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# Production and hidden hunger impacts of sustainable agricultural practices: evidence from rural households in Africa

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**ABSTRACT**
This study employs panel data from the sub-Saharan Africa's Intensification (Afrint) project to examine the impacts of sustainable agricultural practices (SAPs) on crop production and hidden hunger. The dataset consists of 2368 households (4736 plots) across eight countries in sub-Saharan Africa. The study utilizes a multinomial endogenous switching regression model in the empirical estimations to account for sample selection bias caused by observed and unobserved farmer attributes. In addition, the study employed Mundlak fixed effects criteria to address plot level heterogeneity. The results show that joint adoption of SAPs improves total value of output and reduces hidden hunger, relative to adoption of SAPs in isolation. Specifically, an increase in total value of output is at most USD8,288.66/ha whiles decrease in cereal self-provisioning capacity is at most 647.69 kg per adult equivalent. The results therefore suggest that joint adoption of the SAPs should be promoted over adoption in isolation. The results also indicate that the benefits associated with adoption of SAPs, either in isolation or jointly, vary across Africa. This therefore implies that compatibility and potentials of the SAPs in various locations of Africa should be considered when promoting uptake of SAPs.

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Sustainable agricultural practices; value of output; hidden hunger; Africa

## 1. Introduction

Sustainable food production systems continue to play an essential role in ensuring sustainable development in Africa (Zero Hunger Challenge 2016). However, one significant challenge to sustainable food production systems in Africa is degraded soil fertility caused by continuous cropping and insufficient recycling of organic matter resulting in decreased farm production and food insecurity (Teklewold, Kassie, and Shiferaw 2013). The immediate consequences of decreased farm production and food insecurity is increased hunger. Adoption of sustainable agricultural practices (SAPs)[1] has been recognized as one of the essential pathways of addressing such challenge. SAPs improve soil fertility, safeguard ecosystems and biodiversity, improve yields, break poverty traps and reduce hunger (FAO 1989). On this premise, African governments and development practitioners have continuously promoted the adoption of SAPs as an essential vehicle to better the livelihoods of vulnerable populations, and to save the environment. For example, under the Comprehensive Africa Agriculture Development Programme (CAADP), several of the SAPs remained strong pillars promoted under the caption "sustainable land and water management (SLWM) practices" (NEPAD

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2003). However, every SAP plays a unique role in improving production and hunger reduction in Africa and hence may not reach its full potential unless adopted with related technologies or complemented with other practices (Kassie et al. 2018; Verkaart et al. 2017). Thus, individual and joint adoption of SAPs are common and exist in a considerable body of literature for developing countries (e.g., Ng'ombe, Kalinda, and Tembo 2017). However, cross-country studies that focus on the impacts of single and multiple SAPs adoption on production and hidden hunger over time are limited. Studies including Tambo and Mockshell (2018) and Asfaw et al. (2012) are near starting point for such analysis in Africa. However, these studies used cross-sectional data and hence, fall short of the adoption impacts of single and joint practices over time.

This study contributes to the growing literature on sustainable agriculture by examining the impacts of single and joint adoption of SAPs on rural households' plot-level crop production and hidden hunger in Africa including Ghana, Nigeria, Tanzania, Ethiopia, Kenya and Malawi, Zambia and Mozambique using pooled dataset from sub-Saharan Africa's intensification of food crops project (Afrint I and Afrint II). This study anticipates the impacts of adoption of SAPs on production and hidden hunger to vary by country. Findings from this study could have important implications for agricultural policy and highlight priorities for sustainable development in Africa. The present analysis focuses on four (4) SAPs (i.e., intercropping, zero/no-tillage, residue retention and animal manure) delving into single and joint impacts of these practices on households in each country. These SAPs are commonly used by farm households in the study areas, and information regarding their impacts on production and hunger appears insufficient in the literature.

Aside soil and yield improvement, these practices have been separately noted in different studies to control pests and weeds, provide ecosystem services and hedge against the risk of drought, which consequently leads to safer environment (FAO 1989; Marenya et al. 2012). Other previous studies also note a rapid decline in organic carbon levels when soils are continuously cultivated without application of effective recycling of organic amendments such as crop residues and manures (e.g., Bationo et al. 2007). To the best of our knowledge, we have not yet read any study that explicitly links sustainable agricultural practices adoption (single and joint) to hidden hunger in sub-Saharan Africa. Hidden hunger is a condition in which people suffer from a chronic deficiency of micronutrients or essential vitamins and minerals. The term owes its name to the fact that the symptoms of the problems are not always visible (Pangaribowo and Gerber 2016). Previous studies have mostly focused on the impact of SAPs on plot/household level yield, productivity, income, food and nutrition security, and poverty (e.g., Issahaku and Abdulai 2019; Kassie et al. 2018). However, empirical evidence on hidden hunger impacts of SAPs is sparse, despite the potential consequences of hidden hunger on livelihoods and human health.

Since farmers self-select themselves into the adoption of SAPs, we employed multinomial endogenous switching regression (MESR) model to examine the impact of single and joint adoption of SAPs, on the total value of output and hidden hunger. Such an approach enables us to account for selection bias arising from both observed and unobserved attributes of households. Besides, Mundlak fixed effects model has also been used to account for households' plot-level heterogeneity. The multinomial endogenous switching regression (MESR) model allows for assessment of the impacts of the adoption of single and joint SAPs to reveal the best practice among the SAPs employed by households for policy formulation and take up.

The rest of the paper is organized as follows. Section two and three presents a general conceptual framework and estimation techniques employed in the analyses; section four presents the data source, sampling and description of variables. Results and discussion section are presented in section five, while the concluding remarks are presented in section six.

## 2. Conceptual framework

As mentioned previously, several SAPs packages have been promoted by most governments in Africa to help improve production, reduce poverty and hunger. However, because of the multitude of constraints, households usually make complex decisions regarding the choice of SAPs to improve yields and welfare. These decisions are influenced by the age of household head, farm size, education, gender and household size (Khonje et al. 2018). In addition to these characteristics, adoption decisions are influenced by location or institutional factors (Manda et al. 2016). For instance, a considerable body of literature (e.g., Erenstein 2006) argued that urban centres frequently serve as the main entry points for the provision of agricultural services, and that proximity to such centres enhances information and credit access for adoption. Also, rainfall pattern and nature of land have been noted to play significant roles in the adoption of SAPs in some parts of Africa. For instance, savannah areas are drought-stressed due to less rain and may influence the adoption of zero-tillage as erosion and organic matter management strategy (Hobbs, Sayre, and Gupta 2008; Kassam et al. 2009). On the other hand, the rain forest of Africa experiences excess water from the long rainy season and may not allow the adoption of zero tillage. Similarly, crop residue retention, which has been noted to protect soil from the physical impact of rain and wind (FAO 1964) may be adopted in the Savannah areas. Also, cultivation of crops other than rice in the lowland areas during the rainy season may imply substantial investments in ridges (Erenstein 2006) over zero tillage.

An important problem now is the conceptual linkages of SAPs adoption, production and hidden hunger. For crop production, this study adopted the total value of crop output. In general, the total value of output depends on output and price. Thus, SAPs can influence the total value of farm produce by increasing farm output. Hidden hunger, on the other hand, is a situation when people suffer from micronutrient deficiency. The major driver of micronutrient deficiencies is the consumption of poor diets or lack of nutrient-dense foods (IFPRI 2014; Pangaribowo and Gerber 2016). Ideally, maize, sorghum, rice, and cassava are energy-dense staples but provide small amounts of bioavailable protein, vitamins, minerals and other micronutrients (IFPRI 2014; Smith and Subandoro 2007). Thus, hidden hunger increases with the consumption of these staples. We capture hidden hunger using cereal self-provisioning capacity (hereinafter CSPC) which is constructed using these staples. The CSPC is expressed in annual per adult equivalent (AE) basis.[2] The use of annual CSPC per AE to capture household hunger is based on the idea that energy-dense staples provide small amounts of bioavailable protein, vitamins, minerals and other micronutrients, and frequently result in hidden hunger (IFPRI 2014; Smith and Subandoro 2007). Through production, SAPs can balance the consumption of these staples by substituting them with nutrient-dense food, thereby reducing hidden hunger. As argued in the literature (e.g., Jones, Shrinivas, and Bezner-kerr 2014), farm production diversity is increasingly recognized as a potential instrument to ensure the supply of diverse foods and improve nutrient quality. Intercropping in combination with zero tillage, residue retention or animal manure does not only promote production and consumption of diversified food but also increases market participation through which households generate income to diversify diets, thereby reducing hidden hunger. SAPs are economical and resource-conserving and therefore lowers the use of costly external input technologies (FAO 1989). This allows households to save income to acquire diversified foods.

Following the arguments above, we assume that each of the outcomes (i.e., total value of farm output and CSPC) are functions of households' choice of SAPs, along with a vector of other explanatory variables ($X$) specified as follows:

$$Q_{ijt} = \delta_j X_{ijt} + \beta_i A_{ijt} + \varepsilon_{ijt} \tag{1}$$

where $Q_{it}$ represents outcome of household $i$; at time $t$; $X_{it}$ is a vector of household/farmer, farm/plot level, location and institutional characteristics; $A_{it}$ is households' choice of SAPs in year $t$; $\delta$ and $\beta$ are parameters to be estimated; and $\varepsilon_{ijt} = u_{ijt} + v_i$, is a random error term consisting of composed error terms of unobserved heterogeneity ($u_{ijt}$) for household $j$ and the usual error terms of plot $i$ in household $j$ ($v_{ij}$). Equation (1) further implies that the impact of household's choice of a specific combination of SAPs on the outcome variable $Q_i$, can be measured by the estimates of the parameter

