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Average and heterogeneous effects of smallholder farm sizes on dietary diversity in northern Ghana

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Abstract

The relationship between farm size and dietary diversity has recently gained attention among development practitioners and policymakers. To study this issue, we utilized cross-sectional data from 900 farm households in Northern Ghana. The analysis employs three econometric approaches—ordinary least squares, two-stage least squares, and instrumental variable (IV) quantile regression. We subjected our estimates to Conley-Hansen-Rossi bound tests to assess the validity of total farmland under household control as an IV for farm size, which serves to illustrate the robustness of the causal inferences linking farm size to household dietary diversity. The results show that a 1-ha increase in cultivated land improves household dietary diversity score by 3.221 units. The effect of cultivated land on dietary diversity is enhanced by market information, use of improved seeds, chemical fertilizers and herbicides, and overall household asset value. In conclusion, the results indicate that farm size increases household dietary diversity when moving along the dietary diversity distribution. This highlights the importance of considering the influence of farm size at different points along the conditional dietary diversity score distribution, as relying solely on mean effects may obscure important counteracting effects.

KEYWORDS
farm size, household dietary diversity score, instrumental variable quantile regression models, smallholders

1 | INTRODUCTION

Poverty and food insecurity are pervasive challenges facing many individuals and families worldwide, with sub-Saharan Africa (SSA) being particularly vulnerable (Bjornlund et al., 2022; Saha et al., 2021). Over the past decade, addressing poverty and food insecurity has assumed a topmost significance for policymakers and the international development spheres, as reflected in the UN's Sustainable Development Goals 1 and 2 to end all variants of poverty and achieve zero hunger. Despite these efforts, estimates indicate that the world is not on course to attain these goals by 2030, with almost 690 million people (i.e., 8.9% of the world's population) still suffering from starvation and malnutrition in 2019 (FAO et al., 2020; United Nations, 2020). This number was expected to increase due to the COVID-19 pandemic, jeopardizing nearly 924 million persons at the risk of severe food insecurity by the end of 2023 (FAO et al., 2022).

Food insecurity is a complex issue, stemming from a variety of factors such as poverty, inadequate financing in farming, natural disasters, degrading soils, and the issues of food waste (FAO et al., 2020; Food Security Information Network [FSIN], 2020). Given the multidimensionality of food insecurity, numerous measures have been proposed to address this issue. One such measure involves supporting smallholder farmers to enhance their ability to increase food production (FAO et al., 2020). This focus on empowering smallholder farmers is driven by the fact that they manage the production of 80% of the food in the world (Global Agriculture & Food Security Program [GAFSP], 2019). Nonetheless, smallholders also face several problems that impact their food production and make them the most food-insecure group. These challenges include conflicts, weather extremes, desert locusts, economic shocks, and infectious diseases like COVID-19 and African Swine Fever (Riesgo et al., 2016). Therefore, supporting smallholders is key for enhancing agricultural productivity and food production, and for reducing the perils of famine and poverty in countries of the Global South (Global Agriculture & Food Security Program [GAFSP], 2019).

The development of small-scale farms has been a central agricultural strategy since the inception of the Asian Green Revolution. Hazell (2020) argues that this approach is founded on three key tenets of small farms. First, small farms with regard to efficiency are better than large farms in terms of land utilization, as demonstrated by Yan et al. (2019), Wassie et al. (2019), and Rada and Fuglie (2019). This entails that the production of food by small farms is more per unit-area than larger farms. Second, small farms are the predominant cultivable land category and cultivate a significant proportion of arable land. Consequently, small farms have the potential to drive overall agricultural growth and enhance food security of nations. Third, in economies with high labor and low income, small farms not only offer greater efficiency but also aid in the development of rural areas and reduce poverty, notably in areas where the bulk of people are smallholders living in poverty (Giller, Delaune, Silva, van Wijk, et al., 2021). In fact, Lowder et al. (2016) note that small farms (less than 2 ha) represent about 85% of the 570 million farm holdings worldwide. They observe that average farm sizes have declined in most low-and lower-middle-income nations such as Ghana and Rwanda between 1960 and 2000.

Contrariwise, in some upper-middle-income nations, including India and South Africa, and almost all high-income nations, such as China and the United States, mean farm sizes increased over the same period. As agricultural land is largely fixed, the predominance of small farms worldwide implies a trend toward smaller average farm sizes (Riesgo et al., 2016). It is important acknowledge that the large majority of these small farms are not commercial and make only a marginal contribution to feeding growing the rural population let alone, the urban. This creates a dualism in small-scale agriculture between a small number of commercial farmers who are above the poverty line and a large number of semi-subsistence farmers who are mostly poor (Woodhill et al., 2020), hence the need to transform small-scale agriculture to be more commercially viable and to tackle poverty and hunger.

The increasing rural population densities across SSA and the changing smallholder farm sizes in the region are exacerbating the already fragile rural welfare and food security situation (Fan & Rue, 2020; Giller, Delaune, Silva, Descheemaeker, et al., 2021). While studies across regions of the world including SSA have indicated that rising rural population growth has induced agricultural change leading to higher yields, these changes have led to the shortening in fallow durations of lands, land rotation, and agricultural innovation adoption, as well as a surge in input use, such as labor and other production inputs per unit of land (e.g., Aravindakshan et al., 2020; Branca et al., 2022). However, these improvements seem to be limited to increases in agricultural yields, as land expansion is limited and continues to shrink, casting doubts on the ability of these dwindling farm sizes to provide up to the mark living standards for resident families on these farms. Consequently, the pace of agricultural intensification continues to decrease year on year (Zabel et al., 2019). van Vliet (2019) posit that until the pace of attrition of persons from farming grows substantially, the average farmland owned by households is going to diminish. It is therefore crucial to understand how changes in farm sizes among smallholders are impacting household food security in SSA, especially in Ghana, in order to formulate effective land and food policies. This study attempts to fill this void.

