Joint Agricultural Input Adoption and Food Security in Tanzania

Srabashi Ray[1]

Job Market Paper[2]

December 20th, 2019

Most recent version available at http://srabashi.wixsize.com/aecon

Please do not circulate without the author's permission

Abstract

Since the late 2000s there has been a renewed focus on providing incentives for the joint adoption of hybrid seed and fertilizer to improve agricultural development and alleviate food insecurity in Sub-Saharan Africa. This study estimates treatment effects of joint input adoption on productivity, profitability and multi-dimensional indicators of food security using a nationally representative survey dataset. Rather than treating adoption as a single dichotomous choice, the methodology controls for potential self-selection behavior into multiple possible input combinations. The results of this study show that joint input use statistically significantly increases productivity by 83 percent and food security by 12 percent amongst adopters. However, positive impacts of input use is limited to farm households where adoption is profitable such as regions with favorable agro-ecological conditions and access to market, credit and extension services. The policy implication of this study highlights that agricultural policy focusing on the yield enhancing aspects of improved inputs is inadequate since adoption decisions are motivated by profit expectations. However, if adoption can be induced amongst non-users of inputs, it is likely to improve their productivity and food security status.

JEL-Classification: O12, O13, O15, O2, O55, Q12, Q18

Keywords: Microeconomic Development, Agricultural Policy, Farm Inputs, Food Security, Input Subsidy Packages, Farm Household, Tanzania.

[1] PhD Candidate, Department of Applied Economics, Oregon State University (OSU), Corvallis, USA. email: rays@oregonstate.edu

[2] I am grateful to my advisor John Antle for guidance and encouragement. Thanks to members of my committee Kassahun Melesse, Jeff Reimer, Steph Bernell and Stephanie Grutzmacher. I would also like to thank Lieven Claessens and the Africa RISING team at International Institute of Tropical Agriculture (IITA), Tanzania for their support. Comments and suggestion from participants at Sustainable Development Conference 2018, Northwest Development Workshop 2019, Agricultural & Applied Economics Association 2019 and brownbag seminars at the Department of Applied Economics, Oregon State University were helpful to improve this research. All remaining errors are mine.

1. Introduction

Food insecurity, one of the persistent problems of the 21st century, is most acute in Sub-Saharan Africa (SSA). More than 30 percent of the population in Eastern Africa is under-nourished, with even worse conditions among poor farm households (FAO et al. 2019). Food and nutrition insecurity have been directly linked to low rates of agricultural productivity since the majority of food insecure households live in rural areas, and rely on agriculture for food and livelihoods (Carletto et al. 2015).

Hybrid seeds and fertilizer have played an essential role in agricultural development across the world. 50 percent of the productivity gains in Asia during the Green Revolution is attributed to inorganic fertilizer use (Tomich, Kilby, Johnston 1995; Hopper 1993). A suite of other technological improvements such as irrigation and mechanization further contributed to the success (Goldman and Smith 1995). The adoption of fertilizer and other inputs in SSA has been limited by a number of factors that constrain profitability, including low investments in infrastructure, adverse policies, and vulnerability to weather stresses (Sheahan and Barrett 2017; Foster and Rosenzweig 2010; Jayne, Mather, and Mghenyi 2010). Further, intensive cereal cultivation without adequate soil nutrient replenishment has contributed to an ongoing decline in soil quality across SSA (Breman and Debrah 2003). A combination of hybrid crop varieties adapted to local conditions and complementary inputs, particularly fertilizer, could improve resilience to weather shocks and raise agricultural productivity (Druilhe and Barreiro-Hurlé 2012). This has been widely acknowledged and implemented as 'smart' Input Subsidy Packages (ISPs) that subsidize both hybrid seeds and fertilizer (Morris et al. 2007). Input use can also improve food security on account of the greater availability of home-grown food and potentially higher income that can support more food purchases and non-food expenditure. Women's control over income and productive assets further contribute to better food security outcomes (World Bank 2007).

[Table 1]

There is a rich literature on the adoption and impact evaluation of agricultural technologies (Foster and Rosenzweig 2010; Sunding and Zilberman 2001; Feder, Just, and Zilberman 1985). In particular, studies on hybrid seeds have shown positive impact on productivity, food consumption and poverty (Kassie et al. 2018; Mathenge, Smale, and Olwande 2014; Shiferaw et al. 2014; Duflo, Kremer, and Robinson 2011). Jayne and Rashid (2013) present a review of the relatively low yield response of maize to nitrogen fertilizer in East Africa[3]. Several authors have discussed that input decisions are inter-related and maybe made either simultaneously or sequentially (Smale and Heisey 1993; Antle 1983; Pitt 1983). In case of hybrid seed and fertilizer adoption this is particularly relevant. Higher yield potential from hybrid seeds is realized when supplemented with an external nutrient source such as chemical fertilizer (Vanlauwe et al. 2011; Kaliba et. al. 2000). In Tanzania, between 2010-11 and 2012-13, farms growing hybrid maize with fertilizer had 94 percent higher maize yield compared to when neither input was used. In contract, farms using either hybrid seed or fertilizer had only a 15 and 62 percent higher yield respectively (Table 1). Given the low productivity of the maize-based production system in Tanzania, where crops are vulnerable to heat stress, drought and pests, it is reasonable that farmers' input choices are interdependent and staggered during the cropping cycle. While the hybrid seed use or non-use decision must be made before planting, fertilizer adoption, intensity of use and related farm management decisions can be made during the growing season. Between 2010-11 and 2012-13, on average the unconditional probability of hybrid seed adoption was 27 percent which increased to 34 percent when conditioned on fertilizer use. Similarly, the unconditional probability of fertilizer use was 19 percent which increased to 24 percent conditional on hybrid seed use (Table 2).

[Table 2]

[3] This review includes the Kilimanjaro region of Tanzania where marginal product of nitrogen fertilizer for maize is estimated at 11.7 kg.

The purpose of this paper is to model joint adoption of agricultural inputs instead of a single dichotomous choice. Adoption of inputs in this study refers to the use of different input combinations by micro level farm households that choose the profit maximizing combination of inputs based on their profit expectations in each growing season. Using an Agricultural Household Model (AHM) and nationally representative survey data from Tanzania, this study estimates treatment effects of joint input use on productivity, profitability and multi-dimensional indicators of food security.

This paper makes the following contributions to the literature. First, the model developed here allows for simultaneous adoption decisions for hybrid seed (H) and nitrogen fertilizer[4] (F) amongst maize producers. It is based on an Endogenous Switching Regression (ESR) model used in recent impact evaluation literature (Teklewold et al. 2013; Kassie et al. 2013; Asfaw et al. 2012). The ESR also models the self-selection behavior by farmers into different input regimes. Using this framework, it compares the heterogenous treatment effects of single input use i.e. only hybrid use (H0) or only fertilizer use (0F), with joint adoption (HF).

Second, this study estimates the impact of agricultural inputs on productivity, profitability and multi-dimensional indicators of food security. While hybrid seed and fertilizer are yield-enhancing inputs, they also increase the cost of production. Treatment effects on both productivity and profitability provide insight into the economic factors influencing input adopt decisions**.** Due to its complexity, food security is best evaluated with a combination of indicators that richer datasets are now making available (FAO 2002). Evaluation studies of food security have disproportionately focused on food production and expenditure, which are measures of 'availability' and 'access' but do not capture aspects of diet quality and psychological stresses of imminent food shortages (Ruel, Quisumbing, and Balagamwala 2018). In this study, food security is measured in terms of three

[4] Urea is the primary source of nitrogen fertilizer amongst maize producers in Tanzania. Less than 5 percent of farms in the sample use other sources of fertilizer.

indicators i.e. food expenditure per capita (FEXP); Household Diet Diversity Scale (HDDS); and Food Insecurity Experience Scale (FIES).

Third, using a nationally representative survey dataset, this study evaluates the underlying framework of ISPs across agro-ecological zones, socio-economic and geographic characteristics of a household. There is an ongoing debate about whether large scale input subsidies or investments in infrastructure, research and extension are the most efficient means to generate sustainable agricultural development in SSA (Jayne and Rashid 2013; Baltzer and Hansen 2011). A recent World Bank report argues that input subsidies are regressive in nature and their impact on productivity and poverty is limited without complementary public investments in agriculture (Beegle and Christiaensen 2019). The results of this study show that the effect of joint adoption (i.e. the Average Treatment Effect on Treated, ATT) varies by agro-ecological zones (AEZs) with heat and water stress limiting the productivity and profitability of adoption. Also, profitability is lower for farms located further away from a market with limited access to credit. In terms of food security, joint input adoption has a positive impact on all three indicators but a lower magnitude of impact on diet diversity (HDDS) and food insecurity experience (FIES).

The next section briefly describes the theoretical and empirical frameworks of this paper. The third section discusses the data and its limitations. The fourth section presents empirical results and extensions. To conclude, the key policy implications are discussed.

2. Theoretical and Empirical Framework

The theoretical framework is based on an Agricultural Household Model (AHM) (Singh, Squire, and Strauss 1986). If separability holds, production decisions are based on expected profit (Π_j) maximization from input regime *j*. Since hybrid seed (H) and fertilizer (F) are non-essential inputs, farms make the extensive margin choice of the combination of inputs to adopt as well as the intensive margin decisions for the amount of input to be used. These decisions are staggered over the cropping cycle based on expectations of future profit. The input regime *j* with highest expected profit is adopted (Equation 1). Given two non-essential input choices, there are four potential input regimes (Equation 2). In regime 1, neither inputs are used. In regimes 2 and 3 either hybrid seed or fertilizer is used respectively. In regime 4, both hybrid seed and fertilizer are used.

(1) $j\colon \Pi_j > \max_{\mathrm{m} \neq \mathrm{j}} \Pi_m$

(2) $j = \begin{cases} 1 \; if \; H = 0, F = 0 \\ 2 \; if \; H = 1, F = 0 \\ 3 \; if \; H = 0, F = 1 \\ 4 \; if \; H = 0, F = 1 \end{cases}$

Sheahan, Black, and Jayne (2013) and Suri (2011) highlight the statistical challenges of modelling simultaneous input use. A farm household self-selects into one of the input regimes based on its expectations of future prices, weather conditions and their own managerial skills. For example, given expectations of unfavorable weather and risk aversion a farm might self-select into a combination of traditional seed and fertilizer use. The summary statistics disaggregated by input regimes show the observed heterogeneity amongst households selecting into different input regimes (Table 3). Several studies have used Endogenous Switching Regression (ESR) to control for self-selection behavior (Kassie et al. 2018; Khonje et al. 2015; Teklewold et al. 2013; Di Falco, Veronesi, and Yesuf 2011).

[Table 3]

The ESR models selection behavior by assuming a linear relationship between the error terms of the selection and outcome equations (Dubin and McFadden 1984; Bourguignon, Fournier, and Gurgand 2007). It adopts a two-stage approach. First, the selection decision is modelled in a random utility framework. Farm household selects regime *j* by maximizing the difference in expected profit from any other regime $m \neq j$ i.e. $\max_{m \neq j}\left(\Pi_j - \Pi_m\right) > 0$ or $\Pi_j^* < 0$, such that

(3) $\Pi_j^* = \max_{m \neq j}(\Pi_m - \Pi_j)$

Π_j^* is defined by a linear combination of observed input and output prices, farm and household characteristics $(\boldsymbol{z})$ and unobserved factors (η_j). The farm and household characteristics include factors that may impact the adoption decision such as plot quality and size, geographical location in terms of AEZs, distance to market and weather conditions, access to services such as extension and credit, and household characteristics such as livestock ownership, access to non-farm income and demographics of the household head.

(4) $\Pi_j^* = \boldsymbol{z}'\boldsymbol{\gamma_j} + \eta_j, j = 1, \dots 4$

Assuming η_j are independent and identically distributed (IIA), adoption of input regime *j* is estimated with a multinomial logit model where P_j is the probability that *j*-th input combination is chosen.

(5) $P_j = P(\Pi_j^* < 0|\boldsymbol{z}) = \frac{\exp(\boldsymbol{z}'\boldsymbol{\gamma_j})}{\sum_{j=1}^{4} \exp(\boldsymbol{z}'\boldsymbol{\gamma_j})}$

The input choices for maize production directly determines maize yield (kg/ha) and net revenue from maize production ($/ha) (Equation 6). Consumption decisions of the household are derived by maximizing utility subject to total household farm and non-farm income. Status of household food security (measured with three indicators discussed later in this section) is primarily dependent on food consumption determined by total income and other household characteristics including housing quality, access to clean drinking water and general health status of family members. Given the high incidence of subsistence agriculture and direct and indirect impact of farm productivity on food security, it is modelled with a reduced form specification (Equation 7). This also allows us to differentiate between potentially heterogenous impact of different combinations of input use. A structural approach in this context would require complex assumptions regarding the share of food crops consumed at home or sold in the market as well as the hypothesized relationship between farm production and indicators of diet quality and subjective measures of food security.

