INTERNATIONAL CONFERENCE OF AGRICULTURAL ECONOMISTS
ICAE
29th | Milan Italy 2015
UNIVERSITÀ DEGLI STUDI DI MILANO AUGUST 8 - 14
AGRICULTURE IN AN INTERCONNECTED WORLD

Impact of Improved Maize Variety Adoption on Household Food Security in Ethiopia: An Endogenous Switching Regression Approach

Moti Jaleta[1], Menale Kassie[2], and Paswel Marenya[1]
[1] *International Maize and Wheat Improvement Center (CIMMYT), Addis Ababa, Ethiopia*
[2] *CIMMYT, Nairobi, Kenya*

Abstract

This paper analyzes the adoption and impacts of improved maize varieties (IMVs) on food security in Ethiopia. Survey data collected in 2011 from 2455 sample households in 39 districts was used in the analysis. Endogenous switching regression model supported by binary and generalized propensity score matching methods was used to empirically assess the impact of IMV adoption on per-capita food consumption expenditure and perceived household food security status. Results show that education of household head, farm size, social network, and better agro-ecologic potential for maize production are the major determinants of household decisions to adopt IMVs. In addition, the average per-capita food consumption is high for adopters and the impact of IMV adoption on per-capita food consumption is slightly higher for non-adopters had they adopted IMVs. Thus, policies and development strategies encouraging further adoption of IMVs could enhance food security of smallholder farmers in maize-based systems.

Keywords: *Improved maize, adoption, impact, endogenous switching regression, smallholder, Ethiopia.*

JEL codes: C31, C34, D6, D13

IAAE

1. Introduction

Food security is one of the major challenges the World has been fighting for long. The prevalence of food security problem in regions with increasing population growth and more exposed to agonies of climate change makes the challenge rather complex and put more people under malnutrition (Parry et al., 1999; Brown et al., 2008; Godfray et al., 2010; Beddington, 2010). Recent data show that close to 0.8 billion people in the World are undernourished. About 28% of this are living in sub-Saharan Africa and of which more than half are living in East Africa (FAO, 2015).

In the region, Ethiopia is one of the countries strongly associated with prolonged food security problem and recently set a clear agricultural production and productivity development policy to tackle the challenge and lift millions of smallholder farmers out of the food insecurity trap. This has been supported by research and extension endeavors particularly on improving the production and productivity of major staple crops widely grown by resource poor smallholder farmers. In this regard, effort that has been made on maize research and extension is a good example.

In Ethiopia, maize is widely produced and consumed by smallholder farmers. It is the major staple crop leading all other cereals in terms of production and productivity, and only surpassed by *tef* [1]in terms of area (CSA, 2014a). As a strategic food security crop, since 1970s, international and national research centers exerted collaborative efforts in improving the genetic potential of maize and its adaptability to different agro-ecologies in the country. Through this integrated effort, about 60 improved maize varieties have been released or registered in the country since the 1970s (MoA, 2012). Except in both extreme lowlands and highlands, maize is adapted to and grown in diverse agro-ecologies starting from mid-lowlands to highlands of the country.

Although a large number of maize varieties have been released, the level of improved maize variety adoption by smallholder farmers is still low (Feleke and Zegeye, 2006; Tura et al., 2010; Kassa et al., 2013). For smallholder farmers in maize-based systems, maize is directly associated

[1] *Tef* is an endemic and fine-grained cereal crop widely grown in Ethiopia.

with their food security. On average, 76% percent of maize produced is consumed at home (CSA, 2014b). No other cereal crop produced reaches to this level in terms of retention for home consumption. Thus, for smallholder farmers in maize-based systems, their perception on own-food security status is directly related to the amount of maize harvest they produced in a given year, which is again related to maize productivity influenced by factors such as varieties used and crop management efforts put forth.

The main objective of this paper is to assess the impact of improved maize variety adoption on food security of maize growing smallholder farmers using both objective and subjective assessment outcomes, i.e., per-capita food consumption expenditure and self-perceived and reported household food security status, respectively.

The remaining part of the paper is structured as follows. Section 2 presents survey design and data used in the analysis. Methodological framework is discussed in section 3. Section 4 discusses both descriptive and empirical analysis results and section 5 concludes the paper.

2. Survey Design and Data

The cross sectional data used in this analysis came from a stratified random sample of 2455 farm households from 39 districts in five regional states of Ethiopia (Tigray, Amhara, Oromia, Benishangul-Gumuz, and SNNPR[2]). First, a list of 118 maize growing districts was obtained from the CSA/IFPRI 2002 dataset that contained both the production data and area under maize in each district level. The CSA/IFPRI 2002 data showed that an average maize productivity of 2.051 tons/ha with a standard deviation of 0.648. Based on these values, we assigned a mean ± standard deviation cut-off points to categorize the districts in to a '*high'*, '*medium'*, and '*low'* maize potential. Accordingly, districts with average maize productivity of less than 1.403 tons/ha were assigned as '*low potential*', above 2.698 tons/ha as '*high potential*', and between 1.403 and 2.698 tons/ha (both inclusive) as '*medium potential*' maize districts. We then selected 39 districts (slightly above 30% of the districts listed in the sampling frame) using a proportionate probability sampling method. Geographical locations of the sample districts and the maize production potential of each district are given in Figure 1.

[2] Southern Nations, Nationalities and Peoples Regional State.

< Figure 1 here >

In each selected district, 4 peasant associations (PAs) were randomly selected from maize growing PAs and in each PA, an average of 10-16 farmers were randomly selected for one-to-one interviews. This resulted in a sample of 603 households from the high potential districts, 1528 and 324 from the medium and low potential districts respectively (Table 1).

< Table 1 here >

The household level survey was conducted on one-to-one basis using experienced and trained enumerators. The overall fieldwork was closely monitored and supervised by staff from the Ethiopian Institute of Agricultural Research (EIAR) and the International Maize and Wheat Improvement Center (CIMMYT).