$\beta$ through OLS regression, without any form of bias. This is particularly true if Equation (1) is properly specified (i.e., if the choice of SAPs is exogenously determined). However, it is obvious that the adoption variable is potentially endogenous because observed and unobserved factors influencing adoption may also influence the outcomes of interest. Households who choose to use SAPs may be systematically different from those who do not use SAPs. Assuming that such differences actually exist between households who use SAPs and those who do not, self-selection may set-in since such differences may influence the household's choice of SAPs and outcome variables (i.e., total value of output and hidden hunger). Given the self-selection problem, estimates of Equation (1) with OLS would generate biased and inconsistent estimates. Moreover, the error term includes time-invariant unobserved heterogeneity that may be correlated with the outcome $Q_{it}$ (Wooldridge 2002). Given the availability of panel data, the standard panel data approach would have been either a fixed or random-effects estimator. However, since the cross-sectional variation is higher than the within variation for both the dependent and independent variables, the random effects estimator is more efficient than the fixed effects (Woldeyohanes, Heckelei, and Surry 2017). Another critical limitation of fixed effects is the failure of inclusion of households with unbalanced or single plots in the analysis. Random effects model on the other hand thrives on the assumption that unobserved heterogeneity (e.g., innate ability) are independent of the explanatory variables. To address these issues, we follow the Wooldridge (2002) approach for estimating unbalanced panel data. Specifically, we estimate pooled selection and pooled OLS models using the Mundlak (1978) device within the framework of multinomial endogenous switching regression (MESR). The MESR controls for selection bias due to time-varying unobserved heterogeneities by allowing the household's choice of SAPs to interact with observed and unobserved heterogeneity via separate regressions for adopters and non-adopters. The model also enables the construction of a counterfactual based on returns to characteristics of adopters and non-adopters and proceeds in two stages (Bourguignon, Fournier, and Gurgand 2007). In the first stage, a multinomial logit model accounting for unobserved individual heterogeneity is estimated to generate inverse Mills ratios (selection bias correction terms). In the second stage, the outcome equations are estimated using OLS and including the inverse Mills ratios as additional regressors to capture selection bias due to time-varying unobserved heterogeneity. On the other hand, the Mundlak device combines the fixed-effects and the random-effects estimation approaches and controls for time-constant unobserved heterogeneity (Mundlak 1978). The Mundlak's fixed effects assumes that the time-invariant unobserved heterogeneity ($u_{ij}$) in ($\varepsilon_{ij}$) is a linear function of the averages of the time and plot varying explanatory variables i.e., $u_{ij} = \pi_i \bar{X}_i + \omega_i$ with $\omega_i \sim IID(0,\ \sigma^2)$, $E(\omega_i|\bar{X}_i) = 0$ and $\bar{X}_i$ is the vector of averages of the time and plot varying explanatory variables and $\pi_i$ is the corresponding vector of coefficients, and $\omega_i$ is a normally distributed error term (Mundlak 1978). Previous empirical studies have employed such approach to control for observed and unobserved heterogeneity (e.g., Kassie et al. 2008, 2018). The next section outlines the how the MESR is combined with the Mundlak-Chamberlain approach (Chamberlain 1984; Mundlak 1978) to control for selection bias and unobserved heterogeneity whilst estimating the impacts of the adoption of SAPs on total value of output and hunger.

## 3. Estimation techniques

### *3.1. Multinomial logit selection model*

In this section, we model the dynamics of adoption behaviour under the framework of random utility where households choose from a package of 16 SAPs, a single or multiple SAP(s) that maximize their utility. We assume that farm households are risk neutral, and consider the net utility derived from choosing SAPs. Assuming a set of $N$ possible practices, the household $i$ chooses SAP $j$ over any alternative SAP $m$ if utility $U_{ij}$, of choosing SAP $j$ is greater than the utility $U_{im}$ of choosing SAPs $m$ (i.e., $U_{ij} > U_{im}$ and $m \neq j$ in all cases). However, the utility $U_{ij}$ derived from choosing $j$ over other practices is a latent variable and therefore not directly observable. The problem then becomes a question of specifying equation that defines the utility $U_{ij}$. Although the preferences of households are not known, household and choice attributes are observed (Greene, 2002) and can be related to the utility as:

$$U_{ij} = \alpha_j Z_{ijt} + \gamma_j \bar{Z}_{ijt} + \varepsilon_{ijt} \tag{2}$$

where $U_{ij}$ is a latent variable representing the utility that the farmer derived from choosing practice $j$ at time $t$; $Z_i$ is as defined earlier; $\bar{Z}_i$ is the mean of plot varying explanatory variables that help account for any unobserved time constant heterogeneity (Chamberlain 1984; Mundlak 1978; Wooldridge 2002) and include farm size, tenure security, village extension access, rainfall conditions (i.e., above average, average, below average and drought), distance to the closest road, fertilizer use, labour cost, household size, age of household head; $\alpha_j$ is the associated parameter to be estimated; and $\varepsilon_{ij}$ is the error term which is independently and identically distributed. Though $U_{ij}$ is unobservable, the household's choice is observable. Assuming $A$ is index variable for household's choice from the SAPs package, Equation (1) translates into the observed outcome equation for the choice defined as:

$$A = \begin{cases} 1 \text{ if } U^*_{i1}(\pi) > \max\limits_{m \neq j} [U^*_{im}(\pi)] \text{ or } \eta_{i1} < 0 & \\ \quad :: :: :: :: & \text{for all } \ m \# j \\ J \text{ if } U^*_{ij}(\pi) > \max\limits_{m \neq j} [U^*_{im}(\pi)] \text{ or } \eta_{ij} < 0 & \end{cases} \tag{2}$$

where $\eta_{ij} = \max\limits_{m \neq j} [U^*_{im}(\pi) - U^*_{ij}(\pi)] < 0$ in (3) as indicated by Bourguignon, Fournier, and Gurgand (2007); further, Equation (2) implies that the decision maker will choose package $j$ to maximize expected utility of wealth if package $j$ provides greater expected utility of wealth than any other package $m \neq j$, that is if $\eta_{ij} = \max\limits_{m \neq j} [U^*_{ij}(\pi) - U^*_{im}(\pi)] > 0$.

Giving that $\varepsilon$ in Equation (1) is identically and independently Gumbel distributed, McFadden (1973) argued that the probability that the decision maker $i$ chooses package $j$ can be specified by a multinomial Logit Selection (MNLS) model:

$$P_{ijt=} \Pr(\eta_{ij} < 0 | Z_{ijt}, \bar{Z}_{ijt}) = \frac{\exp(\alpha_j Z_{ijt} + \gamma_j \bar{Z}_{ijt})}{\sum_{i=1}^{N} \exp(\alpha_k Z_{ijt} + \gamma_k \bar{Z}_{ijt})} \tag{3}$$

The parameters of MNLS model are then estimated using *mlogit* command in STATA 15.

### 3.2. Multinomial endogenous switching regression (MESR)

As mentioned previously, the estimation of the impact of SAPs with MESR proceeds in two stages. The first stage involves using the multinomial logit selection (MNLS) model with the Mundlak device as presented under section 3.1 to estimate the factors influencing household's choice of SAPs (Table 1). In the second stage, the relationships between the outcome variables and a set of exogenous variables are estimated for each chosen package, following Dubin and Mcfadden (1984) (hereafter referred to as the DM model) and Bourguignon, Fournier, and Gurgand (2007) to correct selection bias. For Bourguignon, Fournier, and Gurgand (2007), consistent estimates of the impacts of SAPs on an outcome of interest can be obtained by estimating the following MESR models:

$$\begin{cases} \text{Regime 1: } Q_{i1t} = \delta_1 X_{it1} + \sigma_1 \hat{\lambda}_{i1t} + \vartheta_1 \bar{X}_{i1t} + \omega_{i1t} \text{ if } A = 1 \\ \qquad :: :: :: :: \\ \text{Regime } J\text{: } Q_{iJt} = \delta_J X_{iJt} + \sigma_J \hat{\lambda}_{iJt} + \vartheta_J \bar{X}_{iJt} + \omega_{iJt} \text{ if } A = J \end{cases} \tag{4}$$

where $Q'_{ij}s$ are the total value of output and hidden hunger of the $i$th household in regime $j$, where $\sigma_j$

**Table 1.** Adoption of SAPs in the sampled countries over the entire period (%).

| Choice of SAPs | Description of SAPs | Ethiopia | Ghana | Kenya | Malawi | Nigeria | Tanzania | Zambia | Mozambique | Pooled |
|---|---|---|---|---|---|---|---|---|---|---|
| $I_0Z_0R_0A_0$ | Non-adopters | 21.26 | 14.59 | 24.50 | 23.42 | 17.87 | 22.38 | 25.99 | 42.42 | 24.37 |
| $I_1Z_0R_0A_0$ | Adopters of intercropping only | 3.24 | 7.21 | 15.14 | 14.05 | 14.44 | 5.42 | 6.50 | 5.05 | 8.42 |
| $I_0Z_1R_0A_0$ | Adopters of zero tillage only | 12.61 | 8.11 | 7.03 | 7.21 | 4.15 | 3.43 | 3.97 | 3.25 | 5.89 |
| $I_0Z_0R_1A_0$ | Adopters of residue retention only | 2.70 | 1.80 | 4.86 | 4.14 | 10.83 | 14.26 | 13.36 | 15.88 | 9.34 |
| $I_0Z_0R_0A_1$ | Adopters of animal manure only | 9.91 | 3.24 | 6.67 | 6.49 | 2.71 | 3.79 | 3.61 | 3.61 | 4.77 |
| $I_1Z_1R_0A_0$ | Adopters of intercropping and zero tillage only | 1.98 | 1.62 | 3.24 | 6.85 | 4.69 | 3.61 | 4.87 | 1.26 | 3.33 |
| $I_1Z_0R_1A_0$ | Adopters of intercropping and residue retention only | 10.27 | 8.29 | 5.95 | 4.14 | 7.22 | 10.29 | 8.48 | 9.39 | 8.00 |
| $I_1Z_0R_0A_1$ | Adopters of intercropping and animal manure only | 10.45 | 8.47 | 4.50 | 4.68 | 8.12 | 4.51 | 3.43 | 0.54 | 5.47 |
| $I_0Z_1R_1A_0$ | Adopters of zero tillage and residue retention only | 1.98 | 1.44 | 5.23 | 1.80 | 5.78 | 5.96 | 6.68 | 5.78 | 4.65 |
| $I_0Z_1R_0A_1$ | Adopters of zero tillage and animal manure only | 1.98 | 0.72 | 3.42 | 5.59 | 3.97 | 4.15 | 2.89 | 1.81 | 3.01 |
| $I_0Z_0R_1A_1$ | Adopters of residue retention and animal manure only | 10.27 | 4.86 | 2.70 | 2.34 | 4.51 | 2.71 | 2.17 | 2.35 | 3.95 |
| $I_1Z_1R_1A_0$ | Adopters of intercropping, zero tillage and residue retention only | 2.88 | 0.72 | 4.86 | 2.52 | 4.69 | 5.78 | 5.78 | 5.96 | 4.51 |
| $I_1Z_1R_0A_1$ | Adopters of intercropping, zero tillage and animal manure only | 1.80 | 0.72 | 2.52 | 4.14 | 2.35 | 2.17 | 3.61 | 0.36 | 2.24 |
| $I_1Z_0R_1A_1$ | Adopters of intercropping, residue retention and animal manure only | 3.24 | 29.37 | 3.78 | 4.32 | 3.07 | 3.25 | 2.71 | 1.26 | 5.89 |
| $I_0Z_1R_1A_1$ | Adopters of zero tillage, residue retention and animal manure only | 2.70 | 1.62 | 2.34 | 3.06 | 2.71 | 2.53 | 1.99 | 0.54 | 2.30 |
| $I_1Z_1R_1A_1$ | Adopters of intercropping, zero tillage, residue retention and animal manure | 2.70 | 7.21 | 3.24 | 5.23 | 2.89 | 5.78 | 3.97 | 0.54 | 3.87 |