Household dietary diversity, a food access measure, is used as a proxy for food security. It is estimated based on a construct on the consumption of food groups by households during a given period. Food items are grouped into 12 diverse categories, as proposed by the UN's FAO (2011). These food groups include cereals, tubers, and roots; legumes; vegetables; meat; eggs; fish and other sea foods; fruits; milk and milk products; oils and fats; sweets and spices and condiments and beverages. Each food category adds one score toward the Household Dietary Diversity Score (HDDS) if a food item from that category was consumed by any household member in a given 7-day period (i.e., long-run diversity of consumption). Thus, the HDDS ranges from 0 to 12. The objective of this study is to determine the impact of smallholder farmland sizes on household food security in Northern Ghana, both in terms of mean and distributional effects. This region is particularly well-suited for this research due to its high concentration of smallholder farms and persistent food insecurity issues, as noted by Lu et al. (2021) and Addai et al. (2023). Land plays a key role in the rural livelihoods of the majority of Africans, and food insecurity and poverty reduction cannot not be achieved unless the issue of access of land, security of tenure, and the capacity to use land productively and in a sustainable manner is addressed (Keovilignavong & Suhardiman, 2020). Land governance in SSA in mostly spearheaded by heads of clans/tribes translating to individual household ownership instead of communal or state ownership. This form of land ownership and governance can either increase or reduce farmers' rights to access and use the lands, and to a certain extent their physical, social, and economic access to food. The situation is even worsened with the generational transfer of land rights, which leads to diminishing farm sizes (Leonard et al., 2020). By exploring the nexus between farm sizes and food security outcomes in this context, the goal is to gain valuable insights into the challenges facing smallholders in the region and inform the development of effective land policies to address these issues.

We contribute to the body of literature in various valuable ways. First, it provides valuable insights into how changing farmland sizes, especially among smallholders, are affecting food security in SSA, where the mainstream households live below the poverty line and rely heavily on farming. Most previous research (e.g., Abay et al., 2020; Frelat et al., 2016; Hazell, 2020; Noack & Larsen, 2019) have only studied the average effect of farm size on household food security. These studies often assume a constant nexus between cultivated land and food security across the distribution, which may not be the case. However, little is known about the distributional effects of changing farm sizes on food security, especially among smallholders. It is possible that the means farm size masks significant differences in the nexus between farm size and food security across the distribution of dietary diversity. To address this issue, our study adopts a quantile regression procedure that permits us to examine the entire distribution of food security and explore different facets of the relationship between cultivated land and food security while controlling for other covariates as discussed in Section 3.

Second, our study uses a novel instrumental variable (IV) quantile regression procedure advanced by Chernozhukov and Hansen (2006, 2008) to measure the distributional impacts of farm sizes. This approach isolates the ceteris paribus nexus between farm sizes and household dietary diversity across the distribution while controlling for selectivity bias arising from observable and unobservable sources of heterogeneity. This method is well-suited for examining the distributional effects of changing farm sizes on household dietary diversity and has not been used in previous studies (Abay et al., 2020; Galli et al., 2020; Urfels et al., 2023).

Third, understanding the implications of decreasing farm sizes due to population growth is of great importance to policymakers. Development policies in SSA have not adequately addressed the need to adapt smallholder-led agricultural strategies to take care of the setbacks of small and changing farm sizes. This is especially true in heavily populated regions that rely heavily on rain-fed agriculture (Soko et al., 2023). The number of small farms is mounting, and these farms are becoming smaller and producing fewer food surpluses, which has serious consequences for the livelihoods and food security of rural and urban populations (Toma et al., 2021). Our study expounds on the distributional effects of changing farm sizes on food security and provides valuable insights for policymakers seeking to develop effective strategies for addressing food insecurity in SSA.

This rest of the paper continues as follows. Section 2 has the conceptual framework underlying the study in addition to the analytical approach. Section 3 provides the data and descriptive statistics of the variables employed in the study. This is preceded by a discussion of the estimates from the econometric approaches. Finally, Section 5 presents the conclusion and policy implications of the study.

2 | CONCEPTUAL FRAMEWORK

Throughout the Green Revolution in Asia, significant quantities of basic foodstuffs that nourished urban centers and rural areas were produced by small farms (Fan & Rue, 2020). Currently, small farms are decreasing in size and majority of them do buy instead of selling foodstuffs. However, they are able to meet food security needs for the bulk of the people in the countryside, but then, it appears that they contribute little towards urban areas' food supply (Hazell, 2020). Existing data on the quota of marketed surpluses contributed by diverse farm sizes do not automatically elicit this decrease, as they do not distinguish consumption of sales in the countryside from the consumption of sales in the cities (Jayne et al., 2019).

Herrero et al. (2017) indicate that on average, small farms, that is, farms that are less or equal to 2 ha, have been able to crop about 55% of all the grains in China. Herrero et al. (2017) further show that small farms produce about 30% of household food in Global South (not including China), 10% in Middle East and Northern Africa, 15% in Central America, and an insignificant share in South America. The authors also observed that middle-sized farms (2–20 ha) constitute vital producers all over the place, excluding China, and that large-sized farms (>20 ha) lead in Central and South America. In a related study, Noack and Larsen (2019) show that although the discrepancies in farm incomes decline with expanding farm sizes, the differences in local food supply surge with cultivated land. These results indicate that farm households stand to gain from large farms, earn bigger and steady incomes whilst consumers experience from lesser and increased unstable food supplies.

These results from previous literature imply that the small quota in overall grain produced in each region is significantly less than the equivalent countryside inhabitant's quota. This means that cumulatively, small farms are unable to meet all the food demanded by people in the countryside, not to think of feeding the growing urban population (Woodhill et al., 2020). This may imply that household dietary diversity and therefore food security are being threatened by the changing (declining) farm sizes of smallholders. Moreover, Frelat et al. (2016) posit that more land does not guarantee more food availability in SSA. They indicate that the inverse farm-size productivity nexus observed by various research (e.g., Rada & Fuglie, 2019; Wassie et al., 2019) is less serious in land-constrained areas of SSA with access to market, which opens the need for more research on the impacts of farm sizes on food security and other dimensions.

2.1 | Identifying average farm size effects

The farm households food security status is generally modeled as a function of household and farm-specific characteristics, including farm size (Agidew & Singh, 2018; Magaña-Lemus et al., 2016; Warr, 2014). Nevertheless, we specify our empirical model in a contemporaneous form considering that our data are cross-sectional:

$$F_{ik} = \alpha + \varphi S_{ik} + \gamma X_{ik} + \varepsilon_{ik}, \tag{1}$$

where $F_i$is the HDDS, S_{ik} is the household i's farm size in region k, X_{ik} is a vector of farm-specific and household characteristics. Since various factors impact on household dietary diversity, a straight application of Ordinary Least Squares (OLS) to Equation (1) may bias estimates of farm size outturns. An inverse nexus between cultivated land and gender of household heads would perhaps marshal up the bias in the farm size outturn. To address this, we follow Kubitza and Krishna (2020) and Moshoeshoe (2015) by employing the IV approach to estimate the average and diverse farm size impacts.

2.2 | The instrument and its validity

Notable among the fundamental methods in the traditional quantitative impact assessment is the one that depends on counting all variables that are possibly associated with the endogenous response variables in addition to the result variable and to estimate the influence of endogenous variables by OLS or non-linear models (Kubitza & Krishna, 2020). However, a research design may be deficient in some of these prerequisites, most especially, when time-invariant differences are a source of endogeneity and that fixed effects, modeling not counting much in establishing causation. It is by means of the exclusion restriction condition when instrumenting which is mostly considered as the most viable alternative (Abadie et al., 2002). However, identifying an effective and efficient IV is neither easy nor straight forward.

