−0.59*
	(0.10)	(0.16)	(0.19)	(0.17)	(0.17)	(0.24)	(0.048)	(0.17)	(0.21)	(0.14)	(0.19)	(0.34)
Durbin-Wu-Hausman χ^2	4.52**	9.13***	0.04	0.69	0.17	0.08	0.4	0.75	3.83*	0.87	1.75	3.26*
F-Statistic	12.64***	12.64***	12.64***	12.64***	12.64***	12.64***	12.64***	12.64***	12.64***	12.64***	12.64***	12.64***
Sargan and Basmann overidentification χ^2	16.75***	3.23	8.74*	21.71***	1.29	13.12***	0.27	18.34***	7.82**	0.39	0.13	2.51
Observations	2154	2154	2154	2154	2154	2154	2154	2154	2154	2154	2154	2154

Notes: IV probit marginal effect and IV coefficient estimates presented with standard errors clustered at the enumeration area in parentheses. Significance denoted: ***p < 0.01, **p < 0.05, *p < 0.1. *Zone fixed effects were used in the probit estimation due to no variation in consumption patterns for some food groups within some states.

dietary diversity. Our preferred specification is the dietary diversity-agricultural revenue specification not only because it passes all instrumental variable tests, but because agricultural revenue can be derived either through variations in crops grown or the specialisation of farms towards higher value crops. As both types of production are present, our preferred specification with agricultural revenue includes not only crop choice by farmer, but also crop specialisation. Our elasticity estimates are similar to those found by Babatunde et al. (2010) for farming households in rural areas of Kwara state in Nigeria and Aromolaran (2004) for low income households in rural south western region in Nigeria. Our results also illustrated the limited effect of agricultural revenue changes on diet composition (Table 9). Increases in agricultural income raise the probability of consumption of both vegetables and fish, while the substitution of calories across food groups is limited to diet changes of reduction in beverage consumption and increase in tuber consumption.

The low dietary diversity-agricultural revenue elasticity illustrates the potentially limited role that agricultural interventions designed solely to raise the agricultural revenue of households might be expected to have on dietary diversity and diet composition. This may be particularly true if interventions do not change local availability of foods that are not normally consumed in local diets. The findings in this paper suggest it might be important for policy interventions targeted at improving nutrition of agricultural households to be broader than income expansion. Bhagowalia et al. (2012) found higher effects of agriculture income on nutrition when combined with better health and education outcomes.

While our estimates of the dietary diversity-crop choice elasticity do estimate a small effect of changes in crop count on dietary diversity, this specification is not well identified, as the instruments do not pass the Sargan-Basmann overidentification test. The result of this statistical test does reveal an important behavioural relationship to be investigated in future research. The small effect of crop group count on dietary diversity is likely due to the weak relationship between rainfall and temperature shocks on crop count in our data used for identification. As farmers do not change crop choice greatly across agricultural seasons, an area of future research could be to investigate when farmers choose to diversify production into foods not normally consumed in local diets that meet macro or micronutrient needs of the population. This would yield insights into the design of agricultural interventions that could be expected to have larger nutritional effects.

Another promising dimension of the production-nutrition relationship that could be investigated in future work is the role of intrahousehold production on household dietary diversity. While it is expected that increase in agricultural income can lead to improved nutrition in the household, the literature on intrahousheold allocation (see Berhman 1997) indicates that the extent could depend on the source and the recipient of the income. Using data on pastoralists in eastern Africa, Villa, Barrett, and Just (2011) estimate income elasticities of dietary diversity for demographic cohorts allowing asymmetric behaviours within the household. They find that household heads disproportionately bear the nutritional burden when household income is below mean, while other cohorts disproportionately enjoy the nutritional gains when it is above mean. The authors also find that adult daughters are better off than other household members in their dietary diversity, sons as worse off, and little difference between male heads and their wives. In future work, we hope to explore intrahousehold dimensions of the production-nutrition relationship.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

Notes

1. Available at http://ndb.nal.usda.gov/index.html
2. There have been a few studies that have focused on effect of climate variability on agriculture in Nigeria, although most are state or region specific rather than nationally representative. Adamgbe and Ujoh (2012) examine the patterns and trends of the variations in the climatic parameters and the implications of such variations on efficient yield rates of some food crops in Benue state using data on climatic variables (rainfall, temperature, sunshine). Among the seven climatic parameters used in their study, sunshine and rain days have the highest influence on the yield of all the seven crops while dates of onset and duration have the least influence. Adejuwon (2005) examines the impact of climate variability on the yield of the major crops (cowpeas, groundnut, millet, maize, sorghum and rice) cultivated in the Nigerian Arid Zone, using Bornu and Yobe states as case studies. The author found that among the more powerful determinants of crop yield were rainfall at the onset and at the cessation months of the growing season and during the long periods with normal and above normal rainfall, crop yield sensitivity tends to be weak. However, Adejuwon (2005) found that during the years with unusually low precipitation, crop yield sensitivity becomes more pronounced. Ayinde and Muchie (2011) examine the effect of variability in rainfall and temperature on agricultural productivity in Nigeria and find strong effects of variability in rainfall while temperature appears not be as important for agricultural production in Nigeria. Temperature change was revealed to exert negative effect while rainfall change exerts positive effect on agricultural productivity but found that previous year rainfall was negatively significant in affecting current year agricultural productivity.
3. The data can be found at: http://power.larc.nasa.gov.
4. We include agricultural revenue as opposed to agricultural profit due to limitations in estimating the shadow value of household labour allocated to agricultural production. Revenue is directly observable in our data set while profit would have to be imputed.
5. In our data across season, we do not see large changes in agricultural capital stocks over time and this stylised fact is commonly indicated as a major determinant of yield gaps and low productivity in African agriculture.
6. Note that farmers could have farmed more than one crop within each dietary diversity group.
7. The specification in Table 7 was also estimated with several other sets of instruments, including a set of instruments that omitted the agricultural capital variable. This specification produced similar elasticities in sign and magnitude, but did not pass the IV tests. For this reason, the set of instruments including agricultural capital was chosen as the preferred specification. Agricultural capital does not vary within season in our sample and is unlikely to be correlated with consumption as low levels of capital are reported in most agricultural households.
8. Two alternative specifications were estimated for production diversity. The first uses the number of distinct crops grown by the household to measure production diversity instead of the number of crop groups. This yielded a very similar crop count-dietary diversity elasticity of 2.1 per cent, significant at the 10 per cent level. In the second alternative specification, the logs are dropped from dietary diversity and production diversity. The IV estimate of effect of the number of crop groups grown on dietary diversity was 1.05 (significant at the 10% level). This suggests producing an additional crop (food) group results in consumption of an additional food group. The results from both alternative specifications are available upon request.
9. Robustness checks of our results are presented in Tables A1 and A2 in the online appendix. In the first, tree crops are excluded since they are less subject to seasonal variation. Table 10 shows the results of the specifications in Tables 6 and 7 with the exclusion of tree crops. In the agricultural revenue-dietary diversity relationship, we find a slightly stronger effect on dietary diversity compared to our main results in Table 6. A 10 per cent increase in agricultural revenue increases dietary diversity by 2.1 per cent. In the production diversity-dietary diversity relationship, we found a similar 2.2 per cent increase in dietary diversity associated with a 10 per cent increase in production diversity. However this effect was not precisely estimated. The value of household durable assets is included as additional variable in the agricultural revenue-dietary diversity specification and the results are presented in Table A2. We find the revenue-nutrition diversity elasticity to be of the same magnitude (1.7%) as the result in Table 6.

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