Note: Each element in the choice is a binary variable for intercropping (I), zero tillage (Z), residue retention (R) and animal manure (A). Subscript 1 = adoption and 0 = otherwise.

is the covariance between the errors terms in outcome and selection equations; $\vartheta_j' s$ are the coefficients of the means of the plot level covariates $\bar{X}_{i1t}' s$; $\omega_{ij}' s$ are error terms with an expected value of zero; and $\hat{\lambda}_j$ is the inverse mills ratio computed from the estimated probabilities in Equation (3) as:

$$\lambda_{ijt} = \sum_{m \neq j}^{J} \rho_j \left[ \frac{\hat{P}_{im} \ln(\hat{P}_{im})}{1 - \hat{P}_{im}} + ln(\hat{P}_{ijt}) \right] \tag{5}$$

where $\rho$ is the correlation coefficient of the error terms. Standard errors in Equation (5) are bootstrapped to account for the heteroscedasticity arising from the generated regressors due to the two-stage estimation procedure. For proper identification of Equation (4), it is important for the variables in the multinomial logit selection (MNLS) model to contain at least one instrument in addition to those automatically generated by the nonlinearity of the model. In this study, we included as instruments variables related to information access and network in the adoption equation but excluded them from the equations for total value of output and cereal self-provisioning capacity (CSPC) (i.e., Equation 5). These variables include whether farmers received extension advice and membership to farmer-based organization. Information proxied by extension advice and farmer-based organizations furnishes farmers with information about SAPs and how to apply such practices on farm. Farmers' extension access and participation in farmer-based organizations are therefore likely to have indirect influence on our outcomes through adoption of SAPs. Many other empirical studies (e.g., Abdulai, 2016; Kassie, et al., 2015) have used similar variables in impact evaluation as instruments. Even though these instruments are intuitively strong, the assumption of exclusion restriction may be violated, especially if it turns out that farmers learn additional (productivity-enhancing) issues from extension advice and farmer groups other than just SAPs.[3] Nonetheless, we establish the admissibility of these instruments by performing simple falsification tests following the literature (Di Falco, Veronesi, and Yesuf 2011). Results confirm that selection instruments are valid as they jointly affect adoption decisions but not outcome equations. However, the results are not presented in order to save space but available upon request. It is also worth mentioning that the inverse mills ratios included in the second stages of the MESR only account for selection bias caused by systematic differences between adopters and non-adopters or time varying unobserved heterogeneity. To capture the inconsistencies arising from time-invariant unobserved variables, we employed the Mundlak-Chamberlain device. Like the choice model, we constructed the mean values of (i.e. $\bar{X}_{it}$'s in 5) of time-varying explanatory variables. These were then added to explanatory variables during the second stage estimation of the MESR models. Such approach controls for plot level unobserved heterogeneity (Chamberlain 1984; Mundlak 1978; Wooldridge 2002) and has been employed in recent studies in developing countries (e.g., Issahaku and Abdulai 2019; Kassie et al. 2018; Khonje et al. 2018)

### 3.2.1. Estimation of average treatment effects on the treated

Using the above framework, we can compute the average treatment effects (ATT) of SAPs as:

$$E[Q_{itJ}|j = J] = \delta_J X_{itJ} + \sigma_J \hat{\lambda}_{itJ} + \vartheta_J \bar{X}_{itJ}\; j = 2,\ 3,\ 4,\ 5,\ 6,\ 7,\ 8 \ldots\ldots.16 \tag{7}$$

On the other hand, the counterfactual expected total value of output and hidden hunger on a plot with a technology set j that contains one or more SAPs is computed as follows:

$$E[Q_{it1}|j = J] = \delta_1 X_{itj} + \sigma_1 \hat{\lambda}_{itj} + \vartheta_1 \bar{X}_{itj}\; j = 2,\ 3,\ 4,\ 5,\ 6,\ 7,\ 8 \ldots\ldots.16 \tag{8}$$

From the above expressions, the average treatment effect on the treated (ATT) is the difference between Equations (7) and (8) expressed mathematically as:

$$ATT = E[Q_{itJ}|j = J] - E[Q_{it1}|j = J] = (\delta_J - \delta_1) X_{itJ} + (\sigma_J - \sigma_1) \hat{\lambda}_{itJ} + (\vartheta_J - \vartheta_1) \bar{X}_{itj} \tag{9}$$

The first two terms of Equations (9) indicate change in outcome due to the difference in returns to observed characteristics and time-invariant unobserved characteristics, respectively, and the last term is attributed to changes in outcomes due to differences in time-varying unobserved heterogeneity. Since eight countries are under study, the impact of the 16 categories of SAPs are estimated for each of the countries using Equation (9). It is also anticipated that the impacts of SAPs adoption on the total value of output and hidden hunger are likely to vary by agroecological zone differences captured by plot location/country. For instance, the total value of output and hidden hunger response to some of the SAPs in countries with low population density are likely to vary from that of countries with medium or high population density. In densely populated areas where land is scarce, intercropping only or manure only or both may be cost-effective and profitable than in sparsely populated areas. Also, adoption of residue retention in high densely populated areas may improve yields over time once yields can no longer be maintained simply by moving to new plots (Binswanger and Pingali 1988). In sparsely populated areas where farms are usually larger in size, zero-tillage may save labour cost and suppress weeds, respectively while animal manure may be avoided partly due to lower quantities and intensive labour required in application (Binswanger and Pingali 1988). Given such caveats, we hypothesized that aside from variation of the single joint impacts of SAPs in each country, the impacts of the SAPs will vary across different locations within the same country.

## 4. Data, sampling and variable description

This study uses a dataset that traces production information across different locations in Africa to provide insight into how the effects of the adoption of SAPs vary across different areas of sub-Saharan Africa. In this regard, we employed the Afrint dataset drawn from two rounds (i.e., Afrint I and II) of surveys conducted in 2002/2004 and 2008/2010 as part of sub-Saharan Africa's intensification of food crops agriculture (*Afrint*) project for the present analysis. *Afrint* I captured information from 3,537 households in the 2002/2004 period. In Afrint II, however, only 2,368 households were re-interviewed. In this study, the panel data containing detailed information about households' production of maize, sorghum, rice and cassava is used. This data was gathered through a multistage sampling procedure. In the first stage, Ghana, Kenya, Malawi, Nigeria and Tanzania, Ethiopia, Uganda, Zambia, and Mozambique were selected based on the production potential of maize, rice, sorghum, and cassava. The second stage included the selection of regions based on agroecological potential. The third stage involves selection of 2–10 villages within regions based on resource endowment, market and infrastructural access and soil fertility. Finally, 300–400 households were randomly selected from the villages. The information used for this analysis is from 4,776 plots from a balanced panel of 2,388 households in Ghana, Kenya, Malawi, Nigeria and Tanzania, Ethiopia, Zambia, and Mozambique. Uganda was dropped because there was no panel for this country. The data used for this study contain information on households' plot level adoption of SAPs, maize, rice, sorghum, and cassava production. Balancing the panel resulted in an attrition rate of 5 percent. This attrition rate was attributed to death and migration, and omission of observations that were deemed to be outliers. Non-randomness of household attrition was further tested using attrition probit (Fitzgerald and Moffit 1998). In the case of attrition probit, all baseline explanatory variables that could influence the attrition, plus lagged values of the total value of output or cereal self-provisioning capacity were estimated against the attrition variable (1 = attritors and 0 = non-attritors) using probit. The results indicated no significant differences between attritors and non-attritors. Further tests for equality of coefficients for attritors and non-attritors in the models suggested attrition bias is likely not an issue in the study. The results can be provided upon request. Thus, the final sample for this study contains 316 households for Ethiopia cultivating plots 632 plots; 359 households for Ghana with 718 plots; 266 households for Kenya with 532 plots; 305 households for Malawi cultivating 610 plots; 225 households for Nigeria cultivating 450 plots; 263 households for Tanzania cultivating 526 plots; 348 households for Zambia cultivating 696 plots; and 286 households for Mozambique cultivating 572 plots.

The SAPs considered are intercropping, zero tillage, residue retention and animal manure and the adoption of these over time produced sixteen categories including non-adoption of any of the SAPs (Table 1) for the entire period. Among the SAPs adopted in isolation, residue retention ($I_0Z_0R_1A_0$) is the most common SAP among households and represent 9% of households in the sample. With respect to joint adoption, intercropping with residue retention ($I_1Z_0R_1A_0$) only is the most common SAP in the sample (8%). As stated earlier, the outcome variables considered in the present study are the total value of output, and cereal self-provisioning capacity, a measure of hidden hunger. In Table 2, these variables are summarized with other variables, but detail measurement of each is presented in Table A1 in the appendix. It is also worth noting that variables such as participation in off-farm activities, access to input credit and contract farming are potentially endogenous. Whiles participation in off-farm activities affect SAPs adoption through income earned (income effect), it may also reduce time allocation to on-farm activities (labour-loss effect). Also, input credit in the form of fertilizer may not only affect investment in soil improving SAPs such as animal manure, intercropping and residue retention but may increase demand for labour or ease production constraints. On the other hand, contract farming as risk mitigation strategy comes with production packages, including technologies to be used on a farm and technical advice via extension services. While this may increase the adoption of SAPs, it may also enhance access to extension advice and other production inputs. The potential endogeneity of these variables was addressed using a two-stage procedure by Blundell and Smith (1989). The approach involves the specification of the potential endogenous variable as a function of explanatory variables influencing adoption, together with a set of instruments in a first stage linear probability model. Observed values of participation in off-farm activities, access to input credit, contract farming and their corresponding residuals from the first stage models were incorporated into the MESR model to enable consistent estimation of these variables. The results of these variables are presented in Table A2 in the appendix.