Following Kubitza and Krishna (2020) recommendation of IV identification, the IV employed in this paper is the size of the land under the household's control. It is expected that total farm size under a household's control a farm affects a household farmland—that is the amount of land allocated for farming but does not affect household dietary diversity. This is verified using a simple admissibility test (Addai et al., 2023; Asante et al., 2023; Di Falco et al., 2011) and in which the instrument should be strongly correlated with the treatment variable but not the outcome variable. Our falsification test results show that our IV is strongly correlated with farm size with statistically significant results from a linear model estimated by OLS ($F[1{,}898] = 362.96$, $p-value = .000$). The second test of a regression of the HDDS on total farm size estimated by OLS shows that our IV is not significantly correlated with the outcome variable ($F[1{,}898] = 0.00$, $p-value = .973$). These falsification test results confirm the validity of the suggested IV, which permits us to compute the mean effects of the cultivated land on household dietary diversity by two-stage least squares (2SLS) specified as

$$S_k = \lambda IV_k + \gamma X_{ik} + \varepsilon_k, \tag{2}$$

$$F_{ik} = \alpha + \varphi \hat{S}_k + \gamma X_{ik} + \upsilon_{ik}, \tag{3}$$

where $IV_k$is the IV of k, S_k, and X_{ik} is a vector of all exogenous elements.

2.3 | The IV quantile regression model of household dietary diversity

To analyze heterogeneous farm size effects on household dietary diversity, we employ the instrumental variable quantile regression (IVQR) model proposed by Chernozhukov and Hansen (2006, 2008). Let F_s be the plausible dietary diversity indicators counter to probable values s of the endogenous variable S. Here, S indicates random variables, whereas s represents the values S may assume. For instance, F_s is the HDDS when (farm size) $S = s$. The core of the study is the conditional quantiles of dietary diversity levels given farm size $s$and quantile index τ(e.g., 0.25th, 0.50th, etc.), represented as $q(s,x,\tau)$ and quantile treatment effects (QTE), which gives the variance amongst the distribution points of F_s under different measures of s, specified as

$$q(s,x,\tau) - q\left(s',x,\tau\right) \text{ or } \frac{\partial q(s,\tau)}{\partial s} \text{ (for continuous treatment } s\text{)}. \tag{4}$$

Depending on observed household head variables and farm-specific factors $X = s, F_s$ is linked with the quantile function $q(s,x,\tau)$ as

$$F_s = q(s,x,U_s), \tag{5}$$

where $U_s \sim U(0,1)$ is the ordered variable that highlights the differences in dietary diversity status for households with comparable observable attributes x and the treatment state s. U_s also determines individual household's comparative status in terms of dietary diversity and consequently can similarly be considered as representative of the household's status. With designating farm size to be endogenous, we need a host of valid IVs Z to achieve its QTE. In our case, Z denotes the total farmland (hectares) under the household's control. Thus, we have the resulting structural model as

$$F = S'\varphi(U) + X'\gamma(U), \tag{6}$$

$$S = \delta(X,Z,V), \tag{7}$$

where $U \mid X,Z \sim U(0,1)$, δ is an unknown function, and $V$is a random vector that is statistically reliant on U. When $U = \tau$, the linear conditional quantile function that we wish to compute is specified as

$$q(S,X,\tau) = S'\varphi(\tau) + X'\gamma(\tau), \tau \in (0,1), \tag{8}$$

1. where $q(S,X,\tau)$ represents the τ^{th} quantile of dietary diversity F_i given dim $(\gamma(\tau))$-vector of exogenous variables X at τ^{th} quantile, S is a dim$(\varphi(\tau))$-vector of possible endogenous variables at the τ^{th} quantile and $q(\cdot)$is sternly growing in households resources τ. The main assumption that allows us to address the endogeneity of the treatment variable and hence estimate the QTE is the rank similarity,[1] which implies that U_s is identical in distribution to $U_{s'}$dependent on V (i.e., $U_s \sim U_{s'}$). Specifically, this suggests that the treatment mechanism does not result in an orderly variation in household's status crosswise likely outcomes. Thus,

$$P[F \le q(S,X,\tau) \mid X,Z] = P\left[F - S'\varphi(\tau) - X'\gamma(\tau) \le 0 \mid X,Z\right] = \tau. \tag{9}$$

Equation (9) is derived based on $\{F \le q(S,X,\tau)\} \equiv \{U \le \tau\}$ assuming a rank invariance (or similarity) condition. Equation (9) is the main equation for identification. It suggests that 0 is the τ^{th} quantile of the random variable $F - S'\varphi(\tau) - X'\gamma(\tau)$ conditional on $X$and$Z$.[2] Hence, the IVQR challenge for $(\varphi(\tau),\gamma(\tau))$ is the answer to the ensuing optimization equation

$$0 = \underbrace{\arg\min}_{\widehat{\theta_\tau}} \frac{1}{n}\sum_{i=1}^{n} \rho_\tau\left(F_i - S_i'\varphi(\tau) - X_i'\gamma(\tau) - Z_i'\lambda(\tau)\right) \tag{10}$$

where $\theta_\tau = \left\{\varphi(\tau)', \gamma(\tau)'\right\}$ and $\rho_\tau(u) = (\tau - 1(u \le 0))u$ is the symmetric least absolute loss (i.e., the "check function") (Angrist & Pischke, 2009). An estimate for $\varphi(\tau)$, $\hat{\varphi}(\tau)$ is that it derives the estimate of the IV, $\hat{\lambda}(\tau)$. It is as close to zero as probable in the ordinary quantile regression of $F_i - S_i'\varphi(\tau)$ on$X$ and Z as the IV should just impact on dietary diversity measures through its influence on farm size. That is,

$$\hat{\varphi}(\tau) = \underbrace{\arg\inf}_{\varphi \in \mathrm{A}} n \left[\hat{\lambda}(\varphi,\tau)'\right] \hat{\mathrm{A}}(\varphi) \left[\hat{\lambda}(\varphi,\tau)\right] \tag{11}$$

where $\hat{\mathrm{A}}$ is the parameter space for φ, $\hat{\mathrm{A}}(\varphi) = \mathrm{A}(\varphi) + o_p(1)$ and $\mathrm{A}(\varphi)$ is any uniformly positive definite matrix in $\varphi \in \mathrm{A}$. Practically, $\mathrm{A}(\varphi)$ is equivalent to the variance–covariance matrix of $\sqrt{n}\left(\hat{\lambda}(\varphi,\tau) - \lambda(\varphi,\tau)\right)$ such that $W_n(\varphi) = n\left[\hat{\lambda}(\varphi,\tau)'\right]\hat{\mathrm{A}}(\varphi)\left[\hat{\lambda}(\varphi,\tau)\right]$ is the Wald statistic for testing $\lambda(\varphi,\tau) = 0$. The parameter estimates are therefore given by $(\hat{\varphi}(\tau),\hat{\gamma}(\tau)) = (\hat{\varphi}(\tau),\hat{\gamma}(\hat{\varphi}),\tau))$ (for more details, see Chernozhukov & Hansen, 2006).