A questionnaire was developed and tested to collect the adoption data. The questionnaire captured individual, household, farm and plot level characteristics, as well as the institutional environment. The individual characteristics included demographics such as age, gender, and education of the head of the household, and his or her knowledge of different varieties. Household characteristics included; resource endowments, farm and non-farm assets, and the use of maize varieties. Institutional factors included access to markets, institutions and infrastructure.

The characteristics of the different farm plots were also taken, in particular fertility, slope, soil type, distance from homestead, manager of each plot from the household members, etc.), crops grown on each plots including the detailed inputs used per plot, maize varieties grown per plot, source of maize seed and number of years/seasons the maize seed used was recycled, production and marketing constraints, and so forth. The data were collected during January to June 2011 and covered production and input use for the 2009/10 production seasons.

3. Methodological Framework

In this paper, we used combinations of methodologies to ensure robustness of empirical results. To determine factors affecting the adoption of improved maize varieties, a binary Probit model was used. An endogenously switching regression (ESR) model and a propensity score matching

(PSM) method were used to estimate the effect of improved maize variety adoption on household food security. The latter two methods are discussed below briefly.

3.1. Endogenous Switching Treatment Effect Regression Analysis

3.1.1. Econometric Model Specification

A survey of recent literature shows that many impact assessment studies based on cross-sectional data have moved towards endogenously switching regression model (Alene and Manyong, 2007; Amare et al., 2012; Asfaw et al., 2012; Kassie et al., 2014; Abdulai and Huffman, 2014; among others) The assumption behind using endogenously switching treatment effect regression is that, in addition to the observed variables, there might be unobservable farm and/or household characteristics that could potentially influence both the adoption of improved maize varieties and household food security. A farm household self-selects into adopting agricultural technologies due to observable and unobservable variables. Estimating the impact of technology adoption on household food security without accounting for this problem might suffer from potential endogeneity bias and thus the estimated results may over- or under-estimate impacts compared to the actual impact. To correct for this, endogenous switching regression analysis was used and selectivity is modeled using a Probit model. The overall econometric modeling framework used is described below.

A farmer (i) adopts improved maize varieties if the expected utility from adoption (U_a) is higher than the corresponding utility from non-adoption (U_{na}), i.e., $U_a - U_{na} > 0$. Let A_i^* be the latent variable that captures the benefit from adopting improved maize varieties by the i^{th} farmer, and given as:

$$A_i^* = Z_i\alpha + \varepsilon_i \quad where \quad A_i = \begin{cases} 1 \ if \ \ Z_i\alpha + \varepsilon_i > 0 \\ 0 \ \ otherwise \end{cases} \tag{1}$$

where Z is vector of household, farm and village level variables that affect the decision to adopt and/or not adopt improved maize varieties and ε is an error term. For households growing improved maize varieties and for those who didn't grow during the 2009/10 production season, the outcome equation (in this case, food security status) corrected for endogenous adoption is given as:

$$Regime\ 1{:}\ Y_{1i} = X_{1i}\beta_1 + \sigma_{1\varepsilon}\hat{\lambda}_{1i} + \eta_{1i} \quad if\ \ A_i = 1\ (IMV\ adopters) \tag{2a}$$

$$Regime\ 2{:}\ Y_{2i} = X_{2i}\beta_2 + \sigma_{2\varepsilon}\hat{\lambda}_{2i} + \eta_{2i} \quad if\ \ A_i = 0\ (non-adopters\ of\ IMVs) \tag{2b}$$

where Y_i is a binary food security status of household i under regime 1 (adopter of IMV) and 2 (local maize varieties), X_i is a vector of plot, household, farm, and village characteristics that affect maize productivity, and $\hat{\lambda}_{1i} = \frac{\phi(Z_i\hat{\alpha})}{\Phi(Z_i\hat{\alpha})}$ and $\hat{\lambda}_{2i} = \frac{\phi(Z_i\hat{\alpha})}{1-\Phi(Z_i\hat{\alpha})}$ are the inverse Mill's ratios (IMR) computed from the selection equation and are included in equations (2a) and (2b) to correct for selection bias in a two-step estimation procedure, i.e., endogenous switching regression. β and σ are parameters to be estimated, and η is an independently and identically distributed error term. The standard errors in equations (2a) and (2b) are bootstrapped to account for the heteroskedasticity arising from the generated regressors $(\hat{\lambda})$.

The adoption decision of improved maize variety could be endogenous in the outcome equation (food security) and estimating the outcome variable without correcting for the potential endogeneity could result into biased estimates. Thus, identification of the outcome equation from the selection equation using an instrumental variables method is important. For the outcome model to be identified, we used exclusion restrictions, where some variables affecting the selection variable but not the outcome variable are excluded from the outcome equation (Di Falco et al., 2011; Asfaw et al., 2012; Kassie et al., 2014; Shiferaw et al., 2014). Although we admit that getting a true instrument is empirically challenging, we used distance to seed dealers (*walking minutes*), number of traders known to farmer, and number of relatives (who could provide support) in and outside village as instrumenting variables affecting the decision to adopt IMV but not household food security. Using a falsification test, we checked the admissibility of these instruments. A falsification test is a way of checking whether instrumental variables are valid instruments if they affect the selection equation (adoption of IMV in our case) but not the outcome variable (food security). Accordingly, the falsification test on the selected instrumental variables shows that they jointly and statistically significantly affect the decision of IMV adoption (in selection equation: Chi^2=16.26; P-value=0.001) but not per-capita food consumption expenditure and household food security status.