Since the data captured detailed information on four major crops namely; maize, rice, sorghum and cassava, the value of output (measured in USD/ha) was estimated for each of these crops using the output and prices provided by the farmers. These were further aggregated to get the total value of output.[4] For the value of output, we recorded USD1,027.63/ha for plots cultivated without SAPs. For plots with SAPs, the value of output ranged from 1,100.46–USD1,553.01/ha for the adoption of SAPs in isolation, but 1,048.15–USD9,113.01/ha for joint adoption of the SAPs. The results in Table 2 further show that on the average, CSPC per AE per annum is 288.54 kg among the non-adopters. Among the adopters, however, CSPC is lower and ranged from 81.35–126.10 kg on the average for households adopting the SAPs in isolation, but ranged from 99.03–172.37 kg under joint adoption of SAPs. As shown in Table 2, household, farm/plot, location and institutional characteristics also differ by adoption status, suggesting significant differences between plots with and without adoption of SAPs in our sample. It is important to point out that the differences in the total value of output and hidden hunger do not represent the impact of SAPs because confounding factors are not accounted for in the means. The next section presents and discusses the estimation results, considering, the effects of observed and unobserved heterogeneities.

## 5. Results and discussion

The objective[5] of this study is to examine the impact of individual and joint adoption of SAPs on the value of output and hidden hunger [proxied by cereal self provisioning capacitiy (CSPC)]. The second stage estimates of the MESR are presented in Tables S1-S2 of the supplementary material. On the other hand, the first stage parameter estimates of the MESR, which consider the determinants of SAPs adoption in Africa is presented in Table A2 but are also not discussed. However, the results of the joint significance test of inverse Mills ratios and the mean of time-varying variables in the outcome and selection models indicate the presence of sample selection bias in the choice of SAPs. Further, decisions regarding adoption of SAPs depend on household/farmer, plot/farm, location or institutional factors and vary across the SAPs as suggested by our conceptual framework

**Table 2.** Descriptive statistics by adoption of SAPs over the period (2002-2008).

| Variable | $I_0Z_0R_0A_0$ | $I_1Z_0R_0A_0$ | $I_0Z_1R_0A_0$ | $I_0Z_0R_1A_0$ | $I_0Z_0R_0A_1$ | $I_1Z_1R_0A_0$ | $I_1Z_0R_1A_0$ | $I_1Z_0R_0A_1$ | $I_0Z_1R_1A_0$ | $I_0Z_1R_0A_1$ | $I_0Z_0R_1A_1$ | $I_1Z_1R_1A_0$ | $I_1Z_1R_0A_1$ | $I_1Z_0R_1A_1$ | $I_0Z_1R_1A_1$ | $I_1Z_1R_1A_1$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total value of output (USD/ha) | 1,027.63 | 1,137.32 | 1,553.01 | 1,287.42 | 1,100.46 | 2,353.38 | 1,595.53 | 1,048.15 | 9,113.01 | 2,047.25 | 1,772.39 | 1,891.20 | 1,953.64 | 1,699.28 | 2,115.37 | 1,448.49 |
| CSPC(Household annual CSPC per AE in kg) | 288.54 | 101.21 | 126.10 | 81.35 | 123.25 | 172.37 | 120.82 | 114.83 | 153.41 | 99.03 | 113.67 | 100.28 | 115.51 | 157.04 | 157.79 | 105.29 |
| Gender of head (1 = male) | 0.72 | 1.15 | 0.74 | 0.82 | 0.82 | 0.72 | 0.83 | 0.69 | 0.79 | 0.60 | 0.70 | 0.81 | 0.89 | 0.76 | 0.79 | 0.85 |
| Age of head (years) | 38.92 | 40.78 | 41.26 | 40.55 | 41.54 | 40.23 | 39.51 | 41.33 | 39.88 | 39.66 | 40.60 | 38.59 | 40.23 | 39.76 | 43.21 | 39.01 |
| Education of head (years) | 11.63 | 10.35 | 9.21 | 10.29 | 10.44 | 11.83 | 9.35 | 9.79 | 11.34 | 12.68 | 11.52 | 10.52 | 10.38 | 10.49 | 8.89 | 10.36 |
| Household size (number) | 5.61 | 5.64 | 6.23 | 5.60 | 5.51 | 5.77 | 5.74 | 5.67 | 5.45 | 5.45 | 5.67 | 5.85 | 5.86 | 5.62 | 5.77 | 6.00 |
| Farm size (ha) | 4.18 | 4.63 | 3.98 | 4.07 | 4.27 | 4.24 | 4.78 | 4.47 | 3.88 | 4.14 | 4.09 | 4.33 | 4.66 | 4.49 | 4.47 | 4.31 |
| Dependency ratio (Ratio of members aged below 15 and above 61 to those aged 15–61) | 1.01 | 0.93 | 1.06 | 1.03 | 0.97 | 1.06 | 1.12 | 1.02 | 1.03 | 1.03 | 0.97 | 1.01 | 1.00 | 0.99 | 0.95 | 0.99 |
| Nonfarm activity (1 = farmer engages in off-farm income-generating activities) | 0.23 | 0.22 | 0.21 | 0.19 | 0.18 | 0.22 | 0.17 | 0.17 | 0.16 | 0.23 | 0.16 | 0.20 | 0.17 | 0.21 | 0.17 | 0.17 |
| Contract farming (1 = farm produces under contract) | 0.16 | 0.12 | 0.09 | 0.13 | 0.11 | 0.15 | 0.14 | 0.11 | 0.13 | 0.18 | 0.15 | 0.14 | 0.13 | 0.11 | 0.11 | 0.11 |
| Extension advice (1 = farmer received extension advice) | 0.41 | 0.39 | 0.39 | 0.43 | 0.37 | 0.37 | 0.42 | 0.36 | 0.35 | 0.32 | 0.41 | 0.35 | 0.37 | 0.33 | 0.43 | 0.41 |
| FBO membership (1 = yes) | 0.32 | 0.33 | 0.28 | 0.30 | 0.32 | 0.28 | 0.33 | 0.33 | 0.31 | 0.27 | 0.35 | 0.30 | 0.35 | 0.33 | 0.31 | 0.37 |
| Credit access (1 = has access to farm input credit) | 0.32 | 0.30 | 0.23 | 0.29 | 0.25 | 0.25 | 0.26 | 0.23 | 0.32 | 0.26 | 0.33 | 0.28 | 0.32 | 0.22 | 0.34 | 0.29 |
| Tenure security (1 = has full control over land) | 0.64 | 0.63 | 0.59 | 0.63 | 0.62 | 0.62 | 0.60 | 0.65 | 0.57 | 0.58 | 0.66 | 0.63 | 0.64 | 0.63 | 0.60 | 0.60 |
| Asset index (Index of household durable assets) | −0.11 | 0.05 | 0.44 | 0.32 | −0.06 | −0.27 | −0.04 | 0.24 | 0.05 | 1.16 | −0.80 | 0.04 | 1.08 | 0.02 | 1.07 | −0.08 |
| Total livestock unit (TLU)[1] | 6.78 | 6.49 | 6.34 | 7.32 | 7.92 | 5.90 | 7.07 | 7.45 | 6.22 | 5.66 | 7.22 | 6.40 | 5.77 | 5.51 | 7.33 | 6.07 |
| Above average rain (1 = yes)[†] | 0.43 | 0.43 | 0.45 | 0.48 | 0.41 | 0.49 | 0.44 | 0.38 | 0.46 | 0.43 | 0.51 | 0.47 | 0.41 | 0.45 | 0.38 | 0.41 |
| Average rain (1 = yes)[†] | 0.57 | 0.56 | 0.59 | 0.53 | 0.63 | 0.55 | 0.56 | 0.55 | 0.54 | 0.60 | 0.60 | 0.51 | 0.58 | 0.57 | 0.57 | 0.56 |
| Below average rain (1 = yes)[†] | 0.57 | 0.61 | 0.49 | 0.54 | 0.55 | 0.54 | 0.53 | 0.55 | 0.55 | 0.51 | 0.50 | 0.58 | 0.50 | 0.56 | 0.53 | 0.51 |
| Drought (1 = yes)[†] | 0.29 | 0.31 | 0.27 | 0.27 | 0.25 | 0.28 | 0.26 | 0.26 | 0.28 | 0.28 | 0.27 | 0.30 | 0.23 | 0.24 | 0.21 | 0.21 |
| Chemical fertilizer cost (USD/ha) | 21.42 | 21.72 | 21.38 | 19.92 | 23.50 | 21.76 | 21.80 | 20.90 | 24.08 | 21.56 | 18.58 | 22.69 | 26.74 | 20.83 | 23.38 | 19.75 |
| Distance to all-weathered road (km) | 5.21 | 5.80 | 5.22 | 5.40 | 4.22 | 4.63 | 5.97 | 5.73 | 5.67 | 5.86 | 5.83 | 6.21 | 6.92 | 6.41 | 6.41 | 6.42 |
| Number of observations | 1,216 | 420 | 294 | 466 | 238 | 166 | 399 | 273 | 232 | 150 | 197 | 225 | 112 | 294 | 115 | 193 |

Notes: [†] The reference for rainfall conditions is drought. Standard deviations are parentheses. [1] For TLU, conversion factor for cattle = 0.7, sheep = 0.1, goats = 0.1, pigs = 0.2, chicken = 0.01.

and hence suggest the importance of location in the promotion of the SAPs. The next subsections present the total value of output and hunger impacts of SAPs.

### *5.1. Impact of SAPs on total value of crop output*

Table 3 presents the impacts of SAPs on the total value of crop output (TVO) by country. The estimates show significant difference in the output value of plots cultivated with SAPs as compared to those planted without SAPs. However, most of the practices adopted in isolation appear to have lower impacts on TVO as compared to practices adopted jointly. This finding corroborates with other studies (Kassie et al. 2018; Khonje et al. 2018; Manda et al. 2016) which revealed that plots perform better when technologies are adopted jointly. In the pooled sample, for instance, TVO increased by USD959.49 per hectare when plots are cultivated using only intercropping ($I_1Z_0R_0A_0$). However, when intercropping is adopted with only zero tillage ($I_1Z_1R_0A_0$), TVO increased by USD1,168.21 per hectare. Meanwhile, on average, TVO increased by USD1,150.051 per hectare when zero tillage is adopted in isolation ($I_0Z_1R_0A_0$). When adopted with residue retention ($I_1Z_0R_1A_0$), the increase in TVO is USD6, 191.67 per hectare and higher than adopting either residue retention ($I_0Z_0R_1A_0$) or intercropping ($I_1Z_0R_0A_0$) in isolation. The increase in TVO is, however, not significant when intercropping is adopted with only animal manure ($I_1Z_0R_1A_0$) in the sample. In addition, when zero tillage is adopted with only residue retention ($I_0Z_1R_1A_0$) or animal manure ($I_0Z_1R_0A_1$), increase in TVO is USD8, 288.66 per hectare. On the other hand, average TVO stood at USD1,012.19 per hectare when residue retention is adopted with animal manure ($I_0Z_0R_1A_1$). When at least three practices are adopted jointly, sample TVO ranged between USD1,475.42 and USD6,391.19 per hectare.