2.4 | Sensitivity analysis

To make credible causal inferences about the impact of cultivated land on household dietary diversity, we employ the two bounds approach by Conley et al. (2012) that permits us to make extrapolations when there is a possible violation of the exogeneity restriction by the IV.

The foremost approach is the union of confidence intervals (UCI). This method enables us to assess how robust our estimates are taking into consideration the connection between farm size and HDDS, notwithstanding the processes leading to its occurrence. In meeting this condition, Conley et al. (2012) modified the simultaneous equation structure illustrated in Equations (2) and (3) as follows,

$$F_{ik} = \alpha + \varphi S_k + \lambda IV_k + X_{ik}\varphi + \upsilon_{ik}, \tag{12}$$

$$S_k = \lambda IV_k + X_{ik}\varphi + \varepsilon_k. \tag{13}$$

The distinction between this model and the usual two-stage IV model specified in Equations (2) and (3) is the presence of the term, λIV_k, in Equation (12). Assuming strict exogeneity, we require that farm size has no unswerving influence on dietary diversity score, that is, $\lambda = 0$. The Conley et al. (2012) UCI procedure leads one to relax this stringent condition such that $\lambda \neq 0$, and at the same time verifying the relevance of our estimates. As indicated in the conceptual framework, even if $\lambda \neq 0$, it is reasonable to conclude that it is trivial. Assuming that $\lambda = \lambda_0$, Equation (12) becomes

$$(F_{ik} - \lambda_0 IV_{ik}) = \alpha + \varphi S_k + X_{ik}\gamma + \upsilon_{ik}. \tag{14}$$

The suggestion is that IV_k is currently a valid IV for $S_k$when the outcome variable is $(F_{ik} - \lambda_0 IV_k)$. Thus, we can reliably compute φ by 2SLS using IV_k as an instrument for S_k. With the UCI approach, we assume that λ has specific interval, $\lambda \in [-\delta, +\delta]$, because the actual value is unknown, and then estimate the union of intervals for φ is computed assuming any $\lambda_0$is within the range. Conley et al. (2012) indicate that, in as much as $\lambda \in [-\delta, +\delta]$, the amalgamation will include the true parameter value of φ with an asymptotic probability

$\Pr[\varphi \in CI_N(1-\varphi)] \geq 1-\varphi$, where $CI_N(1-\varphi)$ is the 95% confidence interval for φ. That is, $CI_N(1-\varphi)$ will asymptotically include the right farm size outturn φ, at least 95% of the time.

The next approach is the λ, which is the local-to-zero approximations bounds approach. With this approach, we relax the exclusion restriction condition by permitting for unpredictability in our expectations concerning λ. This is comparable to an introduction of various exogeneity errors (A_λ) in the approximated distribution of $\hat{\varphi}$;

$$\hat{\varphi} \overset{approx}{\sim} N(\varphi, V_{2SLS}) + \mathrm{A}_\lambda. \tag{15}$$

$$\mathrm{A} = \left(\mathrm{X}' P_Z X\right)^{-1} X' Z, \tag{16}$$

$$\lambda \sim \mathrm{T}$$

where $V_{2SLS}$is the variance–covariance matrix for 2SLS, $Z$is the IV, $P_Z = Z\left(Z'Z\right)^{-1}Z'$ and T is the distribution of λ. Hence, the distribution of the exogeneity errors is reliant on the sample moments of matrix A[3] and the distribution T, and depicts the deviations of $\hat{\varphi}$ from the asymptotic standard distribution of the 2SLS estimator triggered by violating the exclusion restriction condition. With this, the assumption is that λ follows the Gaussian distribution with mean μ_λ and variance Ω_λ such that the approximate distribution of the interest parameter is illustrated as

$$\hat{\varphi} \overset{approx}{\sim} N\left(\varphi + \mathrm{A}\mu_\lambda, V_{2SLS} + \mathrm{A}\Omega_\lambda \mathrm{A}'\right) \tag{17}$$

This can be implemented by applying a simple type of expectations about λ, which is $\lambda \sim N(0, \sigma^2)$ as in Conley et al. (2012) and Mancusi and Vezzulli (2014). Conley et al. (2012) suggest the method gives valid inference when assumed that our expectations are accurate and give robust estimates comparable to the normal 2SLS procedure.

3 | DATA AND DESCRIPTIVE STATISTICS

We used data collected from rice farm households in Northern Ghana. The data were collected in 2018. A multistage sampling approach was used to select the households. The initial phase involved selecting Ghana's Northern Zone purposively as the region represents Ghana's most significant rice-producing zone. The area includes Ghana's previous Northern, Upper East, and Upper West regions. The next phase entailed the choice of a district, each from the regions, based on rice production levels. They included Savelugu (Northern Region), Nadowli-Kaleo (Upper West), and Kassena Nankana East (Upper East). The third step was a random choice of villages from the operational zones of the Ministry of Food and Agriculture (MoFA). The concluding phase involved randomly selecting rice-producing households from diverse villages based on their size or the population of rice-producing households in the numerous villages. The data gathered comprises several rice farming related variables and household characteristics in the study area. The sample entails 900 farm households, with 300 from each region.

TABLE 1 Variable definitions and summary statistics.