The outcome equations for production (Q_j) and food security (FS_j), are defined as a linear combination of input choices (hybrid seed and fertilizer), other observed explanatory variables ($\boldsymbol{x}$ and $\boldsymbol{y}$) and unobserved factors ($\widetilde{u_J}$ and $\widetilde{v_J}$) in Equations 6 and 7 respectively. The explanatory variables $(\boldsymbol{x})$ for the production outcomes include other inputs such as labor and livestock as well as the plot and household characteristics included in $(\boldsymbol{z})$. The explanatory variables for the food security outcomes $(\boldsymbol{y})$ include additional variables that are likely to impact food security status such as whether the household faced a 'shock' during the survey period, prevalence of food assistance programs, indices of food prices and quality of housing.

(6) $Q_j = \widetilde{\beta_{0J}} + \widetilde{\beta_{1J}} H_j + \widetilde{\beta_{2J}} F_j^d + \boldsymbol{x}'\widetilde{\boldsymbol{\beta_J}} + \widetilde{u_J},\ if\ \Pi_j^* < 0, j = 1, \dots 4$

(7) $FS_j = \widetilde{\alpha_{0J}} + \widetilde{\alpha_{1J}} H_j + \widetilde{\alpha_{2J}} F_j + \boldsymbol{y}'\widetilde{\boldsymbol{\alpha_J}} + \widetilde{v_J}, if\ \Pi_j^* < 0, j = 1, \dots, 4$

where

$H = 1$ if hybrid seed is used,

$F = 1$ if nitrogen fertilizer is used, and

$F^d > 0\ if\ F = 1, F^d$ is rate of nitrogen fertilizer used.

The outcome variables in Equations 6 and 7 are observed if and only if the relevant condition on Π_j^* is satisfied. Farmers' self-selection behavior leads to potential correlation between the error terms of the outcome equation and selection equation leading to biased OLS parameter estimates.

In the second stage of the ESR (Equations 8 and 9), the outcome equations are adjusted with a correction term (λ_{jm}) to control for the selection behavior using a linearity condition and an additive constraint on the correlation terms[5] (Equations 10 & 11).

(8) $Q_j = \beta_{0j} + \beta_{1j}H_j + \beta_{2j}F_j^d + \boldsymbol{x'\beta_j} + \sum_{m\neq j} \delta_{jm}^{Q}\lambda_{jm} + u_j \ \forall j$

$= \boldsymbol{X'_j\beta_j} + \boldsymbol{\lambda'_j\delta_j^Q} + u_j$

(9) $FS_j = \alpha_{0j} + \alpha_{1j}H_j + \alpha_{2j}F_j + \boldsymbol{y'\alpha_j} + \sum_{m\neq j} \delta_{jm}^{FS}\lambda_{jm} + v_j \ \forall j$

$= \boldsymbol{Y'_j\alpha_j} + \boldsymbol{\lambda'_j\delta_j^{FS}} + v_j$

where $\lambda_{jm} = \frac{\widehat{P_m}\ln(\widehat{P_m})}{1-\widehat{P_m}} + ln(\widehat{P_j}), E(u_j) = 0, E(v_j) = 0$

(10a)$E(u_j|\eta_1, \dots \eta_4) = \sigma_j \frac{\sqrt{6}}{\pi}\sum_{j=1}^{4} r_{jm}\left(\eta_j - E(\eta_j)\right) \ \forall j$

where $\sigma_j^2 = V(u_j|\boldsymbol{x},\boldsymbol{z}), r_{jm} = corr(u_m, \eta_j)$

(10b)$E(v_j|\eta_1, \dots \eta_4) = \omega_j \frac{\sqrt{6}}{\pi}\sum_{j=1}^{4} \rho_{jm}\left(\eta_j - E(\eta_j)\right) \ \forall j$

where$\omega_j^2 = V(v_j|\boldsymbol{x},\boldsymbol{z}), \rho_{jm} = corr(v_m, \eta_j)$

(11a) $\sum_{m=1}^{4} r_{jm} = 0$

11b) $\sum_{m=1}^{4} \rho_{jm} = 0$

Equations 8 and 9 are estimated with OLS and bootstrapped standard errors since λ_{jm} is defined over predictions from the first stage. Joint significance of the λ_{jm} terms is a test for the statistical significance of non-random selection. Identification of Equations 8 and 9 are based on the non-linearity of the adjustment term as well as the exclusion criterion that some variables included in **z** are omitted from **x** and **y** (Di Falco, Veronesi, and Yesuf 2011). A valid instrument should be

[5] The model was estimated with alternative specifications discussed in Bourguignon, Fournier, and Gurgand (2007). The results are robust.

statistically significant in the selection equation and insignificant in the outcome equation. The specific exclusion criterion for each outcome equations are discussed in Section 4. The specification of Equation 8 shows that while fertilizer intensity is modelled in the production function, hybrid seed use is included as a binary choice. For food security estimation, both inputs are introduced as binary treatments since a marginal change in fertilizer application is unlikely to substantially change the food security status of a household.

The ESR model parameters are used to calculate Average Treatment Effects on Treated (ATT) and Average Treatment Effect on Untreated (ATU). The former adjusts ATE for the selection behavior and estimate true treatment effects. ATU is used to evaluate the expected outcome for farms that did not use hybrid seed and fertilizer if they had chosen to adopt. The ATT of using only hybrid seed, only fertilizer or both relative to the counterfactual of neither input use is estimated as follows:

(12) $ATT_j^Q = E(Q_j|J = j) - E(Q_1|J = j), j = 2, 3 \; or \; 4$

$$= \boldsymbol{X'}_j[\widehat{\boldsymbol{\beta}_J} - \widehat{\boldsymbol{\beta}_1}] + \boldsymbol{\lambda}_j'\left[\widehat{\boldsymbol{\delta}_J^Q} - \widehat{\boldsymbol{\delta}_1^Q}\right], j = 2, 3 \; or \; 4$$

The first term captures the difference in mean outcome based on observed characteristics. The second term adjusts for the selection on unobservables. Similarly, ATU in terms of production outcomes for farms selecting into no input use if they adopted any of the three potential input combinations is calculated as follows:

(13) $ATU_j^Q = E(Q_j|J = 1) - E(Q_1|J = 1), j = 2, 3 \; or \; 4$

$$= \boldsymbol{X}_1'[\widehat{\boldsymbol{\beta}_J} - \widehat{\boldsymbol{\beta}_1}] + \boldsymbol{\lambda}_1'\left[\widehat{\boldsymbol{\delta}_J^Q} - \widehat{\boldsymbol{\delta}_1^Q}\right], j = 2, 3 \; or \; 4$$

ATT and ATU for food security outcomes are calculated as follows:

(14) $ATT_j^{FS} = \boldsymbol{Y}_j'[\widehat{\boldsymbol{\alpha}_J} - \widehat{\boldsymbol{\alpha}_1}] + \boldsymbol{\lambda}_j'\left[\widehat{\boldsymbol{\delta}_J^{FS}} - \widehat{\boldsymbol{\delta}_1^{FS}}\right], j = 2, 3 \; or \; 4$

(15) $ATU_j^{FS} = \boldsymbol{Y}_1'[\widehat{\boldsymbol{\alpha}_J} - \widehat{\boldsymbol{\alpha}_1}] + \boldsymbol{\lambda}_1'\left[\widehat{\boldsymbol{\delta}_J^{FS}} - \widehat{\boldsymbol{\delta}_1^{FS}}\right], j = 2, 3 \; or \; 4$

In the presence of non-random selection, ATT is unequal to ATE estimates from Equations 6 and 7. Comparison of ATT and ATE let us make richer observations about the nature of selection bias. If ATE>ATT, there is a positive selection bias. Farms that select into treatment would have had higher productivity, profitability or food security if they did not adopt, relative to the non-adopters. If ATE<ATT, there is negative selection bias, implying farms that select into treatment would have lower outcomes if they did not adopt, relative to the non-adopters. If systematic selection is rejected i.e. the differences between adopters and non-adopters is random, then ATT=ATE and pooled OLS estimation of the outcome equations is unbiased (Angrist and Pischke 2009).

2.1 Separability of Production and Consumption Decisions

Separability of production and consumption decisions implies that production choices depend only on input and output prices and technology. Production choices under separability are independent of household endowments and preferences, since the decisions are based on profit maximizing behavior facilitated by functional markets. Consumption decisions are affected by household preferences, subject to the budget constraint determined by production choices. Bardhan and Udry (1999) show that separability is violated when at least two markets fail. Failure of markets such as absence of buyers and sellers of inputs should be distinguished from weak markets as a result of transactions costs are high. In case of SSA, rural markets for inputs and outputs, labor and credit certainly exist but are likely to be weak due to poor rural infrastructure (Foster and Briceno-Garmendia 2010).

A widely accepted test is the joint significance test of household endowment variables in input demand functions under the null hypothesis of separability (Benjamin 1992). A recent study by Dillon and Barrett (2017) uses this test for labor demand and finds evidence against separability in five African countries including Tanzania. Further research is necessary to identify the market imperfections leading to this result. Modelling the different potential sources of separability is beyond the scope of this study. However, the methodology adopted in this study controls for farm household characteristics in production analysis to allow for a variety of sources of non-separability. Benjamin's (1992) test is used post estimation on the selection equation and production outcomes to check for separability.

2.2 Indicators of Food Security

Studies have shown a positive impact of improved agricultural practices on food security due to an increase in agricultural productivity or food expenditure (Shiferaw et al. 2014; Bezu et al. 2014; Asfaw et al. 2012). As noted in the introduction, these outcomes do not capture other important aspects of food security such as diet quality and experiential aspects of food insecurity. Diverse diets comprised of multiple food groups such as fruits, vegetables and animal products as well as staple foods. This leads to better nutritional outcomes and can provide a more balanced diet of macro and micro nutrients which contributes to better nutrient absorption (Swindale and Bilinksy 2006). The Household Diet Diversity Scale (HDDS) is an indicator for the diversity of a household's diet. It is a count of the number food groups[6] that were consumed during the survey period.

Manifestations of food insecurity is not only a matter of low calorie and nutrient intake. Uncertainty about future food availability causes psychological stress and anxiety. Households also use a variety of coping strategies in case of impending food shortages by consuming poor quality of food or relying on social networks during periods on acute food shortages. The Food Insecurity Experience Scale (FIES) is based on a list of yes-no questions that capture moderate food insecurity (psychological stress about the next meal, reduced quality of meals and lack of preferred diet) to severe food insecurity (reduced food consumption in terms of smaller meals, reduced meals or skipped meals)

[6] 12 food groups are used in the HDDS – cereals, starches, pulses and nuts, vegetables, fruits, meat, eggs, fish, milk and milk products, fat, sugar, spices and beverages.

(Ballard, Kepple, and Cafiero 2013). In this study I use HDDS, FIES and food expenditure (FEXP) to evaluate the impact on multi-dimensional aspects of food security.

The distribution of FIES in this dataset is highly skewed since 63 percent of the sample is reported to be food secure according to the FIES. This study uses a binary variable (DFIES) based on the FIES to distinguish between food secure and insecure households. The FIES survey module records information on moderate to severe food insecurity by asking whether a household was vulnerable to imminent food shortages, adopted coping strategies such as consumption of cheaper or poorer quality diet, reduction in meal frequencies and incidence of hunger. The FIES is a count variable for the number of times a household answers 'yes' to any of the 8 questions in the FIES module[7]. Thus, a food security households on the FIES has a score 0 (Ballard, Kepple, and Cafiero 2013). In this study, DFIES is defined as a binary variable that takes the value 0 for food security households and 1 for food insecure households that responded 'yes' to any of the questions in the FIES module. An increase in the DFIES is interpreted as an increase in the probability of food insecurity.

(12) $$DFIES = \begin{cases} 0 \; if \; FIES = 0 \\ 1 \; if \quad FIES > 0 \end{cases}$$

3. Data

This study is based on the Living Standards Measurement Survey (LSMS) from Tanzania which has four rounds of data 2008-09, 2010-11, 2012-13 and 2014-15. The first three are panel rounds and the fourth a refresher round which does not track the same households as the previous three rounds. Due to limitations of available data, this study uses the 2010-11 and 2012-13 rounds.

[7] The FIES module in the LSMS survey closely resembles the list of questions piloted by the Voices of the Hungry (VOH) project (Ballard, Kepple, and Cafiero 2013).

The LSMS dataset collets household data with several modules including the household and agricultural module. It collects information on household characteristics and demographics, plot level data on soil quality, crop choices, input use, expenditure on inputs, revenue from sales as well as average rainfall and temperature. The household module also collects aggregate expenditure on food, disaggregated into 58 food items, with a 7-day recall period which is extrapolated to annual per capita expenditure in this study. Dummy variables for the quarter when the survey was conducted is used to control for potential temporal variations due to this extrapolation.