Also, the results revealed that the impacts of the SAPs vary across different plots. For instance, average TVO increased significantly by USD252.98 per hectare for plots in Ethiopia, USD343.04 in Ghana, USD1,388.12 in Kenya, USD120.53 in Tanzania and USD1,305.80per hectare for plots in Mozambique for the adoption of only intercropping ($I_1Z_0R_0A_0$). However, when intercropping is adopted with only zero tillage ($I_1Z_1R_0A_0$), TVO increased by USD800.61, USD7,819.05, USD1,583.85, USD7,356.96, USD1,617.58 and USD1,643.03 per hectare for plots in Ghana, Kenya, Malawi, Nigeria, Tanzania and Zambia, respectively, but does not exert any significant impact on TVO of plots in Ethiopia and Mozambique. When adopted with residue retention ($I_1Z_0R_1A_0$), TVO increased significantly by USD3,915.75 per hectare for plots in Nigeria and USD872.29 per hectare for plots in Tanzania but did not increase significantly in Ethiopia, Ghana, Kenya, Malawi, and Zambia. When adopted with only animal manure ($I_1Z_0R_0A_1$), TVO increased by USD5,950.64, USD4,505.63 and USD4,296.69 respectively for plots in Kenya, Nigeria and Tanzania.

On the other hand, there is no significant increase in average TVO when zero tillage is adopted with only residue retention ($I_0Z_1R_1A_0$) or animal manure ($I_0Z_1R_0A_1$) in any of the plots considered. However, household TVO increased by USD1,783.34 and USD67.63, respectively for plots in Ethiopia and Zambia when residue retention is adopted with animal manure ($I_0Z_0R_1A_1$). When intercropping is adopted with only zero tillage and residue retention ($I_1Z_1R_1A_0$), only plots in Ethiopia experienced a significant increase in TVO and this stands at USD4,536.60 on the average. When intercropping is adopted with only zero tillage and animal manure ($I_1Z_1R_0A_1$), TVO stood at USD3,627.17 and USD4,945.82 for only households in Tanzania and Zambia. When adopted with only residue retention and animal manure ($I_1Z_0R_1A_1$), TVO stood at USD1,651.09, USD2,150.13 and USD2,172.30 for only households in Ethiopia and Ghana, respectively. Further, TVO stood at USD4,584.414, USD2,016.90 and USD1,292.55 for households in Ghana, Kenya, Nigeria, and Mozambique when zero tillage is jointly adopted with residue retention and animal manure ($I_0Z_1R_1A_1$). When all the SAPs are adopted ($I_1Z_1R_1A_1$) by a household, TVO increased by USD3,159.21, USD615.49, USD1,405.06 and USD321.72 for households in Ethiopia, Malawi, Zambia and Mozambique.

**Table 3.** MESR based average treatment effects of SAPs on total value of outputof the treated (ATT) households.

| SAP choice | Ethiopia | Ghana | Kenya | Malawi | Nigeria | Tanzania | Zambia | Mozambique | Pooled sample |
|---|---|---|---|---|---|---|---|---|---|
| $I_1Z_0R_0A_0$ | 252.98 (81.63)*** | 343.04 (67.23)*** | 1,388.12 (511.57)** | 359.87 (382.39) | 1,332.52 (1,025.09) | 120.53 (51.15)*** | −123.14 (154.33) | 1,305.80 (130.70)*** | 959.49 (398.81)** |
| $I_0Z_1R_0A_0$ | 2,932.27 (2374.02) | −98.14 (68.50) | 936.43 (449.11)* | 2,649.37 (1,612.69) | 215.42 (193.85) | 2,521.67 (2,162.95) | 5,595.97 (5,606.24) | −6,364.99 (7,761.74) | 1,150.051 (796.80)* |
| $I_0Z_0R_1A_0$ | −286.36 (160.93) | 894.98 (1,288.48) | 25.22 (20.67) | 171.58 (55.87)*** | 2,029.32 (1,230.15) | 603.42 (222.48)*** | −11.75 (93.36) | −276.43 (276.02) | −1,012.56 (5,348.84) |
| $I_0Z_0R_0A_1$ | 5,831.54 (4,775.73) | 2,042.32 (2,123.72) | 6,058.60 (4,527.99) | −206.53 (275.56) | 1,285.27 (1,299.70) | 6,620.12 (3,421.91)* | −151.17 (162.50) | −9,582.45 (1,788.39) | 6,345.87 (877.56)*** |
| $I_1Z_1R_0A_0$ | 254.09 (195.31) | 800.61 (307.15)** | 7,819.05 (151.73)*** | 1,583.85 (1,534.28)* | 7,356.96 (490.04)*** | 1,617.58 (166.94)*** | 1,643.03 (762.45)** | −3,450.94 (3,439.19) | 1,168.21 (217.39)*** |
| $I_1Z_0R_1A_0$ | 7.70(200.23) | 89.48 (276.66) | 1,001.66 (658.65) | 563.14 (479.59) | 3,915.75 (1,887.08)** | 872.29 (432.13)* | 49.72 (147.34) | 1,541.88 (2,091.04) | 6,191.67 (502.17)*** |
| $I_1Z_0R_0A_1$ | 2,300.82 (2,855.39) | 301.61 (302.13) | 5,950.64 (597.67)*** | 1,137.30 (1,925.60) | 4,505.63 (464.54)*** | 4,296.69 (878.82)*** | −67.49 (84.05) | 3,864.15 (2,374.54) | 1,547.91 (1,666.39) |
| $I_0Z_1R_1A_0$ | 3,012.97 (3,316.00) | 944.69 (838.28) | −6.98 (4.42) | 2,504.19 (2,637.39) | 5,491.40 (4,689.34) | 1,669.73 (1,030.27) | 1,710.04 (1,834.56) | 242.70 (195.78) | 1,3258.60 (389.27)*** |
| $I_0Z_1R_0A_1$ | −188.23 (139.59) | 941.26 (863.37) | 3,640.91 (2,792.13) | 7,697.35 (6,457.55) | −15.95 (13.47) | 819.02 (1,059.80) | 1,417.54 (1,695.23) | 6,202.35 (4,254.99) | 8,288.66 (4,256.16)* |
| $I_0Z_0R_1A_1$ | 1,783.34 (8,730.25)** | 1,913.63 (6,714.13) | 3,277.33 (1426.26) | 1,959.88 (2,070.01) | 378.91 (556.11) | 1,539.81 (1,934.96) | 67.63 (7.53)** | 1,297.64 (1,375.77) | 1,012.19 (557.35)** |
| $I_1Z_1R_1A_0$ | 5,530.89 (5,656.18) | −43.03 (114.32) | 4,536.60 (2,513.95)* | 1,117.38 (1,505.28) | 1,259.61 (1,107.89) | −430.28 (225.18) | 7,874.07 (7,954.77) | 51.99 (84.09) | 1475.42 (133.13)*** |
| $I_1Z_1R_0A_1$ | 3,329.63 (3,032.27) | 5,994.80 (3,047.62) | −41.41 (55.41) | 3,896.20 (2,861.47) | 721.21 (736.73) | 3,627.17 (706.20)*** | 4,945.82 (226.19)*** | −170.83 (174.46) | 2,054.85 (509.19)*** |
| $I_1Z_0R_1A_1$ | 2,150.13 (218.72)*** | 1,651.09 (672.31)** | 78.34(87.67) | −64.62 (176.44) | 2,478.66 (2,104.52) | 358.99 (811.63) | 6,650.81 (5,055.65) | 1,243.73 (1,548.36) | 6,391.19 (3,563.05)* |
| $I_0Z_1R_1A_1$ | 1,143.08 (1,239.98) | 4,584.414 (2,507.15)* | 2,016.90 (994.30)** | 644.41 (885.83) | 1,292.55 (216.41)*** | 5,844.02 (5,945.20) | 1,915.96 (2,557.41) | 2,172.30 (1,178.72)* | 4,384.43 (8,466.71) |
| $I_1Z_1R_1A_1$ | 3,159.21*** (323.89) | 840.99 (796.68) | −34.75 (53.77) | 615.49 (58.05)*** | 122.57 (196.79) | 65.14 (585.41) | 1,405.06 (208.17)*** | 321.72 (180.52)* | 2,123.22 (1,069.97)* |

Note: Standard errors in parentheses; ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

**Table 4.** MESR based average treatment effects of SAPs on cereal self-provisioning capacity (CSPC) of the treated (ATT) households.