3.1.2. Conditional Expectations and Treatment Effects

The structure of the expected conditional and average treatment effects under actual and counterfactual scenario given in table 2 are specified as:

(a) $E[Y_{1i}|X, A_i = 1] = X_{1i}\beta_1 + \sigma_{1\varepsilon}\hat{\lambda}_{1i}$ *(Adopters with adoption of IMV)* (3a)

(b) $E[Y_{2i}|X, A_i = 0] = X_{2i}\beta_2 + \sigma_{2\varepsilon}\hat{\lambda}_{2i}$ *(Non-adopters without-adoption)* (3b)

(c) $E[Y_{2i}|X, A_i = 1] = X_{1i}\beta_2 + \sigma_{2\varepsilon}\hat{\lambda}_{1i}$ *(Adopters had they decided not to adopt IMV)* (3c)

(d) $E[Y_{1i}|X, A_i = 0] = X_{2i}\beta_1 + \sigma_{1\varepsilon}\hat{\lambda}_{2i}$ *(Non-adopters had they decided to adopt IMV)* (3d)

Situations (a) and (b) are observed from the survey data. However, (c) and (d) are the hypothetically expected situations (counterfactual outcome) where the treated happened to be untreated, and the untreated happened to be treated. Accordingly, the expected change in the level of food security for households adopted IMV, i.e., the average effect on the treated plots (ATT) is given as:

ATT = (a)-(c) =$E[Y_{1i}|X, A_i = 1] - E[Y_{2i}|X, A_i = 1,] = X_{1i}(\beta_1 - \beta_2) + \hat{\lambda}_1(\sigma_{1\varepsilon} - \sigma_{2\varepsilon})$ (4)

Similarly, the expected change in the food security status of a household not growing IMV had they grew IMV, i.e., the average effect on the untreated households (ATU) is given as:

ATU = (d)-(b) =$E[Y_{1i}|X, A_i = 0] - E[Y_{2i}|X, A_i = 0] = X_{2i}(\beta_1 - \beta_2) + \hat{\lambda}_2(\sigma_{1\varepsilon} - \sigma_{2\varepsilon})$ (5)

where X_1 and X_2 are set of explanatory variables affecting maize productivity in regime 1 and 2, respectively. β_1 and β_2 are parameters to be estimated.

It might be the case that households growing improved maize varieties might have had better food security status than households growing only local maize varieties, regardless of the fact that these households are growing IMV, due to unobservable factors that could potentially affect the status of household food security. Following Carter and Milon (2005), we can also define the effect of base heterogeneity for households growing IMV (i.e., BH_1) as:

$BH_1 = (a) - (d) = (X_{1i} - X_{2i})\beta_1 + \sigma_{1\varepsilon}(\lambda_{1i} - \lambda_{2i})$ (6a)

Similarly, the base heterogeneity for maize plots under non-improved varieties (BH_2) is given as:

$$BH_2 = (c) - (b) = (X_{1i} - X_{2i})\beta_2 + \sigma_{2\varepsilon}(\lambda_{1i} - \lambda_{2i}) \quad (6b)$$

Finally, transitional heterogeneity (TH) is explored by having a close look at whether the effect of growing improved maize variety on household food security is larger for households that are actually growing IMV than for households growing local varieties in the counterfactual case that they would have been growing IMV, that is, the difference between equations (6a) and (6b) (i.e., TT and TU).

< Table 2 here >

3.2. Propensity Score Matching

In assessing the impacts of the treatment effect, getting proper counterfactuals from a cross-sectional survey data is a challenge. Propensity score matching (PSM) helps in matching sample households that fall into the treatment group with their proper counterfactuals (non-treatment group but with attributes similar to the sample individuals under treatment group). In this paper, the units to be matched are households growing IMV with their counterfactual households growing only local varieties using three matching algorithms, viz., nearest neighbor, kernel and radius matching methods. Whether the counterfactual households have the same characteristics with the treatment group for observed variables are also tested. Finally, the average treatment effect on the treated (ATT), i.e., the effect of IMV adoption on household level food security status, is estimated based on the different matching methods indicated above. In addition, we also used Generalized Propensity Score (GPS) approach to evaluate the effects of continuous treatment (maize area under IMV) on the response of outcome variables, probability of food security and per-capita expenditure on food consumption (Hirano and Imbens, 2004; Bia and Mattei, 2007).

4. Results

4.1. Descriptive Analysis

Descriptive analysis in table 3 shows that the average per-capita maize consumption, marketed maize surplus, per capita food consumption expenditure and food security status are on the higher side for adopters than non-adopter sample households. Looking more in depth at the different cluster of adopter households divided in four groups depending on maize area allocated to improved varieties, both the average per capita maize consumption and average quantity of maize surplus sold to market are increasing with increasing area under improved maize. The average per-capita food consumption expenditure is higher for lower middle quintile and the proportion of sample households reported food security is high for upper middle quintile households.

< Table 3 here >

The average per capita food consumption expenditure for the total sample households was ETB[3] 2170.68 ($127). However, compared to non-adopters, the average per capita food consumption expenditure was higher for IMV adopters. Interestingly, looking at the binary food security variable, there is no statistical difference between adopters and non-adopters in terms of the proportion of households who self-reported as food secure. But, when we look at the four clusters of food security (chronic, transitory, breakeven and food surplus), relatively a higher proportion of non-adopter households reported as being under chronic food insecurity and a larger proportion of adopters reported food surplus.

In table 4, descriptive statistics of explanatory variables used in adoption and impact analysis are presented. Accordingly, the proportion of male headed households is higher for those who adopted IMV. Non-adopter households relatively have older household heads with lower levels of education. Average family size was higher for adopter households. IMV adoption was high in high and medium maize potential areas. When adoption was categorized by the five administrative regions, larger proportion of sample households were non-adopters in Oromia, Benishangul Gumuz and Tigray regions whereas more proportion of sample households found to

[3] ETB is Ethiopian Birr (Currency), where 1USD was equivalent to 17.01ETB during the survey period.

be adopters in Amhara and SNNPR. In general, adopter households know more number of traders and have more social networks. Compered to non-adopters, adopter households has got satisfied with their credit needs for fertilizer and improved seed purchases.