In datasets with repeated household observations, panel methods are preferred to pooled cross-sectional methods since fixed effects control for farm and household level unobservable factors that may explain production and consumption decisions. However, substantial within-variation is necessary for robust application of panel methods. Bell and Jones (2015) have shown that fixed effects estimation may be unsuitable where time-invariant variables (such as agro-ecological zones) have a causal impact on time varying variables (farm level productivity and food security). They also argue that fixed effects estimation based on within unit variation limits the generalizability of results in terms of between effects for the entire sample. In the presence of heterogenous treatment effects, panel methods can be biased because it upweights groups with higher variance in treatment and underweights groups with lower variance in treatment conditional upon other covariates (Gibbons, Serrato, and Urbancic 2014).

In this study given the limitation of just two rounds of data, application of panel methods is limited since it absorbs much of the variation in the variables of interest. The explanatory variables of interest in this study are the extensive and intensive margin decision of hybrid seed and fertilizer adoption. Only 23 percent of the sample switches between hybrid user and non-user between the two panels. For fertilizer adopters, the rate is even lower at 7 percent. This implies that under fixed effects, large proportion of the sample would not contribute to the estimation of the parameters for hybrid seed and fertilizer use. Further, after time demeaning the data substantial variation is lost for the input intensity variable. Fixed effects transformation on fertilizer intensity rates leads to concentration of 80 percent of sample of fertilizer users close to 0. Therefore, introducing fixed effects at the farm or household level severely reduces the statistical power of the model.

Given the nature of the study the source of variation is largely due to between-panel variation. Input use exposes farms to risks since return on their investment is contingent on favorable weather and management practices that require experience (Kassie et al. 2015). In the context of Tanzania, with low rates of adoption limiting experience with input use, high levels of rural poverty and subsistence agriculture, few farming households are likely to substantially alter their extensive and intensive margin decisions in terms of input use. Rather, these decisions are likely to vary across farms due to heterogeneity in plot quality, AEZs, access to inputs and extension service as well as management skills and experience gained over a relatively longer period of time. Similarly, substantial variation in food security indicators is also unlikely for each household between the two panel rounds. Household level fixed effects eliminates these inter household variation, and increases the probability of highly imprecise parameter estimates. Finally, fixed effects transformation also does not address the problem of time variant unobservables such as weather expectations which is a likely factor driving input decisions every cropping cycle.

In this study, given the limited variation between two panel rounds, the potential correlation between unobservable household variables both fixed and time variant is modelled with the ESR, to use the full statistical power available in the data. The ESR approach, uses equation specific estimation while explicitly modelling potential selection on unobservables both time variant and invariant in nature. It also includes AEZ, time and region level dummies to control for temporal and broad regional fixed effects. The results of econometric estimation are validated by comparing the predicted and observed distributions.

4. Empirical Results

4.1 Summary Statistics

Table 1 shows the summary statistics for the outcome variables of this study. All input combinations are associated with statistically significant improvement in maize productivity, especially when both inputs are used jointly. Maize yield is 94 percent higher at 1301kg/ha under joint adoption when both hybrid seed and fertilizer are used. In comparison, yield is 769 kg/ha and 1086 kg/ha when only hybrid seed or fertilizer is used. Farms using both inputs show 32 percent higher net revenue when neither input is used, compared to 11 percent higher only hybrid seed is used and 15 percent lower when only fertilizer is used. Food security indicators show statistically significantly higher food security status amongst farm households using both inputs relative to all other households. Annual food expenditure in farm households that adopt both hybrid seed and fertilizer is $416 per capita, about 48 percent higher where neither input is used. Diet diversity is higher by 1.4 food groups and the probability of food insecurity is 25 percent lower relative to households using no inputs. Individual input use is also associated with significantly higher food security status relative to neither input use but with a lower magnitude than joint adopters. Food expenditure per capita is about 48 percent higher when both inputs are used compared to 19-24 percent when only fertilizer or hybrid seed is used. Difference on food security status according to the FIES is statistically insignificant amongst no input users and only hybrid seed users. However, only fertilizer users are associated with a 17 percent lower probability of food insecurity respectively according to the FIES.

Table 3 shows the summary statistics of the covariates across different input regimes in production analysis. 40 percent of the sample use hybrid seed or fertilizer with 7 percent adopting both. Farms that use hybrid seed or fertilizer are more likely to hire labor, have greater access to non-farm income, extension, market and credit services and are more likely to own livestock. They are also more likely to be located in cooler AEZs with higher elevation with lower temperatures. Hybrid seed is more likely to be adopted in plots with better soil quality. Farms facing nutrient constraints are more likely to use fertilizer to complement poor soil quality, and households using hybrid seed with or without fertilizer are less likely to have nutrient constrained plots. Maize farms that use hybrid seed report a higher average price for their output, whereas fertilizer users report a marginally lower output price. Farms using fertilizer report lower urea price, while hybrid seed users report higher price for the input relative to non-users. This might be a result of hybrid seed users being concentrated in regions with higher input prices[8]. The summary statistics on household demographics show that younger, more educated, male household heads are more likely to adopt hybrid seed and fertilizer. The systematic differences in observed variables between input users and non-users suggest that farms self-select into input use may have systematic differences in terms of variables unobserved to the researcher.

4.2 Input Regime Selection

The relative risk ratios (RRR) of the selection equation (Equation 5) estimated with multinomial logit regression show (Table 4) the change in the relative probability of adopting input regimes 2, 3 or 4 (combination of hybrid seed and fertilizer) relative to regime 1 (no input use). Higher output price significantly increases the probability of only hybrid seed use and higher price of urea reduces the probability of fertilizer use with or without hybrid seed. Hybrid seed price has the expected sign but is statistically insignificant. Increases in distance to the nearest market, which implies higher travel cost to procure inputs and sell outputs, significantly reduces the probability of any input adoption and has a stronger negative impact on the probability of joint adoption. Access to extension services and credit from commercial institutions or membership of local savings groups increases the probability of input

[8] Input and output prices are calculated based on unit value responses by input users and farms that market their output. Farm households that do not report unit values are assigned the average regional price at the lowest available administrative level.

use particularly for fertilizer. Farm households with more diversified source of income are more likely to adopt hybrid seed. This shows that while input prices, particularly fertilizer have the expected impact on input use decisions, additional factors such as distance to market and credit services that affect implicit cost of adoption also impact the choice of inputs.

[Table 4]

Table 4 also shows a strong regional pattern in input use. AEZs with lower temperatures and lower likelihood of heat stress have a significantly higher probability of hybrid use. Table 3 shows that 66 percent of farms that use only fertilizer are located in the North and Central regions. After controlling for other factors, this is reflected in the high RRR estimate for the North and Central region dummy for input regime 3. The Southern Highlands region (base region category), has a higher concentration of fertilizer use relative to Eastern, Southern, Western and Lake regions. However, hybrid use in the Eastern and Southern regions and joint adoption in Northern and Central regions is comparable to the Southern Highlands.

The RRR for demographic variables reflect the observations from the summary statistics with lower education (base category is highest level of education) reducing the probability of input use. Female headed households are statistically significantly less likely to use hybrid seeds. Larger farm households increase the probability of hybrid seed use and it reduces the probability of fertilizer and joint hybrid and fertilizer use.

4.3 Test for Separability and Validity of Exclusion Criteria

Benjamin's (1993) test for separability is used to test the joint significance of household characteristics post estimation of the input selection, production and net revenue equations (Table A6). If separability holds, household characteristics such as family size, age and sex of the household head should be insignificant. The joint significance test finds that these characteristics does statistically significantly determine input choices and explain production and net revenue for at least some of the input regimes. Therefore, the separability assumption does not hold in this context. This finding is consistent with Dillon and Barrett (2017) who show similar evidence in several East African countries including Tanzania.

In addition to the non-linearity of the selection adjustment terms in Equation 8 and 9, an exclusion criterion is required for better identification of the ESR model. This study uses three different specifications of the exclusion criterion for the three outcome variables – production function, profit function and food security. In case of the production function, the excluded variables impact the input use decision but does not have a significant impact on productivity directly. This study follows Kassie et al. (2015) and Di Falco, Veronesi, and Yesuf (2011) who use distance to nearest market and access to credit as excluded variables. In addition, farm size is also excluded since it is a proxy for the economic status of a household which is likely to impact profitability via adoption decisions for inputs.

Excluded variables in the production function estimation such as distance to market and prices of inputs are important explanatory variable in the profit function estimation. In case of the profit function, the exclusion criterion focuses on variables that impact profitability arguably only through the adoption decisions i.e. access to extension services and weather variables. Farms with access to extension agents are likely to adopt inputs and may be better trained in their use. However, the impact on profitability is not direct. Similarly, weather variables such as amount of rainfall and temperatures impact adoption and productivity but not profitability directly. In case of the food security equations, the exclusion criterion includes the prices of hybrid seed, urea and maize. Validation tests for the three exclusion criteria is based on the joint significance in the selection equation and joint insignificance in the outcome equations (Tables A7, A8 and A9).

4.4 Treatment Effects of Input use on Production, Profitability and Food Security

The equation-wise OLS and ESR results for maize productivity, net profit and food security indicators are reported in the Appendix. A joint significance test of the adjustment terms (λ_{jm} in Equations 8 and 9) controlling for selection behavior of farms into input use decisions show that the selection behavior is statistically significant in at least one of the input regimes. Comparison of ATT and ATE shows positive selection bias (ATE>ATT) into joint adoption in terms of yield (Table 5) and net revenue (Table 6), relative to farms that use neither input. This implies that more productive and profitable farms systematically select into joint input use. ATE estimates show that use of both inputs increases maize yield by 767 kg/ha (112 percent) compared to no input use. However, in the presence of positive self-selection, ATE overestimates treatment effects. After adjusting for selection behavior, ATT of joint input adoption on yield is 559 kg/ha (83 percent). The ATT for only hybrid seed or fertilizer use is relatively lower at 139 – 340 kg/ha respectively (20 – 41 percent). Disaggregated in terms of AEZs, ATT for joint input use is statistically insignificant in arid regions facing water stress relative to farms using either input. This result should be considered indicative since it is based on a small sample of farms using both inputs in arid AEZs.

[Table 5]

The ATT estimates in Table 5 show that joint input use can significantly increase maize productivity by 114 kg/ha to 664 kg/ha. However, joint adoption rates are observed to be as low as 6.4 percent. This can be better understood from the treatment effects of joint input use on net revenue. Individual use of hybrid seeds has an insignificant impact on net revenue. Farms using only fertilizer shows a 15 percent negative impact on net revenue. ATT of joint input use on net revenue is \$19/ha (17 percent) and statistically significant (Table 6). This shows that amongst farms that use both inputs the 83 percent increase in yield benefits translates to a 17 percent increase in net profits. Disaggregated into AEZs, the results show that the net revenue benefits of joint input use is statistically significant only in humid regions with cooler temperatures. The negative ATT of only fertilizer use is further aggravated in regions facing heat and water stress. This shows that the yield benefit of fertilizer use in arid and warm regions does not compensate for the cost of fertilizer use. Amongst farms that don't use any inputs, Average Treatment Effect on Untreated (ATU) for joint input use is statistically significantly negative across all AEZs. Switching to individual use of hybrid seed or fertilizer is also shown to be largely unprofitable.

[Table 6]

Table 7 provides further insight into factors that may contribute to low profitability of joint input use. It disaggregates ATT on net revenue by farms' distance to the nearest market, access to credit and the selling price of maize received by farmers. A farm is considered to be located 'near' a market if it is less than the median distance away from the nearest market. Farmers who are members of credit or savings groups have access to credit. A farm selling their maize at more than the median price is described as receiving a 'higher' maize price. Table 7 shows that in most cases ATT for net revenue is positive and significant for farms with access to credit and located nearer to a market which facilitates higher price for their produce.

[Table 7]

The impact of input use on food security shows that joint hybrid seed and fertilizer use increases food expenditure by $41 per capita (12 percent), diet diversity by 0.69 units and probability of food insecurity by 4 percentage points (Table 8). This shows that in the context of subsistence systems, a cereal specific intervention has a substantial impact on the value of food consumed but a low magnitude of impact on other indicators of food security. ATU in terms of food security indicators show that non-adopters of inputs would achieve higher food security in terms of all three indicators if they chose to adopt both inputs. However, previous discussion shows that adoption of joint inputs is limited by low profitability under adoption.

[Table 8]

Table 9 and 10 show treatment effects of joint input use on food security disaggregated by male and female headed households. Amongst female headed households the ATT of individual input use shows negative impact on food expenditure and male headed households show positive impact on food expenditure when only hybrid seed is used. Under joint adoption, the results show highly positive and statistically significant impact on food expenditure in female headed household compared to male headed households. A similar trend is observed in case of DFIES where joint input use leads to a 12 per cent reduction in the probability of food insecurity amongst female headed households and statistically insignificant in case of male headed households. This is reversed in case of diet diversity where male headed households have a higher ATT of joint adoption at 0.71 compared to 0.6 amongst female headed households. These results should be interpreted carefully since they are based on a small sample of female headed households who use both inputs.