Variable name	Description	Mean	SD
Outcome variable			
Household dietary diversity (HDDS)	HDDS, determined by the intake of 12 food groups in the preceding 7 days (0–12)	6.294	1.457
Treatment variable			
Farm size	Total rice farm size in hectares	0.642	0.543
Explanatory variables			
Credit access	=1 if the household head had access to credit, 0 otherwise	0.331	0.470
Extension access	=1 if the household head had access to extension service, 0 otherwise	0.386	0.487
Market information	=1 if the household head had access to market information, 0 otherwise	0.724	0.447
Gender of household head	=1 if household head is a male, 0 otherwise	0.680	0.467
Age of household head	Age of household head in years	52.451	9.818
Household size	Number of household members	6.121	2.024
Improved seed	=1 if farm household adopted improved rice variety, 0 otherwise	0.718	0.450
Years of rice farming	Years of rice farming	9.702	5.430
Farmer-based organization membership	=1 if household head is a member of a farmer-based organization, 0 otherwise	0.403	0.490
Chemical fertilizer	=1 if household head adopted chemical fertilizer, 0 otherwise	0.592	0.492
Herbicides	=1 if household head adopted herbicide, 0 otherwise	0.696	0.460
Insecticides	=1 if household head adopted insecticide, 0 otherwise	0.319	0.466
Years of schooling	Years of formal education of the household head	3.016	4.495
Family labor	Family labor in man days	173.37	209.705
Hired labor	Hired labor in man days	32.479	83.343
Total asset value	Total asset value in GHS	1130.127	403.336
Off-farm income	Non-farm business income (GHS)	178.164	271.117
Northern Region	=1 if Northern region, 0 otherwise	0.333	0.471
Upper East Region	=1 if Upper East region, 0 otherwise	0.333	0.471
Upper West Region	=1 if Upper West region, 0 otherwise	0.333	0.471
Instrumental variable			
Land under household control	Total land area under household control in hectares	3.986	2.358

Table 1 shows summary statistics of the variables adopted in this study. The HDDS is the variable used to measure dietary diversity in households and as mentioned before, was used as our outcome variable. One of the key advantages of the HDDS is that it takes into account not only the diversity of foods consumed but also their accessibility and availability, which are important factors for assessing food security (WFP, 2009). The affordability of a range of foods from various food categories is a key determinant of dietary diversity and, in turn, food security. Previous research (e.g., Abay et al., 2020; Lu et al., 2021) has shown that households with greater food security and higher socioeconomic status tend to have more diverse diets, as measured by the HDDS.

Our descriptive statistics indicate that the average HDDS among farmers in the sample stands at 6.294 units, while the average farm size, a key treatment variable, measures 0.642 ha. Approximately 33.1% of household heads had access to credit during the production season, and a similar percentage, 38.6%, had access to agricultural extension services. Notably, a significant majority, accounting for 72.4% of household heads, had access to market information, likely influencing their production decisions, income levels, and dietary diversification.

The average years of schooling for household heads were measured at 3, a factor with substantial implications for their decision-making in agricultural production and subsequent income. The majority of household heads, around 68%, were male. The average household size, typically representative of households in many African regions, was six.

Regarding labor usage, an average of 173 man-days of family and hired labor were employed. Household heads generated an average of GHS178.64 from off-farm income sources, while the mean total asset value among household heads amounted to GHS1130.127. The average total land size under the control of each household measured 3.986 ha. The majority of households adopted improved rice varieties (71.8%) and herbicides (69.6%) for their agricultural production. Membership in farmer-based organizations by household heads was relatively low, at 40%. In terms of regional representation, approximately 30% of the respondents were sampled from the Northern, Upper East, and Upper West regions.

4 | RESULTS AND DISCUSSION

4.1 | OLS and 2SLS results of the effects of farm size on household dietary diversity

Table 2 presents the OLS and 2SLS coefficients for the mean effect of farm size on HDDS. Here, we used HDDS as a proxy for food security. From the OLS estimates, farm size is significantly and positively related to HDDS. This indicates that an increase in the farmland size allocated to rice production by a hectare leads to 0.885 units increase in HDDS, other factors held constant. A bigger cultivated land may imply that more production results in more crop output. Hence, an increase in rice output may help cater for dietary diversity of households. This finding is consistent with Herrera et al. (2021) who observed similar results in Northeast Madagascar.

Since the OLS results are expected to be biased due to potential endogeneity, we interpret the subsequent results based on the second-stage regression from 2SLS. As mentioned before, to deal with the endogeneity problem, we estimated the 2SLS regression model and used the total farm size under the household's control as an IV for farmland allocated to rice production. From first-stage results, the IV variable (i.e., land under household control) is statistically significant at 1% indicating that our IV is strong and appropriate for our analysis.

TABLE 2 OLS and 2SLS estimates of farm size on household dietary diversity score.

Variable	OLS results Coefficients	OLS results Robust standard error	2SLS results First-stage Coefficients	2SLS results First-stage Robust standard error	2SLS results Second-stage Coefficients	2SLS results Second-stage Robust standard error
Farm size	0.885*	0.515			3.221**	1.405
Land under household control			0.101***	0.009		
Credit access	0.532	0.467	0.001	0.031	0.504	0.471
Extension access	−0.774	0.578	0.026	0.040	−0.921	0.574
Market information	1.553**	0.666	0.264***	0.042	0.551	0.874
Gender of household head	0.364	0.472	−0.005	0.032	0.440	0.476
Age of household head	−0.017	0.025	0.004**	0.002	−0.021	0.024
Household size	−0.147	0.097	3.9e-4	0.007	−0.142	0.098
Improved seed	2.392***	0.414	−0.021	0.031	2.439***	0.421
Years of rice farming	−0.094**	0.042	0.013***	0.003	−0.119**	0.046
Farmer based organization membership	0.607	0.527	−0.017	0.036	0.668	0.527
Chemical fertilizer	2.292***	0.601	0.101**	0.034	2.038**	0.618
Herbicides	1.016*	0.519	0.026	0.030	0.878*	0.519
Insecticides	−0.579	0.463	−0.015	0.029	−0.575	0.465
Years of schooling	0.031	0.057	0.006	0.004	0.024	0.057
Family labor	−0.005***	0.001	4.0e-4***	9.0e-5	−0.004**	0.001
Hired labor	0.001	0.003	1.7e-4	1.7e-4	0.001	0.003
Total asset value	0.001*	0.001	1.4e-4***	3.7e-5	0.001	0.001
Off-farm income	0.001	0.001	2.1e-4**	7.8e-5	0.001	0.001
Northern Region	−4.083***	0.692	−0.107**	0.048	−4.146**	0.706
Upper East Region	0.993	0.679	0.007	0.039	0.980	0.683
Constant	5.470**	1.740	−0.452***	0.123	5.717**	1.749
Observations	900		900		900	
R-squared	0.2050		0.4390		0.1822	

Note: ***, **, and * denote significance level of 1%, 5%, and 10%. Dependent variable is household dietary diversity score.
Abbreviations: OLS, Ordinary Least Squares; 2SLS, two-stage least squares.

Access to market information also positively influences HDDS. Market information access is an inducing element for people to participate in various markets (Usman & Haile, 2022). A household that is informed on available markets knows what is required by the market, when to sell, whom to sell to, and what price to take (Usman & Haile, 2022). It is consequently probable for them to obtain bigger returns, which they can employ to purchase varied and favorite foodstuff, hence become more food secure. In a related study by Frelat et al. (2016), they found that farmland availability does not imply enough food availability in SSA but market access.