<Table 4 here >

4.2. Adoption of IMVs

Probit estimation results in table 5 show that household and farm characteristics, agro-ecologic potential for maize production, and social capital had significant influence on farm household's decisions to adopt improved maize varieties. Farm households with more educated heads and larger family size tend to adopt improved maize varieties. Compared to low potential areas for maize production, the probability of IMV adoption is higher for maize growing households both in high and medium potential areas. Controlling for diversities in maize potential, there is also a difference in the probability of adoption across administrative regions. Compared to maize growing households in the SNNPR, maize growing farmers in Amhara region have more probability of adopting improved maize varieties. Unexpected results, which needs further investigation is that the probability of adopting IMVs increases with increasing distance to the main market and decreasing with increasing share of fertile plots a household owns.

<Table 5 here >

4.3. Impacts of IMVs on Food Consumption and Food Security

The ESR model results reported in table 6 show that adoption of improved maize varieties in maize growing areas of Ethiopia has significant food security effects. Had the adopting households not adopted, their average per capita food consumption would have decreased by ETB 308.02 ($18). For an average family size of 6.5 per household, the average household level consumption loss resulting from not adopting IMV could be as high as $117 per household per annum. On the other hand, if non-adopter households would have adopted IMVs, their per capita food consumption would have increased by ETB 312.29, which is slightly higher than the benefit adopters would have lost due to non-adoption.

Looking into the binary food security variable, the average probability of being food secure decreases by 2.4 percentage points for IMV adopters had they not adopted. In the same way, the average probability of food security increases by 2.1 % point for non-adopters had they adopted IMVs. A closer look at the the four categories of food security status showed that larger probability differences are observed for households who reported that they were food secure. For these sample farmers their average probability of being food surplus decreased by 2.7 percentage points if they had not adopted IMVs and for non-adopters, their probability of being food surplus increased by 2.5 percentage points had they adopted IMVs. These percentage points seem small in magnitude but the difference is statistically significant at 1% level. As the main purpose of this paper is not to explain what factors affect the per-capita food consumption expenditure and food security of maize producing households, the endogenously switching regression results used as an intermediate input to estimate ATT and ATU are not discussed but presented in table A1 as annex.

< Table 6 here >

Figure 2 gives distribution of adopters and non-adopter households by their respective propensity scores and common support area. About 98% of the sample households fall in common support area showing that there is good overlap of adopters and non-adopters' distribution. These data therefore lend themselves to matching of adopters to their potential counterfactuals (in the non-adopter categories).

< Figure 2 here >

In table 7, using three matching algorithms (nearest neighbor, kernel and radius matching), average treatment effects are presented based on propensity score matching method. For the three matching algorithms, there is a significant difference in per-capita food consumption between adopters and non-adopter households. In addition, the self-reported food security status of households is significantly different between adopters and non-adopters particularly for those who reported their status as food surplus.

< Table 7 here >

Generalized propensity score (GPS) approach is also used to analyze the continuous treatment effects of IMV adoption on the outcome variables (per-capita food consumption expenditure and household food security status). Figure 3 presents the dose-response and marginal treatment effects on the probability of food security and per-capita food consumption expenditure in relation to area under improved maize variety. Accordingly, the expected probability of food security reaches its maximum when households allocate about 1-1.5 ha of their land to IMVs. There is a positive marginal probability of food security up to the first 1 ha of area under IMVs. Looking at the per capita food consumption expenditure, both the expected and marginal per-capita consumption expenditure are increasing with area under IMV and the marginal consumption expenditure reaches saturation point after 1.5 ha of farmland is allocated to IMVs.

< Figure 3 here >

5. Conclusions and Implications

Using survey data collected in 2011 from 2455 sample households in 39 maize growing districts of Ethiopia, and applying endogenously switching regression approach supported by binary propensity score matching method, this paper analyzes the impact of IMV adoption on farm household food security. The two methodologies were used to reduce the potential effect of self-selection bias due to both observable and unobservable household and farm characteristics. In addition, we used generalized propensity score approach to evaluate the continuous treatment effect of IMVs on household food security. Results obtained are consistent across the empirical approaches we used.

Given the number of IMVs released and registered in the country, household level adoption of these varieties is still low. Education level of household head, farm size, agro-ecological factors that enhance potentials for maize production, social networks are the major factors influencing household decision in adopting IMVs. Impacts of IMV adoption on per-capita food consumption is significantly high for adopter households compared to their counterfactuals (had they not adopted IMVs). The per-capita food consumption impact of IMV is slightly higher for non-adopters had they adopted IMVs. Looking into the different status of households in their level of food security, adoption of IMV significantly affects the probabilities of being food surplus both for adopter and non-adopter households. This implies that agricultural policies and strategies targeting farm household food security in maize-based systems shall encourage the adoption of IMVs.

Acknowledgements

The authors would like to acknowledge The Standing Panel for Impact Analysis (SPIA) in the CGIAR for financing the Diffusion and Impact of Improved Varieties in Africa (DIIVA) project. Data used in the analysis were collected through the financial support from DIIVA project. In addition, part of the survey was covered under the Sustainable Intensification in Maize-Legume Cropping Systems for Food Security in Eastern and Southern Africa (SIMLESA) program funded by the Australian Government through the Australian Center for International Agricultural Research (ACIAR).

References

Abdulai, A., Huffman, W., 2014. The adoption and impact of soil and water conservation technology: An endogenous switching regression application. *Land Econ.* 90(1), 26-43.

Alene, D.A., Manyong, V.M., 2007. The effects of education on agricultural productivity under traditional and improved technology in northern Nigeria: An endogenous switching regression analysis. *Empir. Econ.* 32,141-159.

Amare, M., Asfaw, S., Shiferaw, B., 2012. Welfare impacts of maize-pigeonpea intensification in Tanzania. *Agric. Econ.* 43(1), 27-43.