[Table 9]

[Table 10]

4.5 Limitation & Extension

This study models the direct impact of agricultural input use on farm household outcomes. Increase in maize productivity on a regional scale can dampen income increases or lead to a fall in agricultural income, particularly for households without access to diversified income sources. On the other hand, improvements in overall agricultural productivity may reduce real food prices, and counter the reduction in real income (World Bank 2007). Evidence suggests that the impact of input adoption on food prices has been weak (Jayne and Rashid 2013). However, potential local level impacts cannot be rejected. Further analysis is necessary to evaluate the robustness of these results allowing of price changes in response to increased productivity.

This study is based on input adoption behavior of risk neutral farm households. Input use decisions by resource poor farmer are based on their profit expectations. Agricultural inputs such as fertilizer has been shown to be risk increasing (Antle 2010). Incorporating risk aversion in input choices can further explain non-adoption of inputs.

The food security analysis in this study is based on household level food security due to inadequate disaggregation in the data into individual household members. Due to potential differences in intra-household food allocation in terms of quantity and quality, household food security indicators might not be accurate measures of individual food security status.

5. Discussion & Conclusion

This study is an impact evaluation of improved agricultural inputs on productivity, profitability and food security measured in terms of per capita household food expenditure, diet diversity and experience-based measure of food insecurity. It models the selection behavior of input use with nationally representative survey data from Tanzania and estimates treatment effects for joint input use relative to non-use or individual use of hybrid seed and nitrogen fertilizer. It provides evidence in favor of positive selection behavior into joint adoption.

Kathage et al. (2016) have argued that the non-adoption of hybrid seeds in Tanzania needs to be explained by reasons other than lack of awareness or credit constraints. This study shows that low profitability of joint input use can explain non-adoption in many cases. While the ATT in terms of yield is positive and substantial in all AEZs except arid regions, the ATT in terms of net revenue is significant in humid AEZs with lower temperatures. Further, the high treatment effects in terms of yield translates to relatively lower net revenue gains from joint input use. While hybrid seeds and fertilizer are yield enhancing inputs, the decision to adopt inputs for poor farmers with limited financial resources is driven by expected profitability (Michler et al. 2018). This also explains regional concentration of adopters in favorable AEZs where heat and water stresses are less likely. This study also finds that while the adoption of agricultural inputs are limited by low profitability, non-adopters of inputs can improve their food security status under adoption.

The RRR estimates from multinomial logit shows that in addition to prices, access to extension services, credit and distance to markets are associated with input adoption. Beegle and Christiaensen (2019) have argued that subsidy policies are regressive in nature and in the absence of complementary investments in infrastructure, large scale subsidies have had a modest impact. This study provides supporting evidence highlighting the need for investments in infrastructure, irrigation, research and extension that focus on increasing productivity as well as profitability under input use. The disproportionate focus on input subsidies under ISPs, such as the NAIVS in Tanzania, is likely to have a weak impact to induce farms into input package adoption.

There is positive and significant impact of joint input adoption on food security in terms of food expenditure, diet diversity and experience-based indicator. The magnitude of impact is relatively low in terms of increasing diet diversity with joint adoption leading to consumption of less than one additional food group. Rural farm households in Tanzania source a large share of their household food consumption from own production. Since the focus of this study is on input use for maize production, which is associated with a relatively small increase in income, the impact on diet diversity is limited. In terms of annual food expenditure there is a 12 percent increase per capita. On the experience scale, the probability of food insecurity is reduced by 4 percentage points. The evidence shows mixed results in case of female headed households. Individual input use is shown to worsen food security measured in terms of food expenditure and FIES amongst female headed households. However, joint input use shows a positive and statistically significant impact. These results are based on a small sample of female headed households adopting both inputs, and should be considered indicative. Further analysis with better data is required to better understand these results.

References

Angrist, Joshua D, and Jorn-Steffen Pischke. 2009. *Mostly Harmless Econometrics: An Emipiricist's Companion*. Princeton University Press.

Antle, John M. 1983. "Sequential Decision Making in Production Models." *American Journal of Agricultural Economics* 65 (2): 282–90. https://doi.org/10.2307/1240874.

———. 2010. "Asymmetry, Partial Moments, and Production Risk." *American Journal of Agricultural Economics* 92 (5): 1294–1309. https://doi.org/10.1093/ajae/aaq077.

Asfaw, Solomon, Bekele Shiferaw, Franklin Simtowe, and Leslie Lipper. 2012. "Impact of Modern Agricultural Technologies on Smallholder Welfare: Evidence from Tanzania and Ethiopia." *Food Policy* 37 (3): 283–95. https://doi.org/10.1016/j.foodpol.2012.02.013.

Ballard, Terri J, Anne W Kepple, and Carlo Cafiero. 2013. "The Food Insecurity Experience Scale," 61.

Baltzer, Kenneth, and Henrik Hansen. 2011. *Agricultural Input Subsidies in Sub-Saharan Africa*. Copenhagen: Ministry of Foreign Affairs of Denmark, Danida : [Eksp.] www.evaluation.dk : [Eksp.] www.danida-publikationer.dk.

Bardhan, Pranab, and Christopher Udry. 1999. *Human Capital and Income Distribution*. Oxford University Press. http://www.oxfordscholarship.com/view/10.1093/0198773714.001.0001/acprof-9780198773719-chapter-10.

Beegle, Kathleen, and Luc Christiaensen. 2019. "Accelerating Poverty Reduction in Africa." Washington, DC: World Bank. https://openknowledge.worldbank.org/handle/10986/32354.

Bell, Andrew, and Kelvyn Jones. 2015. "Explaining Fixed Effects: Random Effects Modeling of Time-Series Cross-Sectional and Panel Data." *Political Science Research and Methods* 3 (1): 133–53. https://doi.org/10.1017/psrm.2014.7.

Benjamin, Dwayne. 1992. "Household Composition, Labor Markets, and Labor Demand: Testing for Separation in Agricultural Household Models." *Econometrica: Journal of the Econometric Society*, 287–322.

Bezu, Sosina, Girma T. Kassie, Bekele Shiferaw, and Jacob Ricker-Gilbert. 2014. "Impact of Improved Maize Adoption on Welfare of Farm Households in Malawi: A Panel Data Analysis." *World Development* 59: 120–131.

Bourguignon, François, Martin Fournier, and Marc Gurgand. 2007. "Selection Bias Corrections Based on the Multinomial Logit Model: Monte Carlo Comparisons." *Journal of Economic Surveys* 21 (1): 174–205. https://doi.org/10.1111/j.1467-6419.2007.00503.x.

Breman, Henk, and Siegfried Debrah. 2003. "Improving African Food Security." *SAIS Review* 23 (1): 153–70. https://doi.org/10.1353/sais.2003.0002.

Di Falco, Salvatore, Marcella Veronesi, and Mahmud Yesuf. 2011. "Does Adaptation to Climate Change Provide Food Security? A Micro-Perspective from Ethiopia." *American Journal of Agricultural Economics* 93 (3): 829–846.

Dillon, Brian, and Christopher B. Barrett. 2017. "Agricultural Factor Markets in Sub-Saharan Africa: An Updated View with Formal Tests for Market Failure." *Food Policy*, Agriculture in Africa – Telling Myths from Facts, 67 (February): 64–77. https://doi.org/10.1016/j.foodpol.2016.09.015.

Druilhe, Zoé, and Jesús Barreiro-Hurlé. 2012. "Fertilizer Subsidies in Sub-Saharan Africa." ESA Working paper. http://www.fao.org/3/a-ap077e.pdf.

Dubin, Jeffrey A., and Daniel L. McFadden. 1984. "An Econometric Analysis of Residential Electric Appliance Holdings and Consumption." *Econometrica* 52 (2): 345–62. https://doi.org/10.2307/1911493.

Duflo, Esther, Michael Kremer, and Jonathan Robinson. 2011. "Nudging Farmers to Use Fertilizer: Theory and Experimental Evidence from Kenya." *American Economic Review* 101 (6): 2350–90. https://doi.org/10.1257/aer.101.6.2350.

FAO. 2002. "International Scientific Symposium on Measurement and Assessment of Food Deprivation and Undernutrition." FAO. http://www.fao.org/3/y4249e/y4249e00.htm#Contents.

FAO, IFAD, UNICEF, WFP, and WHO. 2019. "The State of Food Security and Nutrition in the World 2019. Safeguarding against Economic Slowdowns and Downturns." Rome: FAO. http://www.fao.org/3/ca5162en/ca5162en.pdf.

Feder, Gershon, Richard E. Just, and David Zilberman. 1985. "Adoption of Agricultural Innovations in Developing Countries: A Survey." *Economic Development and Cultural Change* 33 (2): 255–298.

Foster, Andrew D., and Mark R. Rosenzweig. 2010. "Microeconomics of Technology Adoption." *Annu. Rev. Econ.* 2 (1): 395–424.

Foster, Vivien, and Cecilia Briceno-Garmendia. 2010. "Africa's Infrastructure: A Time for Transformation." Washington DC: World Bank. https://siteresources.worldbank.org/INTAFRICA/Resources/aicd_overview_english_no-embargo.pdf.

Gibbons, Charles E., Juan Carlos Suárez Serrato, and Michael B. Urbancic. 2014. "Broken or Fixed Effects?" Working Paper 20342. National Bureau of Economic Research. https://doi.org/10.3386/w20342.

Goldman, Abe, and Joyotee Smith. 1995. "Agricultural Transformations in India and Northern Nigeria: Exploring the Nature of Green Revolutions." *World Development* 23 (2): 243–63. https://doi.org/10.1016/0305-750X(94)00115-F.

Jayne, Thomas S., and Shahidur Rashid. 2013. "Input Subsidy Programs in Sub-Saharan Africa: A Synthesis of Recent Evidence." *Agricultural Economics* 44 (6): 547–62. https://doi.org/10.1111/agec.12073.

Kassie, Menale, Moti Jaleta, Bekele Shiferaw, Frank Mmbando, and Mulugetta Mekuria. 2013. "Adoption of Interrelated Sustainable Agricultural Practices in Smallholder Systems: Evidence from Rural Tanzania." *Technological Forecasting and Social Change*, Future-Oriented Technology Analysis, 80 (3): 525–40. https://doi.org/10.1016/j.techfore.2012.08.007.

Kassie, Menale, Paswel Marenya, Yohannis Tessema, Moti Jaleta, Di Zeng, Olaf Erenstein, and Dil 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 (1): 76–95. https://doi.org/10.1111/1477-9552.12221.

Kassie, Menale, Hailemariam Teklewold, Paswel Marenya, Moti Jaleta, and Olaf Erenstein. 2015. "Production Risks and Food Security under Alternative Technology Choices in

Malawi: Application of a Multinomial Endogenous Switching Regression." *Journal of Agricultural Economics* 66 (3): 640–59. https://doi.org/10.1111/1477-9552.12099.

Kathage, Jonas, Menale Kassie, Bekele Shiferaw, and Matin Qaim. 2016. "Big Constraints or Small Returns? Explaining Nonadoption of Hybrid Maize in Tanzania." *Applied Economic Perspectives and Policy* 38 (1): 113–31. https://doi.org/10.1093/aepp/ppv009.

Khonje, Makaiko, Julius Manda, Arega D. Alene, and Menale Kassie. 2015. "Analysis of Adoption and Impacts of Improved Maize Varieties in Eastern Zambia." *World Development* 66 (February): 695–706. https://doi.org/10.1016/j.worlddev.2014.09.008.

Mathenge, Mary K., Melinda Smale, and John Olwande. 2014. "The Impacts of Hybrid Maize Seed on the Welfare of Farming Households in Kenya." *Food Policy* 44 (February): 262–71. https://doi.org/10.1016/j.foodpol.2013.09.013.

Michler, Jeffrey D., Emilia Tjernström, Simone Verkaart, and Kai Mausch. 2018. "Money Matters: The Role of Yields and Profits in Agricultural Technology Adoption." *American Journal of Agricultural Economics*. https://doi.org/10.1093/ajae/aay050.

Morris, Michael, Valerie A. Kelly, Ron J. Kopicki, and Derek Byerlee. 2007. *Fertilizer Use in African Agriculture: Lessons Learned and Good Practice Guidelines*. World Bank Publications.

Pitt, Mark M. 1983. "Farm-Level Fertilizer Demand in Java: A Meta-Production Function Approach." *American Journal of Agricultural Economics* 65 (3): 502. https://doi.org/10.2307/1240498.

Ruel, Marie T., Agnes R. Quisumbing, and Mysbah Balagamwala. 2018. "Nutrition-Sensitive Agriculture: What Have We Learned so Far?" *Global Food Security*, February. https://doi.org/10.1016/j.gfs.2018.01.002.