The estimates show that households that adopted improved rice seeds are more food secure than those who did not. Adoption of improved seeds improves crop productivity, which in turn improves food supply for household consumption. This is in line with the results of Shikuku et al. (2019). Their study found that timely access to quality seeds accompanied by skills transfer resulted in improved nutrition and food security in Tanzania.

Household heads' years of rice farming negatively and significantly influence dietary diversity. The adoption of chemical fertilizers is linked with increased HDDS. This could be because adoption of chemical fertilizers enhances productivity, which in turn increases the household food security. This is corroborates with the results of Rockler et al. (2023). Their study suggest that all things considered equal, chemical fertilizer plays a crucial role in the world's food security because adoption of both organic and chemical fertilizers tend to lead to higher yields.

The use of herbicides has a significant and positive and influence on HDDS. This is plausible because the use of herbicides helps to reduce crop yield losses due to competition from weeds. Thus, it enhances crop productivity (Schneider et al., 2023), which in return leads to improved household food security.

Family labor negatively and significantly impacted HDDS. This corroborates with the point raised by Kuiper et al. (2020) that less unskilled labor in the rural–urban location can impact significantly on food security.

The total asset value of household heads has positive effects on HDDS. Asset value serves as an endowment of wealth for households. This empowers them to buy food with perhaps more liquid income when they are experiencing food deficits. They can also buy agricultural inputs to utilize for food production, a finding that corroborates with the findings of Seivwright et al. (2020).

Using Upper West as the reference region, location of household heads in the Northern region negatively influences dietary diversity. This implies that compared to the Upper West region, most households in the Northern region are less food secure. It is also worth noting that farm size of smallholders is positively and significantly influenced by farm size under household control, market information, age of household head, years of farming, chemical fertilizer usage, total asset value, off-farm income, and family labor use.

The causal effects from 2SLS's second-stage model results indicate that farmland size for rice production positively and significantly influences dietary diversity score. It can be observed that increasing farmland size by 1 ha increases dietary diversity score by 3.221 units. Comparing the 2SLS results with the OLS estimates, we can see some slight downward biases in the OLS estimates.

4.2 | Sensitivity analysis

As a further check of the validity of the IV and to illustrate that the ceteris paribus effect of farm size on dietary diversity and hence food security are robust, we adopt the Conley et al. (2012) two bounds test. This allows us to draw conclusions when there is a possible violation of the exogeneity restriction by the IV. On one hand, the UCI allows one to examine how robust the presence of an unswerving connection between the IV (land under household control) and the resultant variable (i.e., HDDS) notwithstanding the manner via which it may emerge. On the other hand, the local to zero (LTZ) relaxes the exclusion restriction to make room for uncertainty in our priors about the δ.

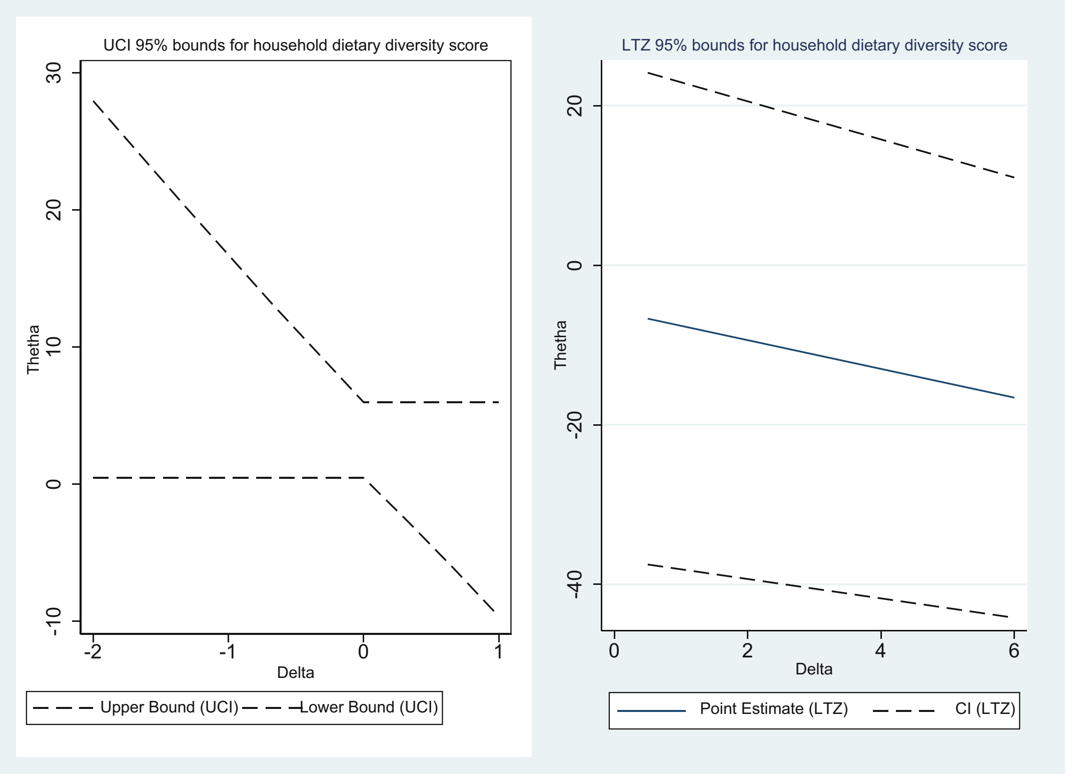

FIGURE 1 Conley–Hansen–Rossi bounds test for the validity of total land under household control in the HDDS regression. [Colour figure can be viewed at wileyonlinelibrary.com]

The sensitivity results are presented in Figure 1. As shown in the figures, we have an undeviating farm line at $\theta = 0$ (the zero line). The farm's horizontal line beneath the zero-line indicates the 2SLS farm size result coefficients for HDDS. Thus, once the 95% upper limit moves beyond the zero-line, that is once confidence bounds entails the zero-effect, the 2SLS coefficients are erstwhile significant at 5% level of significance. However, if the upper limit crosses the zero-line at the higher value of delta, δ, it suggests that the 2SLS coefficients are robust to possibly violate the exclusion restriction condition.

From Figure 1, the UCI 95% confidence interval includes a zero throughout. Thus, our conclusion concerning the causal impact of cultivated land on dietary diversity score is confirmed by this test. However, the LTZ 95% confidence interval excluded up to a delta value of about $\delta = 0.4$. This figure approximates to about 12.4% of the 2SLS computed mean effect of farm size on HDDS. Thus, even if one believed that total land under household control (i.e., the IV) on dietary diversity score is equivalent to 0.4 and qualitatively one can conclude that the influence of farm size on HDDS (food security) remains unchanged.

The sensitivity results show that the estimates of the effect of farm size on dietary diversity score are strong to any probable endogeneity of the IV. Therefore, it is slightly probable that the positive outturn of farm size on HDDS is entirely determined by some unobservable factors.