Asfaw, S., Shiferaw, B., Simtowe, F., Lipper, L., 2012. Impact of modern agricultural technologies on smallholder welfare: Evidence from Tanzania and Ethiopia. *Food Policy.* 37(3), 283-295.

Beddington, J., 2010. Food Security: Contributions from Science to a new and greener revolution. *Philos T Roy Soc B.* 365:61-71.

Bia, M., Mattei, A., 2007. Application of the Generalized Poropensity Score. Evaluation of public contributions to Piedmont enterprises. Working Paper n. 89. Department of Public Policy and Public Choice (POLIS) Universita del Piemonte Orientale 'Amedeo Avogadro' Alessandria.

Brown, M.E., Funk, C.C., 2008. Food Security under Climate Change. *Science*. 319:580-581.

Carter, D.W., Milon. J.W., 2005. Price Knowledge in Household Demand for Utility Services. *Land Econ.* 81, 265-283.

CSA, 2014a. Report on Area and production of major crops (Volume I). The Federal Democratic Republic of Ethiopia. Central Statistical Agency, May 2014, Addis Ababa.

CSA, 2014b. Report on Crop and livestock product Utilization (Volume VII). The Federal Democratic Republic of Ethiopia. Central Statistical Agency, September 2014, Addis Ababa.

Di Falco, S., Veronesi, M., Yusuf, M., 2011. Does adaptation to climate change provide food security? A micro-perspective from Ethiopia. *Am. J. Agr.Econ.* 93(3), 829-846.

FAO, 2015. The state of food security in the World. Food and Agriculture Organization of the United Nations, Rome.

Feleke, S., Zegeye, T., 2006. Adoption of improved maize varieties in Southern Ethiopia: Factors and strategy options. *Food Policy.* 31(5), 442–457.

Godfray,H.C.J., Beddington, J.R., Crute, I.R., Haddad, L., Lawrence, D., Muir, J.F., Pretty, J., Robinson, S., Thomas, S.M., Toulmin, C. 2010. Food Security: The Challenge of feeding 9 Billion People. *Science*. 327:812-818.

Hirano, K., Imbens, G.W., 2004. The Propensity Score with Continuous Treatments. http://scholar.harvard.edu/imbens/files/hir_07feb04.pdf

Kassa, Y., Kakrippai, R.S., Legesse, B., 2013. Determinants of adoption of improved maize varieties for male headed and female headed households in West Harerghe zone, Ethiopia. *Int. J. Econ. Behav. Organ.* 1(4), 33-38

Kassie, M., Jaleta, M., Mattei A., 2014. Evaluating the impact of improved maize varieties on food security in Rural Tanzania: Evidence from a continuous treatment approach. *Food Security*. 6(2), 217-230.

MoA, 2012. *Crop Diversity Register.* Issue No. 15. Ministry of Agriculture, Animal and Plant Health Regulatory Directorate. June 2012, Addis Ababa.

Parry, M., Rosenzweig, C., Iglesias, A., Fischer, G., Livermore, M. 1999. Climate Change and World food security: a new assessment. *Global Environ Change*. S51-S67.

Shiferaw, B., Kassie, M., Jaleta, M., Yirga, C., 2014. Adoption and Impacts of improved wheat varieties on food security in Ethiopia. *Food Policy*. 44, 272-284.

Tura, M., Aredo, D., Tsegaye, W., La Rovere, R., Mwangi, W., Mwabu, G., 2010. Adoption and continued use of improved maize seeds: Case study of central Ethiopia. *Afr. J. Agr. Res.* 5(17), 2350-2358.

Tables

Table 1. Distribution of Sample households

Admin Region	Maize potential			Total
	Low	Medium	High	
Tigray	55	0	0	55
Amhara	102	184	46	332
Oromia	150	863	347	1,360
Benishangul Gumuz	0	0	96	96
SNNP	0	386	98	484
Total	307	1,433	587	2,327

Table 2. Expected conditional and average treatment effects

Category	Decision stage: To adopt IMVs	Decision stage: Not to adopt IMNs	Adoption Effect
Adopters of IMV	(a) $E[Y_{1i}\|X_{1i}, A_i = 1]$	(c) $E[Y_{2i}\|X_{1i}, A_i = 1]$	ATT
Non-adopters of IMV	(d) $E[Y_{1i}\|X_{2i}, A_i = 0]$	(b) $E[Y_{2i}\|X_{2i}, A_i = 0]$	ATU
Heterogeneity effect	BH_1	BH_2	TH

Note: (a) and (b) represent observed outcomes (per-capita food consumption and household food security status);
(c) and (d) represent counterfactual outcomes (per-capita food consumption and household food security status);
A_i=1 if household i adopted IMVs;
A_i=0 if household i did not adopt IMVs;
Y_{1i}= Per-capita food consumption and household food security status if a household adopted IMVs;
Y_{2i}= Per-capita food consumption and household food security status if a household did not adopt IMVs;
ATT =average treatment effect on treated;
ATU=average treatment effect on untreated;
BH_1=the effect of base heterogeneity for IMV adoption;
BH_2=the effect of base heterogeneity for non-adoption of IMVs;
TH=transitional heterogeneity (ATT-ATU)

Table 3. Descriptive statistics of outcome and treatment variables

		Total sample (N=2327)		Adopters (N=632)		Non-adopters (N=1695)	
Variable	Description	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Food consumption expenditure	Per capita food consumption expenditure (Birr)	2170.680	3050.489	2388.985**	3107.870	2089.412	3025.756
Food security	Dummy_ Household food security (1=yes)_HH self-assessment	0.666	0.472	0.685	0.465	0.659	0.474
Chronic food insecurity	Dummy_ Household in chronic food insecurity (1=yes)	0.026	0.160	0.019	0.137	0.029*	0.168
Transitory food insecurity	Dummy_ Household in transitory food insecurity (1=yes)	0.308	0.462	0.296	0.457	0.312	0.463
Breakeven food security	Dummy_ Household in breakeven food security (1=yes)	0.530	0.499	0.522	0.500	0.533	0.499
Food surplus	Dummy_ Household in food surplus food security (1=yes)	0.136	0.343	0.162**	0.369	0.126	0.332
Binary adoption	Adopted improved maize varieties (1=yes)	0.272	0.445	1.000	0.000	0.000	0.000