Sheahan, Megan, and Christopher B. Barrett. 2017. "Ten Striking Facts about Agricultural Input Use in Sub-Saharan Africa." *Food Policy*, Agriculture in Africa – Telling Myths from Facts, 67 (February): 12–25. https://doi.org/10.1016/j.foodpol.2016.09.010.

Sheahan, Megan, Roy Black, and T. S. Jayne. 2013. "Are Kenyan Farmers Under-Utilizing Fertilizer? Implications for Input Intensification Strategies and Research." *Food Policy* 41 (August): 39–52. https://doi.org/10.1016/j.foodpol.2013.04.008.

Shiferaw, Bekele, Menale Kassie, Moti Jaleta, and Chilot Yirga. 2014. "Adoption of Improved Wheat Varieties and Impacts on Household Food Security in Ethiopia." *Food Policy* 44 (February): 272–84. https://doi.org/10.1016/j.foodpol.2013.09.012.

Smale, Melinda, and Paul W Heisey. 1993. "Simultaneous Estimation of Seed-Fertilizer Adoption Decisions An Application to Hybrid Maize in Malawi." *Technological Forecasting and Social Change* 43: 16.

Sunding, David, and David Zilberman. 2001. "The Agricultural Innovation Process: Research and Technology Adoption in a Changing Agricultural Sector." *Handbook of Agricultural Economics* 1: 207–261.

Suri, Tavneet. 2011. "Selection and Comparative Advantage in Technology Adoption." *Econometrica* 79 (1): 159–209. https://doi.org/10.3982/ECTA7749.

Swindale, Anne, and Paula Bilinksy. 2006. "Household Dietary Diversity Score (HDDS) for Measurement of Household Food Access: Indicator Guide (Version 2)," 15.

Teklewold, Hailemariam, Menale Kassie, Bekele Shiferaw, and Gunnar Kohlin. 2013. "Cropping System Diversification, Conservation Tillage and Modern Seed Adoption in

Ethiopia: Impacts on Household Income, Agrochemical Use and Demand for Labor." *Ecological Economics* 93 (September): 85–93.

Vanlauwe, Bernard, Job Kihara, Pauline Chivenge, Pieter Pypers, Ric Coe, and Johan Six. 2011. "Agronomic Use Efficiency of N Fertilizer in Maize-Based Systems in Sub-Saharan Africa within the Context of Integrated Soil Fertility Management." *Plant and Soil* 339 (1–2): 35–50. https://doi.org/10.1007/s11104-010-0462-7.

World Bank. 2007. *From Agriculture to Nutrition: Pathways, Synergies and Outcomes*. World Bank. https://doi.org/10.1596/28183.

Tables

Table 1: Difference in Maize Yield, Net Revenue and Household Food Security Indicators for each Input Regime (2010-2013)

	Input Regimes			
	00	H0	0F	HF
	(1)	(2)	(3)	(4)
Yield (kg/ha)	670	769***	1086***	1301***
Net Revenue from Maize ($/ha)	99	111**	82**	129***
Food expenditure per capita ($/person)	282	349***	335***	416***
Household Diet Diversity Score	8	8.6***	8.7***	9.4***
% Food insecure (FIES)	0.46	0.43	0.29***	0.21***
% Severely food insecure (FIES)	0.36	0.27***	0.17***	0.14***

Note: Significance levels in comparison to first input regime j=0 (H=0, F=0)

Table 2: Unconditional and Conditional Probability of Hybrid & Fertilizer use (2010-2013)

	2010-11	2012-13	Avg
	(1)	(2)	(3)
Prob(H)	0.15	0.41	0.27
Prob(F)	0.2	0.19	0.19
Prob(H|F=1)	0.24***	0.45**	0.34***
Prob(F|H=1)	0.32***	0.21*	0.24***

Note: Significance of conditional probability is relative to Prob(H|F=0) and Prob(F|H=0)

Table 3: Summary Statistics Disaggregated by Input Regimes (2010-2013)

Variable	00	H0		0F		HF		Overall
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Fertilizer Rate (kg/ha)	0	0		41		44		8
D.Hired Labor	0.29	0.48	***	0.41	***	0.47	***	0.36
Hired Labor (days/ha) if D.Hired Labor = 1	22	24	0.15	25	0.21	29	***	24
Family Labor (days/ha)	173	156	**	159	0.15	133	***	165
Planted Area (ha)	1.3	1.4	0.11	1.5	**	1.2	0.58	1.3
D.Livestock Owned	0.67	0.71	*	0.78	***	0.78	***	0.70
D.Intercropped	0.73	0.74	0.6	0.77	*	0.67	*	0.73
Elevation(m)	930	1010	***	1275	***	1292	***	1013
D.Nutrient Constrained (Poor Soil Quality)	0.65	0.59	***	0.80	***	0.52	***	0.65
Temperature (C)	23	22	***	21	***	21	***	22
Rainfall (cm)	7.99	7.43	***	8.43	***	7.76	0.26	8
D.Extension Service	0.08	0.14	***	0.31	***	0.27	***	0.14
Age (years)	50	47	***	49	0.14	47	***	49
Education1 (0 years)	0.31	0.23	***	0.16	***	0.10	**	0.26
Education2 (1-6 years)	0.24	0.18	***	0.21	0.14	0.15	***	0.22
Education3 (>6 years) (base category)	0.45	0.59	***	0.63	***	0.75	***	0.52
D.Female Headed	0.27	0.19	***	0.22	**	0.19	***	0.24
Adult Equivalent	5	5	***	5	0.89	4	0.2	5
Maize Price ($/kg)	0.19	0.25	***	0.18	**	0.22	**	0.21
Hybrid Price ($/bag)	23	26	***	23	0.9	25	***	24
Urea Price ($/bag)	33	40	***	27	***	32	0.33	33
Distance to Market (kms)	87	73	***	95	***	61	0.73	84
Farm Size (ha)	2.90	2.99	0.61	3.55	***	2.99	**	3.01
D.Non-Farm Income	0.63	0.74	***	0.69	**	0.71	**	0.67
D.AEZ	0.31	0.41	***	0.58	***	0.61	***	0.39
D.Access to Credit	0.11	0.18	***	0.20	***	0.22	***	0.14
D.Southern Highlands (base region category)	0.22	0.21	***	0.29	0.5	0.34	***	0.24
D.North and Central	0.17	0.66	***	0.06	***	0.52	***	0.23
D.West and Lake	0.38	0.08	***	0.28	***	0.07	***	0.30
D.East and South	0.23	0.05	***	0.37	***	0.07	***	0.23
N	1917	692		401		209		3189
	0.60	0.21		0.13		0.07		

Note: Significance in comparison to first input j=0 (H=0, F=0)

Table 4: Relative Risk Ratio (RRR) for Input Regimes with input use from Multinomial Logit (2010-2013)

	Input Regimes		
	H0	0F	HF
	(1)	(2)	(3)
log(Price Maize)	1.324**	1.012	1.13
	[0.159]	[0.141]	[0.204]
log(Price Urea)	0.963	0.349***	0.455**
	[0.193]	[0.0844]	[0.14]
log(Price Hybrid)	0.892	1.051	0.739
	[0.122]	[0.201]	[0.185]
log(Distance to Market)	0.759***	0.759***	0.447***
	[0.0505]	[0.0613]	[0.0414]
log(Farm Size)	0.880*	1.153	1.354**
	[0.0661]	[0.113]	[0.166]
log(Planted Area Maize)	1.105	1.164	1.142
	[0.0836]	[0.111]	[0.139]
D.Non-Farm Income	1.496***	1.116	1.147
	[0.192]	[0.167]	[0.218]
D.Likestock	1.072	1.462**	1.681**
	[0.143]	[0.242]	[0.362]
D.Credit Access	1.314*	1.777***	1.679**
	[0.209]	[0.337]	[0.383]
D.Intercropped	1.006	1.231	0.754
	[0.129]	[0.195]	[0.141]
log(Elevation)	0.684***	1.2	1.456
	[0.0809]	[0.316]	[0.48]
D.Nutrient Constrained	0.839	2.679***	0.957
	[0.112]	[0.455]	[0.189]
log(Mean Temperature)	0.537	0.0480***	0.204
	[0.52]	[0.0543]	[0.288]
log(Average Rainfall)	0.549***	1.633*	1.356
	[0.105]	[0.424]	[0.441]
D.AEZ	1.553***	1.018	1.377
	[0.246]	[0.201]	[0.339]
D.Extension Service	1.860***	4.392***	4.131***
	[0.328]	[0.773]	[0.897]
log(age)	0.834	1.026	0.962
	[0.165]	[0.254]	[0.304]
D.Education1	0.580***	0.463***	0.221***
	[0.0889]	[0.0951]	[0.0662]
D.Education2	0.585***	0.587***	0.367***
	[0.0868]	[0.106]	[0.0896]
D.Female	0.765*	1.076	1.018
	[0.114]	[0.19]	[0.239]
log(Adult Equivalent)	1.354***	0.744**	0.636***
	[0.158]	[0.104]	[0.111]
Year 2012-13	6.000***	1.996***	5.932***
	[1.022]	[0.453]	[1.723]
D.North and Central	0.248***	1.525*	0.705
	[0.0601]	[0.383]	[0.22]
D.West and Lake	0.384***	0.211***	0.134***
	[0.0849]	[0.0735]	[0.062]
D.East and South	0.929	0.118***	0.0755***
	[0.168]	[0.0362]	[0.0294]
Observations	2,842	2,842	2,842

Table 5: Treatment Effects of Joint Adoption on Maize Productivity by AEZs

	ATE	ATT, Overall and by AEZs				
		Overall	Arid	Humid	Warm	Cool
	(1)	(2)	(3)	(4)	(5)	(6)
H0	116***	139***	245***	122***	114***	172***
0F	474***	340***	109	366***	225***	424***
HF	767***	559***	373	599***	664***	543***

Note:
ATE=$E[Q_j|J=j]-E[Q_1|J=1]$, j =2, 3 or 4
ATT=$E[Q_j|J=j]-E[Q_1|J=j]$, j = 2, 3 or 4

Table 6: Treatment Effects of Joint Adoption on Net Profit by AEZs

	ATE	ATT, Overall and AEZs				
		Overall	Arid	Humid	Warm	Cool
	(1)	(2)	(3)	(4)	(5)	(6)
H0	12***	0.94	8	-0.2	-5	8
0F	-19***	-12**	-40**	-9	-15**	-10
HF	29***	19*	-30	20**	12	23*
		ATU, Overall and AEZs				
		Overall	Arid	Humid	Warm	Cool
H0	12***	3	-3	-15***	-21***	3
0F	-19***	-15***	-33***	4	7**	-15***
HF	29***	-25***	-29**	-66***	-80***	-25***

Note:
ATE=E[Q_j|J=j]-E[Q_1|J=1], j =2, 3 or 4
ATT=E[Q_j|J=j]-E[Q_1|J=j], j = 2, 3 or 4
ATU=E[Q_j|J=1]-E[Q_1|J=1], j = 2, 3 or 4

Table 7: Treatment Effects of Joint Adoption on Net Profit by Key Covariates

	ATE	ATT, Overall, Distance to market, Access to credit and Price of Maize						
		Overall	Near	Far	With Access to Credit	Without Access to Credit	Higher Maize Price	Lower Maize Price
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
H0	12***	0.94	-8	13	-2	1	5	-7
0F	-19***	-12**	-10	-14*	-26**	-9	0.5	-21***
HF	29***	19*	31***	-17	57***	7	28*	10

Note:
ATE=$E[Q_j|J=j]-E[Q_1|J=1]$, j =2, 3 or 4
ATT=$E[Q_j|J=j]-E[Q_1|J=j]$, j = 2, 3 or 4
Near=1, if Distance to Market <median(Distance to Market)
'Higher' Maize Price if Maize Price>median(Maize Price)

Table 8: Treatment Effects on Food Security Indicators

	FEXP			HDDS			DFIES		
	ATE	ATT	ATU	ATE	ATT	ATU	ATE	ATT	ATU
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
H0	56***	43***	10**	0.63***	0.30***	0.18***	-0.03***	0.02	0.02***
0F	37***	-1	155***	0.63***	0.32***	0.24***	-0.12***	-0.001	0.01
HF	118***	41**	43***	1.37***	0.69***	0.14***	-0.19***	-0.04**	-0.13***

Note:
ATE=E[FS$_j$|J=j]-E[FS$_1$|J=1], j = 2, 3 or 4
ATT=E[FS$_j$|J=j]-E[FS$_1$|J=j], j = 2, 3 or 4
ATU=E[FS$_j$|J=1]-E[FS$_1$|J=1], j = 2, 3 or 4
FEXP: Annual Per Capita Food Expenditure
HDDS: Household Diet Diversity Scale
DFIES: Binary variable based on Food Insecurity Experience Scale

Table 9: Treatment Effects on Food Expenditure Disaggregated by Sex of Household Head