| SAP choice | Ethiopia | Ghana | Kenya | Malawi | Nigeria | Tanzania | Zambia | Mozambique | Pooled sample |
|---|---|---|---|---|---|---|---|---|---|
| $I_1Z_0R_0A_0$ | 4.61 (5.54) | 3.58 (3.03) | −7.58 (2.23)*** | −7.44 (1.82)*** | 0.84 (1.18) | −46.20 (21.88)** | 7.16 (8.03) | 7.16 (8.03) | −5.38 (2.21)** |
| $I_0Z_1R_0A_0$ | −18.47 (4.95)*** | −56.43 (29.70)*** | −86.47 (19.95)*** | −10.56 (4.77)** | −0.44 (2.88) | −97.58 (50.30)* | −3.61 (0.98)*** | −3.61 (0.98)*** | −26.16 (7.72)*** |
| $I_0Z_0R_1A_0$ | 3.99 (16.72) | −11.62 (1.56)*** | 0.24 (1.82) | −6.34 (1.64) | −12.59 (5.49)** | −10.33 (3.67)*** | −1.10 (2.12) | −1.10 (2.12) | −4.98 (1.66)*** |
| $I_0Z_0R_0A_1$ | −35.24 (14.54)** | 7.17 (10.71) | −13.04 (6.29)* | 4.42 (8.24) | −22.51 (6.20)*** | −18.16 (17.57) | 5.56 (2.63)** | 5.56 (2.63)** | −16.99 (4.83)*** |
| $I_1Z_1R_0A_0$ | −9.24 (2.98)*** | −2.28 (0.07)*** | 0.09 (1.83) | −300.41 (20.64)*** | −21.44 (5.59)*** | −247.61 (247.27) | −7.72 (4.49) | −10.82 (8.16) | −114.88 (64.29)* |
| $I_1Z_0R_1A_0$ | −2.74 (4.42) | −1.89 (3.44) | −4.62 (2.62)* | −65.13 (33.82)* | 5.26 (3.61) | −5.24 (2.62)* | 23.42 (20.93) | 1.40 (3.24) | 58.83 (50.69) |
| $I_1Z_0R_0A_1$ | −11.73 (7.32) | 1.30 (2.26) | −5.91 (2.52)** | −42.99 (38.95) | −55.94 (13.26)** | 4.78 (6.03) | 2.57 (1.34)* | −53.99 (29.73)* | −24.25 (9.45)** |
| $I_0Z_1R_1A_0$ | −1.12 (7.42) | −63.69 (4.43)*** | −27.04 (27.80) | 7.81 (13.26) | 40.91 (26.51) | 3.36 (7.45) | −14.87 (6.82)** | −1.31 (2.37) | −23.85 (9.54)** |
| $I_0Z_1R_0A_1$ | −39.12 (19.75)* | −4.59 (1.83) | 7.89 (9.16) | −508.14 (48.78)*** | −5.43 (2.50)* | −7.43 (3.28)** | −3.35 (2.30) | 1.37 (7.58) | 114.57 (110.66) |
| $I_0Z_0R_1A_1$ | −29.10 (16.04)* | −30.54 (12.30)** | −27.33 (17.45) | −25.71 (21.44) | −59.09 (60.34) | 79.25 (73.63) | −3.31 (3.61) | 9.86 (8.71) | −33.24 (9.10)*** |
| $I_1Z_1R_1A_0$ | −16.78 (1.08)*** | −13.26 (13.11) | −2.43 (1.27) | 4.89 (6.69) | −3.29 (1.64)* | 7.88 (11.78) | 6.24 (8.97) | −4.66 (2.49)* | 0.49 (2.89) |
| $I_1Z_1R_0A_1$ | −918.97 (56.90)*** | −1.20 (5.43) | −296.65 (29.28)*** | 0.31 (3.44) | −1.24 (1.86) | −7.82 (5.01) | −111.90 (10.60)*** | −0.97 (0.77) | 170.33 (112.14) |
| $I_1Z_0R_1A_1$ | −20.84 (4.75)*** | −29.77 (6.04)*** | 10.84 (6.07) | −34.29 (26.99) | −6.45 (3.32)* | −138.32 (6.98)*** | 3.36 (3.24) | −43.92 (19.20)* | −20.29 (8.55)** |
| $I_0Z_1R_1A_1$ | −4.50 (5.25) | −1.80 (2.30) | −60.50 (6.66)*** | −867.12 (51.47)*** | −4.65 (1.13)** | 2.99 (9.85) | −43.94 (7.06)*** | 1045.83 (994.20) | 320.39 (208.72) |
| $I_1Z_1R_1A_1$ | −8.81 (4.46)* | −57.92 (5.68)*** | −27.84 (4.37)*** | 2.05 (4.41) | −10.75 (5.72)* | 12.92 (14.37) | 27.79 (21.54) | −393.99 (31.37)*** | −36.57 (19.84)* |

Note: Standard errors in parentheses; ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

### *5.1.1. Impacts of SAPs on hidden hunger*

The results of the impact of SAPs adoption on hidden hunger (proxied by CSPC) are presented in Table 4. The results show that household's adoption of SAPs reduced CSPC. For instance, reduction in CSPC ranged between 4.98 kg and 26.16 kg for the adoption of single SAP. Further, CSPC reduces by 114.88 kg when households adopted intercropping with zero tillage ($I_1Z_1R_0A_0$) but did not reduce when intercropping was adopted with only zero tillage and residue retention ($I_1Z_1R_1A_0$) or only zero tillage and animal manure ($I_1Z_1R_0A_1$). Similarly, CSPC reduced by 23.85 kg when zero tillage was adopted with residue retention ($I_0Z_1R_1A_0$) but did not reduce when zero tillage was adopted with only residue retention and animal manure ($I_0Z_1R_1A_1$). On the other hand, CSPC decreased by 20.29 kg when intercropping was adopted with residue retention and animal manure ($I_1Z_0R_1A_1$). Also, the CSPC reduced by 24.25 kg when intercropping was adopted with only animal manure ($I_1Z_0R_0A_1$) or by 33.24 kg when residue retention is adopted with only animal manure ($I_0Z_0R_1A_1$). Also, CSPC reduced significantly by 36.57 kg when all the practices were jontly adopted. The results also show much variation in the reduction of CSPC among plots located in different countries. For instance, the decrease in CSPC was at most 35.24 kg in Ethiopia, 56.43 kg in Ghana, 86.47 kg in Kenya, 10 kg in Malawi, 22.51 kg in Nigeria, 97 kg in Zambia and 5.56 kg in Mozambique for the adoption of each of intercropping, zero tillage, residue retention and animal manure in isolation. On the other hand, decrease in the CSPC was at most 918.97 kg in Ethiopia, 63.69 kg in Ghana, 296.65 kg in Kenya, 867.12 kg in Malawi, 55.94 kg in Nigeria, 138.32 kg in Tanzania, 111.90 kg in Zambia and 393.99 kg in Mozambique for joint adoption of the SAPs as household SAP. As stated earlier, cereal self-provisioning capacity (CSPC) per adult equivalent was used as a proxy for hidden hunger. The results therefore suggest that the household's adoption of SAPs reduced hidden hunger and the reduction differed across locations of Africa.

## 6. Conclusions and policy implications

Following the limited studies on cross-country analyses of the impacts of single and joint adoption of SAPs, this study used panel data from sub-Saharan Africa's intensification project to study how SAPs contribute to the total value of output and hidden hunger-reduction across eight countries in Africa. We employed a Mundlak device within the framework of multinomial endogenous switching regression (MESR) model to account for selection bias resulting from the nonrandom assignment of SAPs, and to assess the impacts of adoption of single and joint SAPs. The results revealed that both single and joint adoption of SAPs enhance total value of output and, as well reduces household's hidden hunger. However, the magnitude of the impacts from joint adoption is higher in most cases as compared to adoption of single SAP. The results also show that the benefits associated with the adoption of SAPs (single or joint) vary across the eight locations considered.

A number of policy implications can be drawn from the findings of this study. More packages that are comprehensive would always result in greater benefits than a partial implementation that might result in reduced welfare impacts. These findings call for the promotion of complete adoption packages whose components are complementary to ensure better adoption outcomes in Africa. Also, the varying impacts across the different locations of Africa imply that the benefits of SAPs are location specific and should be treated as such when it comes to promoting adoption among households in different location of Africa. Thus, while promoting complete adoption of SAPs packages among households, compatibility and location of the households should also be taken into consideration.

## Notes

1. SAPs are broadly defined to include various practices such as conservation tillage, legume intercropping, legume crop rotations, improved crop varieties, the use of animal manure, the complementary use of inorganic fertilisers and soil and stone bunds for soil and water conservation (FAO 1989).

2. We first calculated the annual cereal self-provisioning capacity of households following FAO (2012). We then converted the values to adult equivalent using the OECD adult equivalent scale expressed as: 1+0.7(A−1)+0.5C, where A and C represent the number of adults and children in a household, respectively.
3. We are grateful to an anonymous reviewer for pointing out this information to us.
4. With regards to the prices, we used the median prices of the prices provided by the farmers in order to avoid the effect of variations in local prices.
5. To save space, only the results of the treatment effects (ATT) are discussed.

## Disclosure statement

No potential conflict of interest was reported by the authors.

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## References

Abdulai, AN. 2016. Impact of Conservation Agriculture Technology on Household Welfare in Zambia. *Agricultural Economics (United Kingdom)* 47, no. 6: 729–41.

Asfaw, S., B. Shiferaw, F. Simtowe, and L. Lipper. 2012. Impact of modern agricultural technologies on smallholder welfare: evidence from Tanzania and Ethiopia. *Food Policy* 37, no. 3: 283–295. doi:10.1016/j.foodpol.2012.02.013.

Bationo, A., J. Kihara, B. Vanlauwe, B. Waswa, and J. Kimetu. 2007. Soil organic carbon dynamics, functions and management in West African agro-ecosystems. *Agricultural Systems* 94, no. 1: 13–25. doi:10.1016/j.agsy.2005.08.011.

Binswanger, H., and P. Pingali. 1988. Technological priorities for farming in Sub-Saharan Africa. *The World Bank Research Observer* 3, no. 1: 81–98.

Blundell, R.W., and R.J. Smith. 1989. Estimation in a Class of Simultaneous Equation limited dependent variable models. *The Review of Economic Studies* 56, no. 1: 37–57.

Bourguignon, F., M. Fournier, and M. Gurgand. 2007. Selection bias Corrections based on the multinomial logit model: Monte Carlo Comparisons. *Journal of Economic Surveys* 21, no. 1: 174–205.

Chamberlain, G. 1984. Chapter 22 panel data. *Handbook of Econometrics* 2: 1247–1318. doi:10.1016/S1573-4412(84)02014-6.

Di Falco, S., M. Veronesi, and M. Yesuf. 2011. Does Adaptation to Climate change provide from Ethiopia. *Amer. J. Agr. Econ.* 93, no. 3: 829–846. doi:10.1093/ajae/aar006.

Dubin, J.A., and D.L. Mcfadden. 1984. "An Econometric Analysis of Residential Electric Appliance Holdings and Consumption." *Econometrica* 52 no. 2: 345–62. http://www.jstor.org/stable/1911493. Accessed: 15/01/2009 20:24.

Erenstein, O. 2006. Intensification or extensification ? factors affecting technology use in peri-urban lowlands along an agro-ecological gradient in West Africa. *Agricultural Systems* 90, no. 2: 132–158. doi:10.1016/j.agsy.2005.12.005.

FAO. 1964. *Guide to Sixty Soil and Water Conservation Practices*. Rome, Italy.

FAO. 1989. Sustainable Development and Natural Resources Management. *Twenty-Fifth Conference*, (Paper C 89 / 2 – Supplement 2), 2–562. FAO, Rome.

FAO. 2012. *FAO Statistical Pocketbook: World food and agriculture*. Rome: FAO.

Fitzgerald, J.G., and R. Moffit. 1998. An analysis of sample attrition in panel data. *Journal of Human Resources* 33, no. 2: 251–299.

Greene, William H. 2002. *Econometric Analysis*. 5th ed. eds. Rod Banister et al. New Jersey: Prentice Hall.

Hobbs, P.R., K. Sayre, and R. Gupta. 2008. The role of conservation agriculture in sustainable agriculture. *Philosophical Transactions of the Royal Society B Biological Sciences* 363, no. April 2016: 543–555. doi:10.1098/rstb.2007.2169.

IFPRI. 2014. Addressing the challenge of hidden hunger. In *Global hunger index: The challenge of hidden hunger* (2014th ed.). https://www.ifpri.org/sites/default/files/ghi/2014/contents.html. (Accessed May 28, 2019).

Issahaku, G., and A. Abdulai. 2019. Can farm households improve food and nutrition security through adoption of Climate-smart practices ? empirical evidence from Northern Ghana. *Applied Economic Perspectives and Policy*, 1–22. doi:10.1093/aepp/ppz002.