****, ** and * are significantly higher than the other group mean at 1%, 5% and 10% level.*

Table 4. Descriptive statistics of explanatory variables

		Total sample (N=2327)		Adopters (N=632)		Non-adopters (N=1695)	
Variable	Description	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Sex of household head	Sex of household head (1=male, 0=female)	0.920	0.272	0.933*	0.249	0.914	0.280
Age of household head	Age of household head (years)	42.320	12.744	41.344	13.189	42.683**	12.559
Education of household head	Education of household head (years of schooling)	2.954	3.305	3.468***	3.469	2.762	3.222
Total farmland	Total land operated by a household (ha)	2.536	2.422	2.570	2.403	2.523	2.430
Family size	Household size	6.587	2.536	6.970***	2.652	6.445	2.478
High potential	Dummy_ High maize potential district (1=yes)	0.252	0.434	0.274*	0.446	0.244	0.430
Livestock owned	Livestock owned (TLU)	5.415	5.366	5.782**	0.226	5.276	0.128
Medium potential	Dummy_ Medium maize potential district (1=yes)	0.616	0.487	0.660***	0.474	0.599	0.490
Low potential	Dummy_ Low maize potential district(1=yes)	0.132	0.338	0.066	0.249	0.156***	0.363
Amhara	Dummy_ Amhara (1=yes)	0.143	0.350	0.184***	0.387	0.127	0.334
Oromia	Dummy_ Oromia (1=yes)	0.584	0.493	0.530	0.499	0.605***	0.489
Benishangul Gumuz	Dummy_ Benishangul Gumuz (1=yes)	0.041	0.199	0.025	0.157	0.047***	0.212
Southern Nations and Nationalities and People	Dummy_ SNNP (1=yes)	0.208	0.406	0.261***	0.440	0.188	0.391
Tigray	Dummy_ Tigray (1=yes)	0.024	0.152	0.000	0.000	0.032***	0.177
Number of relatives	Number of relatives within and outside village a household relies on	23.757	38.344	29.810***	58.637	21.500	26.820
Number of traders	Number of traders within and outside village a household knows	1.807	4.136	2.122**	2.803	1.685	4.542
Distance to main market	Walking distance to main market (minutes)	89.922	69.212	98.584***	72.620	86.693	67.636
Distance to seed dealers	Walking distance to maize seed source (minutes)	56.542	67.100	56.839	59.569	56.429	69.784
Share of fertile land	Share of fertile land a household owns	0.425	0.415	0.369	0.416	0.446***	0.412
Information from government	Variety information from government (1=yes)	0.733	0.442	0.726	0.446	0.736	0.441
Information from neighboring farmers	Variety information from neighboring farmers (1=yes)	0.055	0.228	0.051	0.219	0.057	0.232
Need and got credit for seed	Need and got credit for seed purchase (1=yes)	0.052	0.222	0.075***	0.263	0.042	0.200
Need and got credit for fertilizer	Need and got credit for fertilizer purchase (1=yes)	0.089	0.285	0.116***	0.320	0.078	0.267

****, ** and * are significantly higher than the other group mean at 1%, 5% and 10% level.*

Table 5. Decision of adopting IMV: Probit model

Explanatory variables	Coefficient	Std. Err.	Marginal Effects
Sex of household head	0.039	0.125	0.014
Age of household head	-0.003	0.003	-0.001
Education of household head	0.042***	0.011	0.015
Total farmland	0.008	0.024	0.003
Family size	0.041***	0.014	0.014
Livestock owned	-0.003	0.007	-0.001
High potential	0.687***	0.130	0.256
Medium potential	0.653***	0.116	0.219
Amhara [a]	0.496***	0.110	0.189
Oromia [a]	0.074	0.084	0.026
Benishangul Gumuz [a]	-0.323*	0.193	-0.105
Number of relatives	0.004***	0.001	0.001
Number of traders	0.014*	0.008	0.005
Distance to main market	0.001***	0.000	0.001
Distance to seed dealers	-0.001	0.001	0.001
Share of fertile land	-0.154*	0.079	0.055
Variety information from government	-0.042	0.082	0.015
Variety information from farmers	-0.006	0.152	0.002
Maize disease constraint (1=yes)	0.104	0.069	0.037
Need and got credit for seed	0.265	0.181	0.098
Need and got credit for fertilizer	0.187	0.140	0.069
Constant	-1.640***	0.240	
Number of observations	*-1032.54*		
LR chi2(20)	*1752*		
Prob > chi2	*140.95*		
Pseudo R2	*0.000*		
Log likelihood	*0.0639*		

****, ** and * are significant at 1%, 5% and 10% level.*
[a] Tigray region is areference

Table 6. Average treatment effects using endogenous switching regression model

Outcome variable	Farm household type and treatment effect	Decision stage: To adopt	Decision stage: Not to adopt	Average treatment effect
Per capita food consumption	Adopters (ATT)	2430.209	2122.187	308.023(55.447)***
	Non-adopters (ATU)	2545.422	2233.138	312.285(37.938)***
Binary food security	ATT	0.685	0.662	0.024(0.011)**
	ATU	0.678	0.657	0.021(0.008)***
Chronic food security	ATT	0.031	0.027	0.004 (0.003)
	ATU	0.031	0.029	0.001(0.001)
Transitory food security	ATT	0.293	0.311	-0.019(0.010)**
	ATU	0.299	0.313	-0.013(0.008)**
Breakeven foof security	ATT	0.521	0.528	-0.007(0.008)
	ATU	0.518	0.533	-0.015(0.006)***
Food surplus	ATT	0.162	0.134	0.027(0.008)***
	ATU	0.151	0.125	0.025(0.005)***