	ATE	ATT		
		Overall	Male	Female
	(1)	(2)	(3)	(4)
H0	56***	43***	58***	-30*
0F	37***	-1	14	-45**
HF	118***	41**	18	150***

Note:
ATE=E[FS*j*|J=*j*]-E[FS_1|J=1], *j* = 2, 3 or 4
ATT=E[FS*j*|J=*j*]-E[FS_1|J=*j*], *j* = 2, 3 or 4

Table 10: Treatment Effects on HDDS and FIES, Disaggregated by Sex of Household Head

	HDDS				DFIES			
	ATE	ATT			ATE	ATT		
		Overall	Male	Female		Overall	Male	Female
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
H0	0.63***	0.30***	0.35***	0.01	-0.03***	0.02	-0.03**	0.20***
0F	0.63***	0.32***	0.45***	-0.17	-0.12***	-0.001	-0.002	-0.01
HF	1.37***	0.69***	0.71***	0.60*	-0.19***	-0.04**	-0.03	-0.12***

Note:
ATE=E[FS*j*|J=*j*]-E[FS_1|J=1], *j* = 2, 3 or 4
ATT=E[FS*j*|J=*j*]-E[FS_1|J=*j*], *j* = 2, 3 or 4
HDDS: Household Diet Diversity Scale
DFIES: Binary variable based on Food Insecurity Experience Scale

Appendix

Table A1: Equation-wise OLS and ESR result for Production Function

	Equation-wise OLS				Endogenous Switching Regression			
log(Yield)	00	H0	0F	HF	00	H0	0F	HF
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
log(N Fert. Rate)			0.290***	0.418***			0.278***	0.407***
			[7.54]	[7.56]			[7.31]	[6.49]
(1-D.Hired Labor)	-0.0980	-0.172	0.119	0.0635	-0.0674	-0.354**	0.150	0.0621
	[-1.10]	[-1.33]	[0.85]	[0.26]	[-0.62]	[-2.44]	[1.07]	[0.24]
log(Hired Labor)	0.0743**	0.0863**	0.0865*	0.00538	0.0752**	0.0432	0.0934*	0.00608
	[2.46]	[2.14]	[1.78]	[0.07]	[2.15]	[0.94]	[1.87]	[0.07]
log(Family Labor)	0.151***	0.140***	0.139***	0.0938	0.159***	0.157***	0.134**	0.0953
	[6.44]	[3.50]	[2.63]	[1.18]	[6.30]	[2.97]	[2.49]	[1.07]
log(Planted Area)	-0.233***	-0.220***	-0.172***	-0.127	-0.261***	-0.259***	-0.213***	-0.137
	[-10.66]	[-5.45]	[-3.42]	[-1.56]	[-8.98]	[-4.92]	[-3.93]	[-1.40]
D.Non-Farm Income	-0.0272	-0.0112	0.00212	-0.0417	-0.000119	0.0909	0.00912	-0.0367
	[-0.73]	[-0.16]	[0.03]	[-0.33]	[-0.00]	[0.89]	[0.12]	[-0.28]
D.Livestock	0.120***	-0.0339	0.0915	0.214	0.0858*	-0.0989	0.0626	0.215
	[2.94]	[-0.42]	[1.11]	[1.60]	[1.86]	[-0.89]	[0.55]	[1.41]
D.Intercropped	-0.184***	-0.251***	-0.0937	0.00579	-0.221***	-0.197**	-0.131	0.0420
	[-4.42]	[-3.28]	[-1.06]	[0.05]	[-4.05]	[-2.12]	[-1.35]	[0.32]
log(Elevation)	0.128***	0.183***	0.183	-0.156	0.0951*	0.0357	0.116	-0.197
	[3.08]	[2.92]	[1.41]	[-0.89]	[1.70]	[0.34]	[0.83]	[-0.62]
D.Nutrient Const.	-0.140***	-0.0669	-0.0667	-0.339**	-0.210***	-0.242**	-0.230	-0.269
	[-3.37]	[-0.92]	[-0.73]	[-2.41]	[-2.96]	[-2.17]	[-1.52]	[-1.11]
log(Temperature)	0.139	0.641	-0.316	-0.0752	0.386	1.557*	-0.125	-0.272
	[0.44]	[1.16]	[-0.59]	[-0.08]	[1.06]	[1.77]	[-0.23]	[-0.23]
log(Rainfall)	-0.241***	-0.394***	0.353**	-0.306	-0.395***	-0.695***	0.283	-0.283
	[-4.31]	[-3.52]	[1.98]	[-1.46]	[-4.81]	[-3.97]	[1.48]	[-1.19]
D.AEZ	0.129**	0.196**	0.122	-0.113	0.142**	0.371***	0.151	-0.143
	[2.42]	[2.16]	[1.13]	[-0.71]	[2.35]	[2.82]	[1.37]	[-0.75]
D.Extension	-0.0261	0.142	0.150*	0.217**	-0.0302	0.0795	0.0636	0.220
	[-0.38]	[1.53]	[1.90]	[1.99]	[-0.35]	[0.53]	[0.47]	[1.21]
log(age)	-0.291***	-0.374***	-0.271**	-0.171	-0.285***	-0.464***	-0.296**	-0.214
	[-4.94]	[-3.32]	[-2.29]	[-0.89]	[-4.17]	[-3.41]	[-2.54]	[-0.93]
D.Education1	-0.0232	-0.0930	-0.0889	0.163	-0.00475	-0.155	-0.0316	0.242
	[-0.51]	[-1.07]	[-0.84]	[0.84]	[-0.08]	[-1.09]	[-0.26]	[0.91]
D.Education2	-0.0426	-0.0263	-0.00631	-0.0550	-0.0394	-0.113	0.00834	-0.0319
	[-0.94]	[-0.31]	[-0.07]	[-0.29]	[-0.76]	[-0.92]	[0.09]	[-0.15]
D.Female	-0.0503	-0.323***	-0.0105	-0.326**	-0.107**	-0.400***	-0.0384	-0.335*
	[-1.18]	[-3.98]	[-0.11]	[-1.99]	[-2.11]	[-3.41]	[-0.43]	[-1.81]
log(Adult Eq.)	0.0962***	0.182***	0.0675	0.0163	0.128**	0.318***	0.0918	0.0516
	[2.61]	[2.75]	[0.89]	[0.14]	[2.46]	[3.40]	[1.23]	[0.36]
Year 2012-13	-0.0985***	-0.0747	-0.105	0.207*	0.140	0.617***	0.0374	0.191
	[-2.68]	[-0.95]	[-1.47]	[1.81]	[1.31]	[2.83]	[0.31]	[0.89]
D.North and Central	0.461***	0.401***	0.295**	0.516***	0.220*	-0.312	0.0964	0.477
	[7.17]	[2.98]	[2.48]	[3.04]	[1.72]	[-1.14]	[0.48]	[1.55]
D.West and Lake	0.305***	0.157	0.525**	0.0514	0.329***	-0.0617	0.637**	0.0219
	[4.38]	[1.24]	[2.54]	[0.16]	[4.02]	[-0.30]	[2.18]	[0.06]
D.East and South	0.281***	0.142	0.142	0.568**	0.502***	0.436***	0.392	0.611
	[4.89]	[1.62]	[0.67]	[2.18]	[5.33]	[2.85]	[1.43]	[1.53]
Constant	5.516***	4.441**	4.493*	7.191*	5.243***	2.240	5.122**	8.328
	[4.55]	[2.15]	[1.77]	[1.95]	[3.59]	[0.70]	[2.06]	[1.54]
N	1917	662	401	209	1692	541	403	209
Adj. R2	0.221	0.227	0.440	0.394				

Table A2: Equation-wise OLS and ESR result for Profit Function

	Equation-wise OLS				Endogenous Switching Regression			
Net Profit	00	H0	0F	HF	00	H0	0F	HF
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Price of Maize	204.2***	250.5***	328.8***	174.7***	202.6***	235.6***	314.6**	155.6
	[4.44]	[4.92]	[4.66]	[3.60]	[4.35]	[4.27]	[2.37]	[1.36]
Price of Hybrid Seed	-0.156	-0.200	0.000263	-0.394	-0.135	-0.178	-0.181	0.454
	[-0.54]	[-0.38]	[0.00]	[-0.26]	[-0.48]	[-0.30]	[-0.21]	[0.25]
Price Urea	-1.521***	-1.043*	-2.053***	0.423	-1.578***	-0.661	-1.616	0.440
	[-4.22]	[-1.73]	[-2.61]	[0.31]	[-4.16]	[-1.05]	[-1.59]	[0.26]
D.Hired Labor	-23.99***	-25.03*	-64.99***	-63.02*	-23.69***	-27.18**	-64.36***	-67.31**
	[-3.59]	[-1.88]	[-4.08]	[-1.90]	[-3.65]	[-2.16]	[-3.99]	[-1.96]
Distance to Market	0.0332	0.273**	0.0872	-0.319	0.0361	0.435***	0.119	0.173
	[0.62]	[2.27]	[0.69]	[-1.22]	[0.60]	[2.77]	[0.68]	[0.42]
Farm Size	2.742***	-1.229	1.066	5.084	2.912***	-0.876	1.510	4.888
	[3.61]	[-0.58]	[0.70]	[1.44]	[3.69]	[-0.34]	[0.86]	[1.13]
Access to Market	-4.584	-10.36	2.343	57.22	-2.576	-32.54	-9.938	44.63
	[-0.49]	[-0.56]	[0.10]	[1.41]	[-0.27]	[-1.56]	[-0.40]	[0.92]
log(Family Labor)	19.41***	30.04***	2.286	3.039	19.56***	32.15***	2.290	4.387
	[5.03]	[3.88]	[0.21]	[0.15]	[5.77]	[3.92]	[0.21]	[0.21]
log(Planted Area)	-36.31***	-30.39***	-48.11***	-73.65***	-35.64***	-32.72***	-50.48***	-78.37***
	[-8.07]	[-3.23]	[-4.02]	[-3.26]	[-7.19]	[-3.42]	[-4.17]	[-3.10]
D.Non-Farm Income	-1.417	-1.365	14.84	-9.929	-2.025	-14.85	10.02	-20.92
	[-0.26]	[-0.10]	[0.82]	[-0.28]	[-0.39]	[-1.06]	[0.56]	[-0.53]
D.Livestock	8.161	-0.276	15.42	41.55	9.318	-7.255	9.144	43.78
	[1.28]	[-0.02]	[0.84]	[1.13]	[1.36]	[-0.37]	[0.50]	[0.93]
D.Intercropped	-10.19	-28.84*	27.62	48.80	-8.819	-34.14**	18.14	64.59*
	[-1.60]	[-1.89]	[1.59]	[1.42]	[-1.24]	[-2.15]	[0.81]	[1.77]
log(Elevation)	15.69***	8.326	27.89	-14.61	17.66***	13.13	16.07	-26.23
	[2.88]	[0.71]	[1.44]	[-0.42]	[2.62]	[0.94]	[0.69]	[-0.46]
D.Nutrient Const.	-22.59***	-12.93	-14.51	-51.62	-16.87*	-22.95	-31.93	-18.59
	[-3.79]	[-0.88]	[-0.79]	[-1.48]	[-1.83]	[-1.06]	[-1.35]	[-0.32]
log(age)	-24.26***	-40.04*	-15.60	-8.302	-23.72**	-39.10**	-21.59	-10.61
	[-2.67]	[-1.90]	[-0.60]	[-0.15]	[-2.52]	[-2.02]	[-0.87]	[-0.16]
D.Education1	8.551	13.79	-10.83	15.04	8.033	35.04	5.934	73.71
	[1.22]	[0.76]	[-0.44]	[0.34]	[1.08]	[1.60]	[0.21]	[1.17]
D.Education2	-2.439	-18.15	-2.199	-18.33	-2.664	3.492	8.532	11.52
	[-0.36]	[-1.07]	[-0.12]	[-0.36]	[-0.33]	[0.18]	[0.41]	[0.18]
D.Female	-16.23**	-40.00***	30.10	-59.71	-15.52**	-34.73**	34.43	-48.11
	[-2.53]	[-2.80]	[1.31]	[-1.24]	[-2.47]	[-2.25]	[1.30]	[-0.80]
log(Adult Eq.)	9.816*	26.71**	12.17	5.858	8.263	17.54	11.78	8.569
	[1.74]	[2.17]	[0.70]	[0.18]	[1.27]	[1.07]	[0.61]	[0.20]
Year 2012-13	51.26***	49.07***	38.92	71.15*	44.92***	1.179	25.60	-8.759
	[5.69]	[2.91]	[1.43]	[1.85]	[2.86]	[0.03]	[0.75]	[-0.10]
D.North and Central	14.39	1.772	39.33	38.28	28.07*	19.22	52.26	118.7
	[1.55]	[0.07]	[1.40]	[0.87]	[1.76]	[0.42]	[1.38]	[1.04]
D.West and Lake	20.91**	-14.99	122.5***	-78.84	18.95*	34.94	149.0***	-15.84
	[2.18]	[-0.69]	[2.67]	[-1.22]	[1.73]	[1.15]	[3.36]	[-0.14]
D.East and South	28.48***	21.94	99.36**	27.05	21.85*	54.05***	122.5**	83.09
	[3.34]	[1.35]	[2.13]	[0.42]	[1.93]	[2.62]	[2.16]	[1.03]
Constant	-32.66	4.282	-170.4	124.8	-47.31	69.58	3.677	252.6
	[-0.60]	[0.03]	[-0.93]	[0.38]	[-0.74]	[0.52]	[0.02]	[0.53]
N	1692	541	403	209	1692	541	403	209
Adj. R2	0.256	0.265	0.253	0.171				