TABLE 3 Heterogeneous effect of farm size on household dietary diversity: IVQTR estimates.

	Household dietary diversity score					
Variable	**0.15th quantile**	**0.25th quantile**	**0.50th quantile**	**0.75th quantile**	**0.85th quantile**	**0.95th quantile**
Farm size	0.713* (0.377)	0.813** (0.312)	1.059** (0.524)	1.468 (1.215)	1.735 (1.697)	2.354 (2.826)
Credit access	−0.053 (0.358)	0.096 (0.307)	0.467 (0.361)	1.082 (0.754)	1.485 (1.056)	2.416 (1.780)
Extension access	−1.429** (0.413)	−1.532*** (0.360)	−1.785*** (0.441)	−2.206** (0.905)	−2.482** (1.258)	−3.119 (2.102)
Market information	0.560 (0.523)	0.749 (0.469)	1.217** (0.609)	1.993 (1.233)	2.502 (1.698)	3.678 (2.810)
Gender of household head	−0.478 (0.343)	−0.266 (0.302)	0.258 (0.325)	1.127* (0.622)	1.698* (0.866)	3.016** (1.467)
Age of household head	−0.019 (0.017)	−0.018 (0.016)	−0.016 (0.018)	−0.011 (0.036)	−0.008 (0.050)	−0.002 (0.083)
Household size	0.051 (0.077)	0.018 (0.064)	−0.064 (0.085)	−0.200 (0.192)	−0.289 (0.271)	−0.495 (0.457)
Improved seed	0.315 (0.418)	0.692* (0.366)	1.623*** (0.427)	3.169*** (0.861)	4.182*** (1.196)	6.523** (2.018)
Years of rice farming	−0.013 (0.032)	−0.025 (0.030)	−0.056 (0.036)	−0.106 (0.070)	−0.139 (0.096)	−0.216 (0.159)
Farmer based organization membership	0.587 (0.387)	0.618* (0.348)	0.698* (0.372)	0.830 (0.668)	0.916 (0.915)	1.115 (1.521)
Chemical fertilizer	1.396** (0.405)	1.417*** (0.350)	1.467** (0.552)	1.550 (1.226)	1.604 (1.702)	1.730 (2.820)
Herbicides	1.106** (0.380)	1.120** (0.327)	1.156** (0.389)	1.216 (0.813)	1.255 (1.135)	1.345 (1.906)
Insecticides	0.272 (0.326)	0.152 (0.286)	−0.145 (0.347)	−0.640 (0.707)	−0.964 (0.980)	−1.712 (1.636)
Years of schooling	−0.009 (0.043)	−0.014 (0.037)	−0.025 (0.043)	−0.045 (0.089)	−0.057 (0.123)	−0.086 (0.208)
Family labor	−0.002* (0.001)	−0.002** (0.001)	−0.003*** (0.001)	−0.005*** (0.001)	−0.006*** (0.001)	−0.008** (0.002)
Hired labor	−0.001 (0.006)	−0.001 (0.005)	−0.001 (0.004)	−0.001 (0.003)	−0.001 (0.005)	−0.002 (0.008)
Total asset value	0.001 (4.3e-4)	0.001** (3.8e-4)	0.001** (4.7e-4)	0.002* (0.001)	0.002 (0.001)	0.003 (0.002)
Off-farm income	4.7e-4 (6.2e-4)	3.7e-4 (5.4e-4)	1.3e-4 (7.1e-4)	−2.6e-4 (0.001)	−0.001 (0.002)	−0.001 (0.003)
Northern Region	−1.500** (0.605)	−1.954*** (0.553)	−3.076*** (0.614)	−4.939*** (1.102)	−6.161*** (1.501)	−8.983*** (2.503)
Upper East Region	0.048 (0.613)	0.417 (0.482)	1.331* (0.760)	2.849 (1.832)	3.845 (2.585)	6.143 (4.355)
Constant	1.963 (1.284)	2.648** (1.135)	4.342** (1.412)	7.155** (2.868)	8.998** (3.970)	13.258 (6.622)
Observations	900	900	900	900	900	900

Note: ***, **, and * denote significance level of 1%, 5%, and 10%. Standard errors are in parenthesis.

4.3 | Distributional effects of farm size on household dietary diversity

Table 3 shows the distributional causal effects of farm size on dietary diversity score from the 0.15th quantile to the 0.95th quantile of the HDDS distribution. Figure 2 graphs the same results. It can be observed that farm size has a positive and significant effect from the 0.15th quantile to the 0.50th quantile. After the 0.50th quantile, the others even though positive, are not significant. Furthermore, the effect of farm size on HDDS surges with expanding farm size. The figure evidently shows the heterogeneity in the coefficients linked with farm size changes, thus motivating the use of IVQR approach rather than mean regression approaches, to explicitly illustrate the dietary diversity score of smallholders. This result shows the benefits of using quantile regression, rather than the commonly applied OLS regressions, which only models the average relationships. The distributional impact results show an upward slope curve. This indicates that farmers with bigger farm sizes stand to benefit more from higher dietary diversity, up to some point along the distribution, hence, more probable to be more food secure than their compatriots with smaller farm sizes. This is as evidenced by the estimates in Table 3 for dietary diversity score being small at lower farm sizes and increases with an increase in farm size. This reveals the sensitivity of smallholder's dietary diversity to farm size changes. Specifically, the extent of food security of a smallholder household depends on the size of the farm holding. This finding is consistent with that of Abay et al. (2020), who observed same among farmers in the Ethiopian highlands. However, this finding is not an all-size-fits-all measure of food security. For instance, there is an argument that farms less than 2 ha assign a large chunk to food production, and explain the diversity of crops, thereby improving HDDS (Ricciardi et al., 2018). The implication may be that structural changes in farm sizes impair household dietary diversity, an aspect of household food security.

Moreover, Ricciardi et al. (2018) revealed that farms over 1000 ha have the largest percentage of post-harvest loss. Ricciardi et al. (2018) findings mean that these losses may affect food availability, an essential component of household food security. Considering the results of the study, the overall implication is that policies aimed at consolidating lands among farmers, especially smallholders, should be done with some caution as there is bound to be trade-offs on various aspects of household food security. The fact that the ceteris paribus relationship between farm size and dietary diversity is significantly positive among farmers at the lower level of the distribution highlights that making decisions based on average effects of farm size may gloss over the counteracting effects at the diverse points of the food security distribution. More importantly, as small farms constitute a bigger chunk of farms globally, it reiterates their key role in achieving global food security among the masses of the world's population.