****, ** and * are significant at 1%, 5% and 10% level.* ATT=Average treatement effect on treated; ATU=Average treatment effect on untreated

Table 7. Average treatment effects using PSM

Outcome variable	Matching algorithm	Mean outcome variables based matched observations		
		Adopters	Non-adopters	ATT
Per capita food consumption expenditure (ETB/head)	NNM	2432.919	2217.521	215.398(175.257)*
	KBM	2432.919	2217.521	215.398(175.257)*
	Radius	2432.919	2223.46	209.461(178.625)
Binary food security	NNM	0.678	0.653	0.025(0.024)
	KBM	0.678	0.653	-0.025(0.024)
	Radius	0.678	0.662	0.016(0.024)
Chronic food security	NNM	0.021	0.029	-0.008(0.008)
	KBM	0.021	0.029	0.008(0.008)
	Radius	0.021	0.029	0.008(0.008)
Transitory food security	NNM	0.301	0.318	-0.018(0.024)
	KBM	0.301	0.318	0.018(0.024)
	Radius	0.031	0.308	0.008(0.024)
Breakeven food security	NNM	0.515	0.530	-0.014(0.026)
	KBM	0.515	0.530	0.014(0.026)
	Radius	0.515	0.535	0.019(0.026)
Food surplus	NNM	0.163	0.123	0.039(0.018)**
	KBM	0.163	0.123	0.039(0.018)**
	Radius	0.163	0.127	-0.035(0.018)**

****, ** and * are significant at 1%, 5% and 10% level. NNM=Nearest neighbor matching, KBM=Kerne-based matching*

Table A1. ESR estimates for food consumption expenditure and probabilityy of food security

	Per capita food consumption (Birr)				Probability of food security			
	Adopters		Non-adopters		Adopters		Non-adopters	
Explanatory variables	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
Sex of household head	-796.215	910.631	-312.832	636.947	0.246	0.254	0.167	0.141
Age of household head	9.777	12.372	9.503	12.904	-0.009*	0.006	-0.002	0.003
Education of household head	62.993	61.654	14.063	35.493	-0.093***	0.029	-0.004	0.021
Total farmland	75.747	55.070	195.930***	35.125	0.043	0.044	0.147***	0.041
Family size	-247.517***	56.016	-268.072***	60.180	-0.056	0.035	-0.034	0.023
Livestock owned	2.292	22.535	7.416	13.116	0.029*	0.015	0.032**	0.013
High potential	-392.167	392.256	-339.106	279.319	-1.413***	0.465	-0.371	0.240
Medium potential	221.382	437.639	-207.231	226.719	-1.787***	0.451	-0.665***	0.214
Amhara [a]	-1859.557	1393.196	64.601	647.731	-0.005***	0.001	-0.002***	0.001
Oromia [a]	-1137.746	1259.191	360.161	486.594	-0.061	0.320	0.668	0.559
Benishangul Gumuz [a]	0.000		-341.804	563.611	0.428***	0.153	0.791*	0.460
SNNPR [a]	-843.939	1367.786	1798.670***	633.037	1.955***	0.537	1.443***	0.456
Distance to main market	-0.320	1.704	1.698	1.825	0.000	(omitted)	0.712	0.468
Share of fertile land	-219.510	334.695	-182.228	258.029	0.155	0.152	0.226**	0.099
Variety information from government	452.975*	236.876	-520.339	348.425	-0.540	0.290	-0.145	0.176
Variety information from farmers	-566.409**	285.454	-933.749**	457.446	-1.132***	0.360	-0.324	0.259
Maize disease constraint (1=yes)	804.392**	382.658	190.699	222.966	0.194	0.339	0.132	0.217
Need and got credit for seed	-762.090**	378.229	227.578	561.930	0.497***	0.174	0.368***	0.112
Need and got credit for fertilizer	253.801	376.898	-161.719	334.815	-0.541***	0.152	-0.176*	0.093
IMR	26.466	1000.016	524.036	878.081	-2.717***	0.727	-1.021	0.680
Constant	4641.866	2443.585	3452.706***	1029.249	5.805***	1.479	-0.714	0.475
Number of obs.	*571*		*1190*			*568*	*1183*	
F-Value/Wald Chi2	*4.32*		*7.72*			*110.66*	*117.16*	
Prob > F	*0.000*		*0.000*			*0.000*	*0.000*	
R-squared/Pseudo r2	*0.0835*		*0.0605*			*0.1706*	*0.1103*	
Root MSE/P	*3112.8*		*3469.3*					
Log pseudo likelihood						*-293.575*	*-675.776*	