Table A3: Equation-wise OLS and ESR result for Annual Per-Capita Food Expenditure (FEXP)

	OLS Equation Wise				Endogenous Switching Regression			
FEXP	00	H0	0F	HF	00	H0	0F	HF
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
log(Distance to Market)	0.286	-19.72	-10.87	9.146	9.742	-65.02**	4.992	63.28
	[0.03]	[-1.45]	[-0.57]	[0.34]	[0.68]	[-2.20]	[0.12]	[0.88]
D.Shock	-29.28	-107.4***	-37.51	-17.28	-33.68**	-92.16***	-39.09	-12.02
	[-1.62]	[-3.08]	[-1.05]	[-0.35]	[-1.99]	[-2.76]	[-1.13]	[-0.22]
D.Access to Credit	-2.747	44.58	56.51	-20.80	-10.55	81.77	74.22	-35.90
	[-0.17]	[1.49]	[1.28]	[-0.32]	[-0.51]	[1.55]	[1.11]	[-0.39]
D.Food Assistance	40.31	41.14	186.9	64.92	41.27	-6.827	198.6	45.99
	[1.39]	[0.95]	[0.86]	[0.39]	[1.10]	[-0.15]	[0.79]	[0.20]
Farm Size	2.735	-0.366	0.804	6.690	1.202	2.112	-1.612	10.30
	[1.49]	[-0.17]	[0.21]	[1.31]	[0.59]	[0.49]	[-0.39]	[1.07]
D.Livestock	61.92***	67.14***	50.99	34.95	59.05***	102.9***	60.88	27.49
	[4.76]	[2.60]	[1.43]	[0.71]	[4.26]	[3.08]	[1.27]	[0.34]
D.Non-Farm Income	20.52	-24.04	-13.15	66.43	19.01	10.95	30.54	47.31
	[1.45]	[-0.75]	[-0.41]	[0.94]	[1.19]	[0.24]	[0.67]	[0.68]
Housing Quality	32.10***	27.41**	-2.687	-9.722	28.22***	26.53*	2.090	-12.19
	[3.96]	[2.57]	[-0.16]	[-0.40]	[3.36]	[1.94]	[0.13]	[-0.40]
D.Access to Drinking Water	33.20*	45.04	-15.93	113.8**	28.40	46.15	-30.13	115.8**
	[1.71]	[1.54]	[-0.36]	[2.14]	[1.29]	[1.46]	[-0.66]	[2.20]
Price(Cereals)	-57.10***	-15.25	-5.741	48.21	-66.83***	9.710	-31.73	40.14
	[-3.10]	[-0.43]	[-0.09]	[0.59]	[-3.43]	[0.21]	[-0.47]	[0.48]
Price(Starches)	-84.03**	18.74	-322.1***	95.08	-132.7***	31.18	-322.9***	122.1
	[-2.45]	[0.31]	[-3.23]	[0.75]	[-3.23]	[0.41]	[-3.20]	[0.75]
Price(Pulses, nuts, fruits and vegetables)	75.24***	36.81	41.68	79.61	86.96***	17.65	70.25	65.29
	[2.70]	[0.74]	[0.90]	[0.72]	[2.80]	[0.23]	[1.44]	[0.49]
Price(Animal products)	5.475	145.3**	73.05	38.07	25.44	164.4**	95.31	44.94
	[0.21]	[2.17]	[0.91]	[0.34]	[0.92]	[2.30]	[1.08]	[0.33]
Price(Others)	136.9*	-91.73	295.5	-356.7	204.3***	-76.80	337.3	-393.1
	[1.91]	[-0.61]	[1.38]	[-1.57]	[2.61]	[-0.49]	[1.60]	[-1.46]
D.Prod. Diversity	24.91*	43.47	-172.2**	-228.0*	18.84	41.95	-183.2**	-254.2*
	[1.82]	[1.46]	[-2.32]	[-1.97]	[1.38]	[1.37]	[-2.36]	[-1.82]
D.Female	11.86	-50.84**	-34.32	130.0*	24.48	-71.77*	-47.82	165.8
	[0.70]	[-2.02]	[-1.10]	[1.68]	[1.26]	[-1.76]	[-1.30]	[1.62]
Age	-0.354	1.249	1.025	2.433	-0.352	0.535	1.394	2.875
	[-0.76]	[1.40]	[0.77]	[0.97]	[-0.71]	[0.63]	[0.80]	[0.97]
D.Education1	-7.904	-53.22	-41.73	48.08	-0.322	-1.278	-45.73	39.18
	[-0.47]	[-1.54]	[-0.92]	[0.47]	[-0.02]	[-0.03]	[-0.74]	[0.30]
D.Education2	-12.37	4.156	46.20	121.7	-11.56	110.3*	57.93	43.53
	[-0.67]	[0.13]	[1.23]	[1.27]	[-0.45]	[1.80]	[0.58]	[0.24]
log(Adult Eq.)	-28.46***	-19.62***	-14.05	-46.65***	-26.55***	-18.65***	-8.729	-52.24***
	[-10.69]	[-4.77]	[-1.49]	[-3.74]	[-8.31]	[-2.98]	[-0.74]	[-2.93]
Constant	-407.9	-64.57	-1393.7	5083.6**	-607.1	-591.9	-731.8	4800.5
	[-1.05]	[-0.08]	[-1.16]	[2.06]	[-1.09]	[-0.63]	[-0.54]	[1.34]
N	1902	647	396	208	1680	529	395	208
adj. R-sq	0.110	0.151	0.088	0.215				
Other Controls								
Year, AEZ & Region	Y	Y	Y	Y	Y	Y	Y	Y
Quarter of Survey	Y	Y	Y	Y	Y	Y	Y	Y
Production Variables	Y	Y	Y	Y	Y	Y	Y	Y

Table A4: Equation-wise OLS and ESR result for Household Diet Diversity Score (HDDS)

	OLS Equation Wise				Endogenous Switching Regression			
HDDS	00	H0	0F	HF	00	H0	0F	HF
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
log(Distance to Market)	0.0527	-0.0473	0.0511	-0.164	0.0635	0.0695	0.00583	0.462*
	[1.07]	[-0.66]	[0.57]	[-1.27]	[0.89]	[0.40]	[0.02]	[1.66]
D.Shock	-0.0841	-0.242	-0.398**	0.293	-0.0774	-0.143	-0.391**	0.266
	[-0.85]	[-1.44]	[-2.27]	[1.23]	[-0.74]	[-0.85]	[-2.17]	[0.92]
D.Access to Credit	0.378***	0.618***	-0.393	-0.0502	0.428***	0.289	-0.396	-0.257
	[3.00]	[3.93]	[-1.64]	[-0.20]	[3.32]	[1.25]	[-1.15]	[-0.79]
D.Food Assistance	0.336**	-0.102	0.658	-0.390	0.221	-0.487**	0.678	-0.588
	[2.22]	[-0.44]	[1.17]	[-0.63]	[1.40]	[-2.18]	[1.13]	[-0.88]
Farm Size	-0.0118	0.00485	0.0514**	0.0410	-0.0150	0.00354	0.0519**	0.0376
	[-0.86]	[0.30]	[2.41]	[1.22]	[-1.01]	[0.14]	[2.23]	[0.86]
D.Livestock	0.584***	0.512***	0.370*	0.119	0.613***	0.332	0.380	-0.0582
	[6.49]	[2.84]	[1.76]	[0.41]	[5.96]	[1.41]	[1.33]	[-0.17]
D.Non-Farm Income	0.389***	0.475***	0.308	0.332	0.334***	0.477**	0.339*	0.225
	[4.50]	[2.79]	[1.54]	[1.24]	[3.20]	[2.26]	[1.65]	[0.72]
Housing Quality	0.486***	0.518***	0.318***	0.137	0.407***	0.479***	0.324***	0.129
	[11.00]	[7.32]	[3.62]	[1.21]	[8.60]	[6.14]	[3.76]	[1.03]
D.Access to Drinking Water	0.0214	0.0401	0.592***	0.151	0.0328	-0.00762	0.559***	0.118
	[0.19]	[0.24]	[3.32]	[0.52]	[0.27]	[-0.04]	[3.16]	[0.39]
Price(Cereals)	-0.205*	-0.411**	-0.467	0.233	-0.350***	-0.287	-0.490	0.174
	[-1.82]	[-2.06]	[-1.64]	[0.69]	[-2.68]	[-1.13]	[-1.43]	[0.45]
Price(Starches)	0.251	0.366	0.0157	0.425	0.236	0.486	0.0363	0.439
	[1.15]	[1.12]	[0.03]	[0.58]	[1.04]	[1.21]	[0.06]	[0.53]
Price(Pulses, nuts, fruits and vegetables)	0.137	-0.0944	0.479	0.112	0.301	-0.327	0.515	0.154
	[0.77]	[-0.32]	[1.33]	[0.22]	[1.31]	[-1.02]	[1.35]	[0.29]
Price(Animal products)	-0.339*	-0.808**	-0.188	0.0952	-0.165	-0.873**	-0.155	0.197
	[-1.86]	[-2.41]	[-0.39]	[0.15]	[-0.94]	[-2.27]	[-0.33]	[0.25]
Price(Others)	-1.251***	0.192	-1.907*	-2.942**	-0.926**	0.0310	-1.770*	-3.152**
	[-2.75]	[0.22]	[-1.96]	[-2.11]	[-2.17]	[0.03]	[-1.85]	[-2.28]
D.Prod. Diversity	0.246**	0.0754	-0.201	-0.326	0.292***	0.0305	-0.207	-0.541**
	[2.45]	[0.39]	[-0.81]	[-1.10]	[2.67]	[0.14]	[-0.81]	[-2.01]
D.Female	0.158	-0.0732	-0.420*	-0.0935	0.208*	-0.211	-0.457	0.0624
	[1.64]	[-0.38]	[-1.75]	[-0.30]	[1.87]	[-0.88]	[-1.57]	[0.17]
Age	-0.0122***	-0.0162***	-0.0127*	0.00547	-0.0127***	-0.0113*	-0.0126*	0.00740
	[-4.05]	[-2.95]	[-1.76]	[0.59]	[-3.53]	[-1.68]	[-1.71]	[0.65]
D.Education1	0.654***	0.199	-0.180	0.850*	0.678***	0.256	-0.205	0.524
	[5.87]	[0.89]	[-0.64]	[1.82]	[5.45]	[0.95]	[-0.67]	[0.77]
D.Education2	0.534***	0.168	0.165	1.126**	0.509***	-0.149	0.177	0.0929
	[4.94]	[0.79]	[0.61]	[2.50]	[3.72]	[-0.41]	[0.37]	[0.12]
log(Adult Eq.)	0.0111	0.0802***	0.0688*	0.0665	-0.000915	0.0563*	0.0726	0.0716
	[0.58]	[2.88]	[1.71]	[1.25]	[-0.04]	[1.72]	[1.50]	[0.94]
Constant	6.526**	2.590	28.83***	27.48**	9.198***	3.349	29.40***	29.74
	[2.53]	[0.56]	[4.67]	[2.48]	[2.74]	[0.67]	[4.12]	[1.61]
N	1902	647	396	208	1680	529	395	208
adj. R-sq	0.213	0.299	0.323	0.287				
Other Controls								
Year, AEZ & Region	Y	Y	Y	Y	Y	Y	Y	Y
Quarter of Survey	Y	Y	Y	Y	Y	Y	Y	Y
Production Variables	Y	Y	Y	Y	Y	Y	Y	Y

Table A5: Equation-wise OLS and ESR result for Binary Food Insecurity Experience Scale (DFIES)