Jones, A.D., A. Shrinivas, and R. Bezner-kerr. 2014. Farm production diversity is associated with greater household dietary diversity in Malawi: findings from nationally representative data. *Food Policy* 46, no. 1: 1–12. doi:10.1016/j.foodpol.2014.02.001.

Kassam, A., T. Friedrich, F. Shaxson, and J. Pretty. 2009. The spread of conservation agriculture: Justification, sustainability and uptake. *International Journal of Agricultural Sustainability* 7, no. 4: 292–320. doi:10.3763/ijas.2009.0477.

Kassie, M., H. Teklewold, P. Marenya, M. Jaleta, and O. Erenstein. 2015. Production Risks and Food Security under Alternative Technology Choices in Malawi: Application of a Multinomial Endogenous Switching Regression. *Journal of Agricultural Economics* 6

Kassie, M., P. Marenya, Y. Tessema, M. Jaleta, D. Zeng, O. Erenstein, and D. Rahut. 2018. Measuring farm and market level Economic impacts of Improved maize production technologies in Ethiopia: evidence from panel data. *Journal of Agricultural Economics* 69, no. 1: 76–95. doi:10.1111/1477-9552.12221.

Kassie, M., J. Pender, M. Yesuf, G. Kohlin, R. Bluffstone, and E. Mulugeta. 2008. Estimating returns to soil conservation adoption in the northern Ethiopian highlands. *Agricultural Economics* 38, no. 2: 213–232.

Khonje, M.G., J. Manda, P. Mkandawire, A.H. Tufa, and A.D. Alene. 2018. Adoption and welfare impacts of multiple agricultural technologies: evidence from eastern Zambia. *Agricultural Economics*, in press. doi:10.1111/agec.12445.

Manda, J., A.D. Alene, C. Gardebroek, M. Kassie, and G. Tembo. 2016. Adoption and impacts of sustainable agricultural practices on maize yields and Incomes: evidence from rural Zambia. *Journal of Agricultural Economics* 67, no. 1: 130–153. doi:10.1111/1477-9552.12127.

Marenya, P., E. Nkonya, W. Xiong, J.D. Rossel, and K. Edward. 2012. Which would work better for improved soil fertility management in sub-Saharan Africa: Fertilizer Subsidies or Carbon Credits? *Selected Paper Prepared for Presentation at the International Association of Agricultural Economists (IAAE) Triennial Conference*, *18-24 August*, *2012.*, 18–24. Foz do Iguaçu, Brazil: Association of Agricultural Economists (IAAE) Triennial Conference.

McFadden, D., 1973. Conditional logit analysis of qualitative choice behavior. In: Zarembka, P. (Ed.), Frontiers in Econometrics. Academic Press, New York.

Mundlak, Y. 1978. On pooling of time series and cross section data. *Econometrica* 64: 69–85.

NEPAD. 2003. *Comprehensive Africa Agriculture Development Programme*. https://doi.org/Website: http//www.nepad.org; E-mail: sundayd@nepad.org; E-mail: mkandawirer@nepad.org.

Ng'ombe, J.N., T.H. Kalinda, and G. Tembo. 2017. Does adoption of conservation farming practices result in increased crop revenue? evidence from Zambia. *Agrekon* 56, no. 2: 205–221. doi:10.1080/03031853.2017.1312467.

Pangaribowo, E., and N. Gerber. 2016. Innovations for food and nutrition security: impacts and Trends. In *Technological and institutional innovations for marginalized smallholders in agricultural development*, ed. F. W. Gatzweiler, and J. von Braun, 41–64. doi:10.1007/978-3-319-25718-1

Smith, L.C., and A. Subandoro. 2007. Measuring Food Security Using Household Expenditure Surveys. Food Security in Practice Technical Guide Series. https://doi.org/10.2499/0896297675.

Tambo, J.A., and J. Mockshell. 2018. Differential impacts of conservation agriculture technology options on household income in Sub-Saharan Africa. *Ecological Economics* 151, no. 1: 95–105. doi:10.1016/j.ecolecon.2018.05.005.

Teklewold, H., M. Kassie, and B. Shiferaw. 2013. Adoption of multiple sustainable agricultural practices in rural Ethiopia. *Journal of Agricultural Economics* 64, no. 3: 597–623. doi:10.1111/1477-9552.12011.

Verkaart, S., B.G. Munyua, K. Mausch, and J.D. Michler. 2017. Welfare impacts of improved chickpea adoption: A pathway for rural development in Ethiopia ? *Food Policy* 66, no. 1: 50–61. doi:10.1016/j.foodpol.2016.11.007.

Woldeyohanes, T., T. Heckelei, and Y. Surry. 2017. Effect of off-farm income on smallholder commercialization: panel evidence from rural households in Ethiopia. *Agricultural Economics (United Kingdom)* 48, no. 2: 207–218. doi:10.1111/agec.12327.

Wooldridge, J.M. 2002. *Econometric analysis of cross section and panel data*. London, UK: MIT Press.

Zero Hunger Challenge. 2016. Partnering for nourishing our people, nurturing our planet, growing prosperity, harvesting peace transforming our food systems to transform our world background. *Zero Hunger Challenge* 2, no. 6: 1–5.

## Appendix

**Table A1.** Summary statistics, descriptions/measurements for the variables used (2002/04–2008/10).

| Variable | Descriptions/measurement |
|---|---|
| Total value of output | Monetary value of farm produce (USD/ha) |
| CSPC | Cereal self-provisioning capacity per adult equivalent (kg) |
| Labour use | Total labour (number of workers/ha) |
| Labour cost | Total cost of labour (USD/ha) |
| Chemical fertilizer cost | Total cost of fertilizer (kg/ha) |
| Pesticides/herbicides | 1 if farmer uses pesticides/herbicides; 0 if otherwise |
| Livestock holding[1] | Total livestock holding in Tropical Livestock Units (TLU) |
| Above average[2] | 1 if village rainfall is above average; 0 if otherwise |
| Average[2] | 1 if village rainfall is average; 0 if otherwise |
| Below average[2] | 1 if village rainfall is below average; 0 if otherwise |
| Drought[2] | 1 if village is drought; 0 if otherwise |
| Gender of HHH | Gender of household head (1 if male; 0 if otherwise) |

(*Continued*)

**Table A1.** Continued.

| Variable | Descriptions/measurement |
|---|---|
| FBO membership | 1 if farmer is a member of any local farmer organization dealing with agriculture; 0 if otherwise |
| Household size | Household size (number of members) |
| Education | Education of head (years) |
| Dependency ratio | Ratio of household members aged below 15 and above 61 to those aged 15–61 |
| Age | Age of the head of the household (years) |
| Nonfarm activity | 1 if farmer engages in off-farm income-generating activities; 0 if otherwise |
| Contract farming | 1 if farmer grow crops on the basis of pre-arranged contract; 0 if otherwise |
| Input credit access | 1 if farmer have access to farm input credit; 0 if otherwise |
| Tenure security | I if farmer holds a formal title or registration of cultivated land; 0 if otherwise |
| Farm size | Total cultivated area (hectares) |
| Distance to road | Distance from the village center to the nearest all-weather road (km) |
| Extension advice | 1 if farmer received advice from extension staff; 0 if otherwise |
| Asset index | Household asset index |

Notes:[1]For TLU, conversion factor for cattle = 0.7, sheep = 0.1, goats = 0.1, pigs = 0.2, chicken = 0.01. [2]The reference category for rainfall conditions is drought. Standard deviations in parenthesis.