From Table 3, various covariates significantly influence HDDSs along the distribution. Extension access negatively and significantly influences household dietary diversity at the 0.15th, 0.25th, 0.50th, 0.75th, and 0.85th quantiles. This suggests that extension access reduces food security. A possible reason might be due to the limited extension contacts that most smallholders in SSA face due to high extension agent to farmer ratio in the sub-region. This finding contradicts the findings of Brenya and Zhu (2023) who found that extension access improves food security in Uganda. The use of improved seed by smallholders during production positively influenced dietary diversity score along the distribution (0.25th, 0.50th, 0.75th, 0.85th, and 0.95th quantile). This could be because the use of improved seeds leads to higher output levels and hence higher income, which can be used to purchase diversity food groups for household

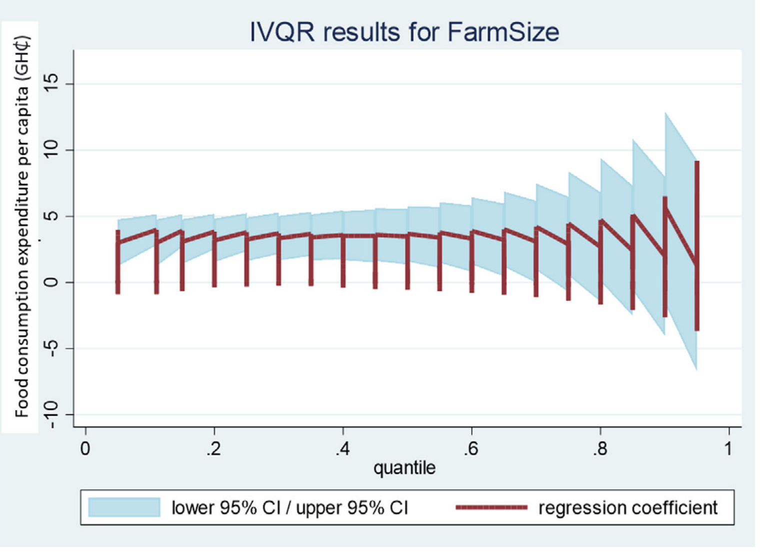

FIGURE 2 Causal effect of farm size on household dietary diversity score. The plausible valid IV for farm size is total land under household control. The estimation coefficients are on the *x*-axis and the quantile index on the *y*-axis. In the shade area is the 95% confidence interval. [Colour figure can be viewed at wileyonlinelibrary.com]

consumption. The findings corroborates with the findings of Lu et al. (2021) who observed the same in Northern Ghana.

On the 0.25th and 0.50th quantiles of the distribution, membership in farmer-based organization improves HDDSs. This is in line with the findings of Theng et al. (2014) who observed same in rural Cambodia. They indicated that participation agricultural cooperatives improve rural household food security through improved rice and livestock productivity.

The use of agrochemicals (chemical fertilizer and herbicides) positively influences household dietary diversity along the distribution (0.15th, 0.25th, and 0.50th quantile). The use of agrochemicals helps to boost productivity and incomes levels and hence more diversified diets among households. This finding is consistent with the findings of Dimkpa et al. (2023).

Family labor usage during production exhibits a mixed significant effect along the dietary diversity distribution (positive [0.15th] and negative [0.25th, 0.50th,0.75th, 0.85th, and 0.95th]). The use of family labor who a mostly unskilled and in situations which the composition is dominated by children will likely impair productivity and farm income and hence adversely jeopardizes that likelihood of the household to diversify their diets. This is in line with the findings of Blanco and Raurich (2022).

Total asset value of the household head positively and significantly influences dietary diversity among households. This is a proxy of liquidity status of household, which can be used to diversify their diets. This finding that corroborates with the findings of Seivwright et al. (2020).

Relative to the Upper West region of Ghana, the Northern region negatively influences household dietary diversity along the entire distribution. This observation reflects the food security status of the region as indicated in the GSS (2020) report on multidimensional poverty on Ghana.

5 | CONCLUSIONS AND POLICY IMPLICATIONS

In this study, we assessed the effects of smallholder farm size on household dietary diversity in Northern Ghana, both in terms of average effects and heterogeneous effects. Using a farm household survey of 900 households, we employed OLS, 2SLS, and IV quantile regression to investigate the nexus between farm size and dietary diversity score. We found that an increase in farmland size allocated to rice production leads to an increase in dietary diversity score. Moreover, the positive effect of farm size on dietary diversity score is further enhanced by access to market information, the use of improved seeds, chemical fertilizers, and herbicides, and the total asset value of household heads.

To test the robustness of our estimates, we subjected them to the Conley et al.'s (2012) bound tests of UCI and LTZ to assess the validity of our IV (total farmland under household control). The robustness checks demonstrate that our estimates are strong even when the exclusion restriction assumption is slightly violated.

Our results suggest that farmland size increases HDDS when moving along the dietary diversity distribution, emphasizing the importance of considering counteracting farm size effects at various points of the conditional HDDS distribution instead of making judgments based solely on mean effects.

The policy implications of our study are significant. Policy decisions related to land and farm sizes of smallholders should consider land consolidation as an instrument to reduce rural household food insecurity. This implies that smallholders stand to benefit in terms of economies of scale of production and HDDS and welfare from farm size increases. Additionally, dissemination of market information should be promoted by various stakeholders, including extension agents and farmer-based organizations, to improve access to markets and increase HDDS. Finally, to improve productivity and household dietary diversity amongst smallholders, affordable access to improved agricultural technologies, such as improved seeds and agrochemicals (chemical fertilizers and herbicides), should be encouraged through subsidization.

This study has the following important limitations. First, although this study provides valuable insights into the nexus between smallholder farm size and food security, we used HDDS as a proxy for food security. Thus, it is important to acknowledge the limitations of using HDDS as the sole measure of food security. While HDDS provides a useful indication of the diversity of foods consumed, it does not necessarily capture the quantity or quality of food consumed. Second, the use of household-level data, rather than plot-level data, may limit the accuracy of farm size estimates. In future research, it would be beneficial to incorporate plot-level data and separate plot-level and household response variables to better capture farm size effects on dietary diversity or food security. Furthermore, the substantial variation in local land quality, which is known to be a key factor in determining average farm size and the ability of farmers to intensify production and increase dietary diversity, is likely to be an important consideration that should be addressed in future research.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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ENDNOTES

[1] A powerful category of this supposition is rank invariance which, in here, implied that a household's percentile rank in the dietary diversity measure distribution when farm size $S=s$ is similar when cultivated land $S=s'$.

[2] That is $0=Q_{F-q(S,X,\tau)}(\tau|X,Z)$, asymptotically, for each τ.

[3] Observed that because the size of A is negatively linked to the projection matrix P_Z, the effect of the exogeneity error $\hat{\varphi}$ is inversely linked with the power of the IV, Z.

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