	OLS Equation Wise				Endogenous Switching Regression			
DFIES	00	H0	0F	HF	00	H0	0F	HF
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
log(Distance to Market)	-0.0159	-0.0259	-0.00513	0.0292	-0.00839	-0.0560	0.0140	0.161**
	[-1.09]	[-1.25]	[-0.19]	[0.92]	[-0.42]	[-1.13]	[0.24]	[2.11]
D.Shock	0.112***	0.0696	0.0793	0.0593	0.114***	0.0570	0.0858	0.0510
	[4.26]	[1.52]	[1.59]	[0.81]	[3.94]	[1.08]	[1.56]	[0.57]
D.Access to Credit	0.0118	0.00913	-0.164***	-0.171**	-0.00419	0.0820	-0.102	-0.234**
	[0.33]	[0.19]	[-2.64]	[-2.55]	[-0.10]	[1.00]	[-1.14]	[-2.25]
D.Food Assistance	0.00532	-0.0169	-0.223	0.111	0.00818	0.0724	-0.259	0.0762
	[0.12]	[-0.26]	[-1.53]	[0.41]	[0.15]	[0.91]	[-1.45]	[0.23]
Farm Size	-0.00456	-0.00609	0.0142**	-0.00434	-0.00292	0.00116	0.0169***	-0.00592
	[-1.28]	[-1.45]	[2.09]	[-0.52]	[-0.72]	[0.19]	[2.63]	[-0.43]
D.Livestock	-0.0604**	-0.0388	0.0244	-0.142	-0.0521*	-0.0409	0.0653	-0.200*
	[-2.47]	[-0.85]	[0.40]	[-1.61]	[-1.95]	[-0.66]	[0.81]	[-1.89]
D.Non-Farm Income	0.0722***	0.0247	0.107**	0.177**	0.0517**	-0.0312	0.0929	0.153*
	[3.09]	[0.56]	[2.14]	[2.35]	[2.20]	[-0.41]	[1.50]	[1.72]
Housing Quality	-0.0727***	-0.0619***	0.00477	-0.0723*	-0.0680***	-0.0744***	-0.000994	-0.0727
	[-6.11]	[-3.16]	[0.19]	[-1.97]	[-5.04]	[-3.63]	[-0.04]	[-1.64]
D.Access to Drinking Water	-0.0318	-0.0322	-0.0289	0.0596	-0.0404	-0.0143	0.00578	0.0562
	[-1.02]	[-0.67]	[-0.52]	[0.77]	[-1.23]	[-0.27]	[0.10]	[0.76]
Price(Cereals)	0.0439	0.119**	0.132*	-0.0636	0.0478	0.112*	0.132	-0.0789
	[1.37]	[2.18]	[1.80]	[-0.65]	[1.47]	[1.80]	[1.49]	[-0.77]
Price(Starches)	0.0815	-0.0585	0.212	-0.186	0.0921	-0.0372	0.222	-0.185
	[1.39]	[-0.65]	[1.44]	[-0.88]	[1.49]	[-0.38]	[1.57]	[-0.72]
Price(Pulses, nuts, fruits and vegetables)	-0.0392	-0.0104	-0.124	-0.132	-0.0591	-0.126	-0.169*	-0.117
	[-0.86]	[-0.13]	[-1.16]	[-1.00]	[-1.35]	[-1.27]	[-1.68]	[-0.78]
Price(Animal products)	0.168***	0.104	-0.182	-0.169	0.188***	0.218**	-0.237**	-0.177
	[3.38]	[1.32]	[-1.48]	[-1.06]	[3.99]	[2.48]	[-2.01]	[-0.90]
Price(Others)	-0.110	-0.00462	-0.105	0.783**	-0.124	0.0699	-0.117	0.711**
	[-0.88]	[-0.02]	[-0.39]	[2.10]	[-1.04]	[0.28]	[-0.45]	[1.98]
D.Prod. Diversity	0.0126	0.0299	0.0521	0.0776	0.0101	0.0571	0.0443	0.0329
	[0.46]	[0.62]	[0.86]	[0.83]	[0.33]	[1.05]	[0.74]	[0.31]
D.Female	0.0836***	0.270***	0.117*	0.0633	0.0943***	0.382***	0.150**	0.0969
	[3.12]	[5.24]	[1.82]	[0.65]	[3.35]	[5.62]	[2.09]	[0.68]
Age	0.00213**	-0.000505	-0.000343	0.00483*	0.00220**	-0.000631	0.000699	0.00515
	[2.56]	[-0.36]	[-0.17]	[1.86]	[2.44]	[-0.35]	[0.34]	[1.56]
D.Education1	0.0208	0.153***	-0.0965	-0.167	0.0108	0.151**	-0.0674	-0.230
	[0.69]	[2.59]	[-1.19]	[-1.50]	[0.31]	[2.08]	[-0.67]	[-1.57]
D.Education2	-0.00540	0.00336	-0.118	-0.0224	-0.0159	0.0256	-0.0439	-0.249
	[-0.18]	[0.07]	[-1.43]	[-0.22]	[-0.46]	[0.23]	[-0.33]	[-1.26]
log(Adult Eq.)	-0.00305	-0.0000573	-0.0250**	-0.00576	-0.00631	-0.0113	-0.0355***	-0.00193
	[-0.61]	[-0.01]	[-2.23]	[-0.40]	[-1.16]	[-1.07]	[-2.67]	[-0.10]
Constant	2.795***	0.0957	-1.983	-1.867	2.752***	0.668	-2.642	-2.110
	[4.09]	[0.08]	[-1.14]	[-0.94]	[3.20]	[0.45]	[-1.40]	[-0.69]
N	1902	647	396	208	1680	529	395	208
adj. R-sq	0.093	0.151	0.086	0.101				
Other Controls								
Year, AEZ & Region	Y	Y	Y	Y	Y	Y	Y	Y
Quarter of Survey	Y	Y	Y	Y	Y	Y	Y	Y
Production Variables	Y	Y	Y	Y	Y	Y	Y	Y

Table A6: Test for Separability

	Selection Equation				Production Function				Net Revenue			
	00	H0	0F	HF	00	H0	0F	HF	00	H0	0F	HF
Household Characteristics												
Log(Adult Equivalent)	0.001	0.0427***	-0.0266**	-0.017***	0.122***	0.274***	0.0939	0.0561	8.263	17.54	11.78	8.569
	[0.06]	[2.90]	[-2.50]	[-2.88]	[2.94]	[3.20]	[1.20]	[0.41]	[1.27]	[1.07]	[0.61]	[0.20]
Female Head of Household	0.0349	-0.0396**	0.00519	-0.0004	-0.101**	-0.346***	-0.037	-0.33**	-15.52**	-34.73**	34.43	-48.11
	[1.49]	[-2.09]	[0.38]	[-0.05]	[-1.98]	[-3.05]	[-0.40]	[-2.01]	[-2.47]	[-2.25]	[1.30]	[-0.80]
Education1	0.15***	-0.0479**	-0.053***	-0.047***	0.0166	-0.0829	-0.0107	0.272	8.033	35.04	5.934	73.71
	[5.82]	[-2.44]	[-3.34]	[-4.55]	[0.28]	[-0.62]	[-0.08]	[1.14]	[1.08]	[1.60]	[0.21]	[1.17]
Education2	0.12***	-0.0546***	-0.0333**	-0.029***	-0.0187	-0.0439	0.0231	-0.008	-2.664	3.492	8.532	11.52
	[4.90]	[-2.86]	[-2.38]	[-3.41]	[-0.30]	[-0.37]	[0.24]	[-0.03]	[-0.33]	[0.18]	[0.41]	[0.18]
Log(Age of Household Head)	0.0153	-0.0234	0.00720	0.001	-0.279***	-0.448***	-0.3**	-0.230	-23.72**	-39.10**	-21.59	-10.61
	[0.48]	[-0.93]	[0.38]	[0.09]	[-4.69]	[-3.25]	[-2.36]	[-1.06]	[-2.52]	[-2.02]	[-0.87]	[-0.16]
Wald Test on Household Characteristics (χ^2)	93.02***				34.04***	32.91***	14.67**	4.84	17.08***	12.71**	2.29	2.82
N	3153				1902	647	396	208	1692	541	403	209

Table A7: Validity of Exclusion Criteria for Production Function

	Selection Equation				Production Function			
	00	H0	0F	HF	00	H0	0F	HF
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Log(Market Distance)	0.0655***	-0.0262***	-0.0138**	-0.0256***	-0.0258	0.0086	-0.0815	-0.0403
	[5.95]	[-3.10]	[-2.22]	[-6.94]	[-0.67]	[0.10]	[-0.86]	[-0.25]
Log(Farm Size)	-0.00472	-0.0192**	0.0129*	0.0110***	0.0031	-0.0466	-0.007	-0.027
	[-0.38]	[-2.00]	[1.72]	[2.61]	[0.10]	[-0.73]	[-0.09]	[-0.24]
Access to credit	-0.0838***	0.0299	0.0394***	0.0146*	0.011	0.1089	-0.1183	0.1497
	[-3.17]	[1.50]	[2.72]	[1.88]	[0.15]	[-0.77]	[-0.99]	[0.90]
Wald Test on Excluded Variables (χ^2)	102.79***				0.49	1.32	3.05	0.76
N	3153				1902	647	396	208

Table A8: Validity of Exclusion Criteria for Profit Function

	Selection Equation				Profit Function			
Excluded Variables	00	H0	0F	HF	00	H0	0F	HF
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
log(Price of Maize)	-0.193***	0.0480**	0.103***	0.0427***	-6.9	1.13	-24.36	26.18
	[-6.79]	[2.15]	[7.19]	[5.17]	[-0.47]	[0.04]	[-0.59]	[0.31]
log(Price of Hybrid)	0.0374	-0.0931***	0.0409**	0.0147	-5.99	-18.13	23.95	-72.43
	[1.18]	[-3.85]	[2.05]	[1.33]	[-0.46]	[-0.59]	[0.53]	[-0.83]
log(Price of Urea)	0.317**	-0.0233	-0.230**	-0.0637	13.19	216	-14.48	306.19
	[2.07]	[-0.19]	[-2.57]	[-1.38]	[0.25]	[1.57]	[-0.1]	[0.96]
Wald Test on Excluded Variables (χ^2)	111.6***				0.49	1.32	3.05	0.34
N	2845				1692	541	403	209

Table A9: Validity of Exclusion Criteria for Annual Food Expenditure Per-Capita

	Selection Equation				FEXP			
Excluded Variables	00	H0	0F	HF	00	H0	0F	HF
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
log(Price of Maize)	-0.0383*	0.0545***	-0.0167	0.000474	35**	82	82**	59
	[-1.90]	[3.51]	[-1.40]	[0.07]	[2]	[1.52]	[2.33]	[4.72]
log(Price of Hybrid)	0.150***	0.0696***	-0.173***	-0.0474***	0.94	2.75	-23	-15
	[4.72]	[2.80]	[-9.26]	[-4.05]	[0.05]	[0.05]	[-0.45]	[-0.13]
log(Price of Urea)	-0.00423	0.00939	-0.00245	-0.00270	89***	-23	42	156
	[-0.19]	[0.58]	[-0.17]	[-0.30]	[3.31]	[-0.35]	[0.47]	[1.2]
Wald Test on Excluded Variables(χ^2)	119.7***				23.64***	2.43	6.18	1.69
N	2812				1680	529	395	208

Table A10: Validity of Exclusion Criteria for Household Diet Diversity Scale

	Selection Equation				HDDS			
Excluded Variables	00	H0	0F	HF	00	H0	0F	HF
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
log(Price of Maize)	-0.0383*	0.0545***	-0.0167	0.000474	0.29***	0.44	0.65***	0.18
	[-1.90]	[3.51]	[-1.40]	[0.07]	[2.86]	[1.61]	[2.71]	[0.76]
log(Price of Hybrid)	0.150***	0.0696***	-0.173***	-0.0474***	0.02	0.04	-0.06	0.68
	[4.72]	[2.80]	[-9.26]	[-4.05]	[0.17]	[0.17]	[-0.18]	[-1.31]
log(Price of Urea)	-0.00423	0.00939	-0.00245	-0.00270	0.19	0.24	0.72	0.11
	[-0.19]	[0.58]	[-0.17]	[-0.30]	[0.93]	[0.67]	[1.37]	[0.864]
Wald Test on Excluded Variables (χ^2)	119.7***				10.58***	4.31	12.78***	2.01
N	2812				1680	529	395	208

Table A11: Validity of Exclusion Criteria for Binary Food Insecurity Experience Scale

	Selection Equation				DFIES			
Excluded Variables	00	H0	0F	HF	00	H0	0F	HF
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Log(Market Distance)	-0.0383*	0.0545***	-0.0167	0.000474	-0.05	0.07	0.02	-0.05
	[-1.90]	[3.51]	[-1.40]	[0.07]	[1.86]	[0.88]	[0.73]	[-0.58]
Log(Farm Size)	0.150***	0.0696***	-0.173***	-0.0474***	-0.07	-0.02	0.09	-0.07
	[4.72]	[2.80]	[-9.26]	[-4.05]	[-0.33]	[-0.4]	[0.91]	[-0.47]
Access to credit	-0.00423	0.00939	-0.00245	-0.00270	0.16**	0.1	-0.06	0.01
	[-0.19]	[0.58]	[-0.17]	[-0.30]	[2.52]	[1.2]	[-0.43]	[0.09]
Wald Test on Household Characteristics (χ^2)	119.7***				10.27**	2.23	1.37	0.63
N	2812				1680	529	395	208