**Table A2.** Parameter estimates of drivers of adoption of SAPs in Africa[1].

| Variable | $I_1Z_0R_0A_0$ | $I_0Z_1R_0A_0$ | $I_0Z_0R_1A_0$ | $I_0Z_0R_0A_1$ | $I_1Z_1R_0A_0$ | $I_1Z_0R_1A_0$ | $I_1Z_0R_0A_1$ | $I_0Z_1R_1A_0$ | $I_0Z_1R_0A_1$ | $I_0Z_0R_1A_1$ | $I_1Z_1R_1A_0$ | $I_1Z_1R_0A_1$ | $I_1Z_0R_1A_1$ | $I_0Z_1R_1A_1$ | $I_1Z_1R_1A_1$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gender of head | −0.12*** | −0.07 | 0.05** | −0.21*** | −0.09 | 0.12*** | 0.01 | 0.11*** | −1.01*** | −0.03 | −0.01 | −0.04* | −0.06 | −0.01 | −0.01 |
| | (0.02) | (0.04)* | (0.02) | (0.03) | (0.05)* | (0.03) | (0.03) | (0.04) | (0.04) | (0.03) | (0.03) | (0.02) | (0.04)* | (0.13) | (0.04) |
| Age of head | −0.10 | −0.88 | 0.13 | 0.26 | −0.93 | −0.03 | 0.23 | 0.59 | −0.36 | −0.31 | −0.09 | 0.06 | 0.00 | 1.63 | −0.35 |
| | (0.40) | (0.53)* | (0.42) | (0.54) | (0.67) | (0.44) | (0.47) | (0.63) | (0.69) | (0.56) | (0.55) | (0.77) | (0.58) | (1.11) | (0.58) |
| Education of head | 0.15 | −0.20 | −0.20** | 0.24 | −0.02 | 0.32 | −0.41 | 0.06 | 0.21*** | −0.10*** | 0.28* | 0.06 | 0.29 | 0.56*** | −0.27** |
| | (0.20) | (0.06)*** | (0.09) | (0.08)*** | (0.34) | (0.13)** | (0.22)* | (0.30) | (0.05) | (0.02) | (0.15) | (0.42) | (0.04)*** | (0.15) | (0.10) |
| Household size | −0.46 | −0.12 | −0.32 | −0.83 | −0.24 | −0.12 | −0.18 | −0.50 | −0.25 | −0.29 | 0.11 | −1.26 | −0.76 | −0.03 | 0.38 |
| | (0.28) | (0.38) | (0.27) | (0.36)** | (0.46) | (0.30) | (0.32) | (0.39) | (0.49) | (0.40) | (0.36) | (0.57)** | (0.42)* | (0.65) | (0.44) |
| Farm size | 0.04 | 0.00 | 0.29 | 0.37 | −0.01 | −0.01 | 0.03 | 0.32 | 0.23 | −0.14 | 0.37 | 0.27 | 0.12 | 0.56 | −0.08 |
| | (0.17) | (0.22) | (0.19) | (0.28) | (0.25) | (0.20) | (0.25) | (0.31) | (0.40) | (0.26) | (0.29) | (0.40) | (0.23) | (0.54) | (0.26) |
| Dependency ratio | −0.36 | −0.56 | −0.48 | −0.44 | 0.32 | 0.10 | −0.38 | 0.30 | −0.07 | 0.10 | −0.18 | 0.28 | −0.30 | −0.42 | −0.15 |
| | (0.20)* | (0.24)** | (0.21)** | (0.25)* | (0.09)*** | (0.23) | (0.23)* | (0.10)** | (0.37) | (0.28) | (0.26) | (0.39) | (0.26) | (0.08)*** | (0.31) |
| Nonfarm activity | −0.22 | 0.60 | −0.55** | 0.40*** | −0.66 | −0.39 | −0.73*** | −0.04 | −0.42 | −0.38 | 0.97*** | −0.64 | 0.06 | 2.28*** | −0.58*** |
| | (0.09)** | (0.74) | (0.24) | (0.06) | (0.80) | (0.54) | (0.13) | (0.77) | (0.96) | (0.73) | (0.q7) | (1.08) | (0.66) | (0.56) | (0.14) |
| Contract farming | −0.88 | −0.90 | −1.40 | −1.16 | 1.57 | −0.64 | −1.56 | −1.82 | −1.58 | 0.36 | −1.85 | −1.93 | 0.79 | 0.36 | 0.28 |
| | (0.74) | (1.02) | (0.74)* | (1.03) | (1.30) | (0.75) | (1.03) | (1.41) | (1.31) | (1.04) | (1.13) | (1.39) | (1.03) | (1.63) | (1.31) |
| Extension access | 0.10 | −0.23 | −0.26 | −0.66 | −0.89 | 0.17 | −0.30 | −0.96 | −0.05 | −0.47 | −0.44 | −0.66 | −0.15 | −0.43 | 1.02 |
| | (0.41) | (0.53) | (0.42) | (0.49) | (0.63) | (0.44) | (0.51) | (0.61) | (0.78) | (0.53) | (0.58) | (0.80) | (0.54) | (0.94) | (0.63) |
| FBO membership | −0.27** | −0.27* | −0.29* | −0.06 | −0.35** | 0.50*** | 0.38 | 0.19 | −1.98 | −0.69*** | 0.34 | −3.50 | 0.43 | −2.09 | 0.65*** |
| | (0.12) | (0.14) | (0.16) | (0.54) | (0.16) | (0.18) | (0.50) | (0.62) | (0.84)** | (0.12) | (0.55) | (1.08)*** | (0.58) | (1.01)** | (0.17) |
| Input credit access | 1.17 | 0.05 | 0.50*** | 0.56*** | 0.19 | −0.17 | 0.32 | 0.16 | 1.86 | 1.53 | −0.73 | 1.28 | 0.00 | 0.20 | 0.09 |
| | (0.44)*** | (0.62) | (0.10) | (0.06) | (0.74) | (0.50) | (0.54) | (0.68) | (0.94)** | (0.65)** | (0.68) | (0.92) | (0.65) | (0.97) | (0.76) |
| Tenure security | −0.09 | 0.29 | −0.21 | 0.40 | −0.15 | −0.34 | −0.22 | 0.76 | 0.84 | 0.60 | −1.09 | 2.08 | 0.26 | 0.51 | −0.22 |
| | (0.42) | (0.53) | (0.46) | (0.53) | (0.66) | (0.45) | (0.52) | (0.62) | (0.83) | (0.59) | (0.59)* | (0.97)** | (0.60) | (0.89) | (0.67) |
| Asset index | 0.19 | 0.44 | 0.01 | 0.14* | −0.14 | −0.08 | 0.36** | −0.35 | −0.19 | −0.15*** | 0.04 | 0.13 | 0.20*** | 0.22 | −0.37 |
| | (0.14) | (0.18)** | (0.15) | (0.08) | (0.25) | (0.16) | (0.17) | (0.24) | (0.29) | (0.03) | (0.20) | (0.29) | (0.01) | (0.29) | (0.25) |
| Livestock holding | −0.19 | −0.13 | −0.03 | 1.13 | 0.11 | −0.36 | 0.19 | 1.01 | −0.54 | 1.02 | −0.64 | 0.61 | −0.49 | −0.19 | −0.56 |
| | (0.33) | (0.39) | (0.34) | (0.49)** | (0.50) | (0.33) | (0.39) | (0.55)* | (0.58) | (0.52)* | (0.40) | (0.66) | (0.42) | (0.65) | (0.50) |
| Above$^a$ average rain | −0.65 | 0.11 | 0.39 | −0.02 | −0.56 | −0.73 | −1.48 | −0.96 | −0.10 | 0.23 | −0.25 | −0.62 | −0.36 | −0.80 | −0.63 |
| | (0.31)** | (0.51) | (0.43) | (0.51) | (0.65) | (0.45) | (0.49)*** | (0.58)* | (0.82) | (0.57) | (0.55) | (0.86) | (0.55) | (0.92) | (0.63) |
| Average rain$^a$ | −0.52 | 0.56 | −0.53 | 0.11 | −1.55 | 0.08 | −0.22 | −0.07 | −0.01 | −0.77 | −0.36 | −1.45 | −0.65 | 0.30 | −0.17 |
| | (0.02)*** | (0.13)*** | (0.45) | (0.55) | (0.69)** | (0.46) | (0.51) | (0.64) | (0.82) | (0.61) | (0.59) | (0.89) | (0.58) | (1.02) | (0.67) |
| Below average rain$^a$ | −0.26 | −0.72 | −0.15 | 1.38 | −0.25 | −0.28 | 0.36 | −0.19 | −0.42 | 0.52 | 0.51 | 0.08 | −0.10 | 1.39 | 0.39 |
| | (0.42) | (0.53) | (0.43) | (0.54)** | (0.68) | (0.46) | (0.49) | (0.62) | (0.78) | (0.54) | (0.59) | (0.84) | (0.57) | (1.03) | (0.67) |
| Livestock holding | 0.11 | 0.10 | −0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.01 | −0.01 | −0.03 | 0.00 | −0.02 | −0.01 | 0.00 | −0.01 |
| | (0.01)*** | (0.01)*** | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) | (0.01) | (0.02) | (0.01)*** | (0.01) | (0.02) | (0.01) | (0.02) | (0.01) |
| Distance to road | 0.12 | 0.02 | 0.01 | 0.01 | −0.01 | −0.01 | 0.00 | −0.04 | −0.02 | 0.04 | 0.00 | −0.02 | 0.01 | −0.03 | 0.06 |
| | (0.06)* | (0.03) | (0.02) | (0.03) | (0.03) | (0.03) | (0.03) | (0.04) | (0.04) | (0.03) | (0.02) | (0.05) | (0.03) | (0.06) | (0.03)** |
| Time period | 0.04 | −0.65 | 0.03 | 0.49 | −0.85 | 0.38 | −0.29 | −0.51 | −1.00 | 0.49 | −0.60 | −1.35 | 0.36 | −0.47 | 0.20 |
| | (0.27) | (0.34)* | (0.28) | (0.36) | (0.44)* | (0.29) | (0.32) | (0.40) | (0.52)* | (0.39) | (0.37) | (0.56)** | (0.37) | (0.61) | (0.42) |

(*Continued*)

**Table A2.** Continued.

| Variable | $I_1Z_0R_0A_0$ | $I_0Z_1R_0A_0$ | $I_0Z_0R_1A_0$ | $I_0Z_0R_0A_1$ | $I_1Z_1R_0A_0$ | $I_1Z_0R_1A_0$ | $I_1Z_0R_0A_1$ | $I_0Z_1R_1A_0$ | $I_0Z_1R_0A_1$ | $I_0Z_0R_1A_1$ | $I_1Z_1R_1A_0$ | $I_1Z_1R_0A_1$ | $I_1Z_0R_1A_1$ | $I_0Z_1R_1A_1$ | $I_1Z_1R_1A_1$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nonfarm_residual | 0.05 | 0.16 | 0.26 | 0.19 | −0.10 | 0.43 | −0.21 | 0.25 | −0.15 | 0.21 | 0.30 | 0.27 | −0.83 | −0.59 | 0.13 |
| | (0.20) | (0.18) | (0.19) | (0.24) | (0.24) | (0.30) | (0.33) | (0.37) | (0.38) | (0.27) | (0.30) | (0.32) | (0.39) | (0.43) | (0.47) |
| Credit_residual | −0.35 | −0.52 | −0.54 | −0.19 | −1.21 | −0.07 | −0.54 | −0.19 | −0.87 | 0.23 | −1.17 | −0.27 | −0.25 | 0.34 | −0.38 |
| | (0.27) | (0.25) | (0.26) | (0.31) | (0.40) | (0.34) | (0.42) | (0.42) | (0.54) | (0.29) | (0.49) | (0.41) | (0.44) | (0.52) | (0.60) |
| Contract_residual | 0.01 | 0.03 | 0.02 | −0.01 | 0.00 | 0.00 | −0.04 | −0.04 | −0.01 | −0.01 | 0.00 | 0.00 | 0.04 | 0.02 | 0.06 |
| | (0.02) | (0.01) | (0.02) | (0.02) | (0.03) | (0.03) | (0.04) | (0.04) | (0.04) | (0.02) | (0.03) | (0.03) | (0.02) | (0.03) | (0.02) |
| Joint significance of time varying covariates | 56.48*** | 28.76** | 41.02*** | 31.85** | 43.13*** | 33.63** | 27.32* | 25.07** | 54.17*** | 67.39*** | 36.30** | 54.45*** | 19.46* | 19.24* | 21.29** |
| Joint significance of country dummy variables | 24.10*** | 30.48*** | 20.12** | 18.98** | 19.67** | 38.20*** | 26.55*** | 14.03** | 24.96*** | 18.79** | 16.94** | 18.70** | 43.68*** | 23.57*** | 14.42* |
| Constant | −1.11 | 3.62 | −4.34 | −3.84 | 0.80 | −1.28 | −2.39 | −8.07 | −16.26 | −4.00 | −0.64 | −3.27 | −0.02 | −8.77 | −2.69 |
| | (1.88) | (2.38) | (2.03)** | (2.52) | (3.14) | (2.04) | (2.19) | (3.11)*** | (2.85) | (2.64) | (2.56) | (3.53) | (2.59) | (4.95)* | (2.72) |
| Number of observations | 4,736 | 4,736 | 4,736 | 4,736 | 4,736 | 4,736 | 4,736 | 4,736 | 4,736 | 4,736 | 4,736 | 4,736 | 4,736 | 4,736 | 4,736 |

Notes: For the above estimates, $I_0Z_0R_0A_0$ is the reference category.[a]The reference for rainfall conditions is drought. Standard errors in parentheses. *** $p < 0.01$, ** $p <$ ;0.05, * $p <$ ;0.1.