****, ** and * are significant at 1%, 5% and 10% level.* [a] *Tigray region is areference.*

Figures

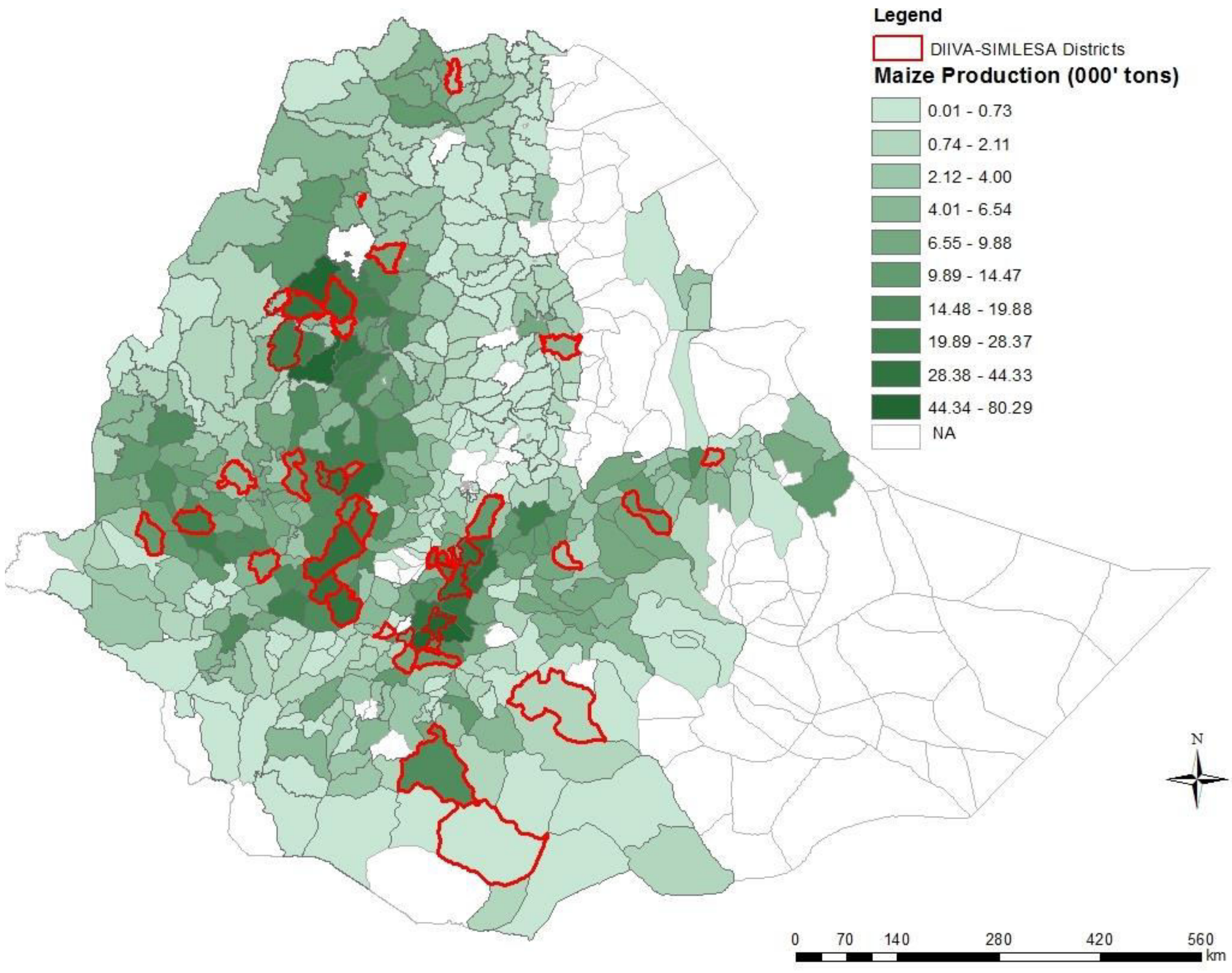

Figure 1. Distribution of sample districts where the survey was conducted.

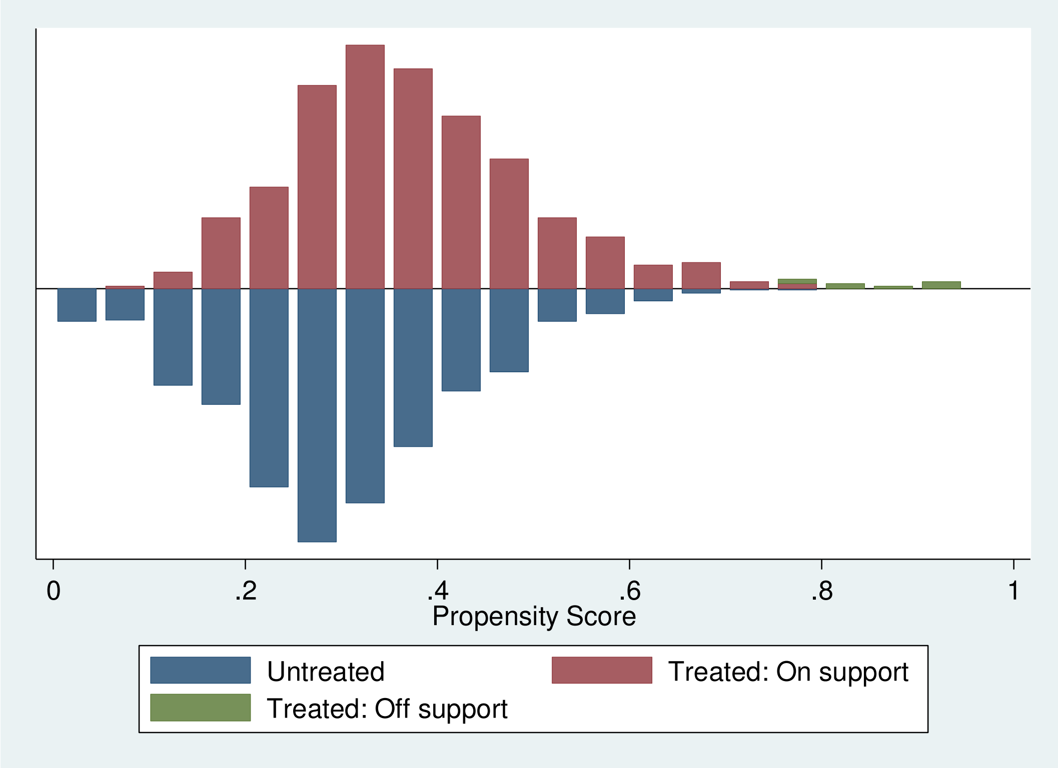

Figure 2. Distribution of adopter (treated) and non-adopters(untreated) housheoldsby their respective propensity score and common support area

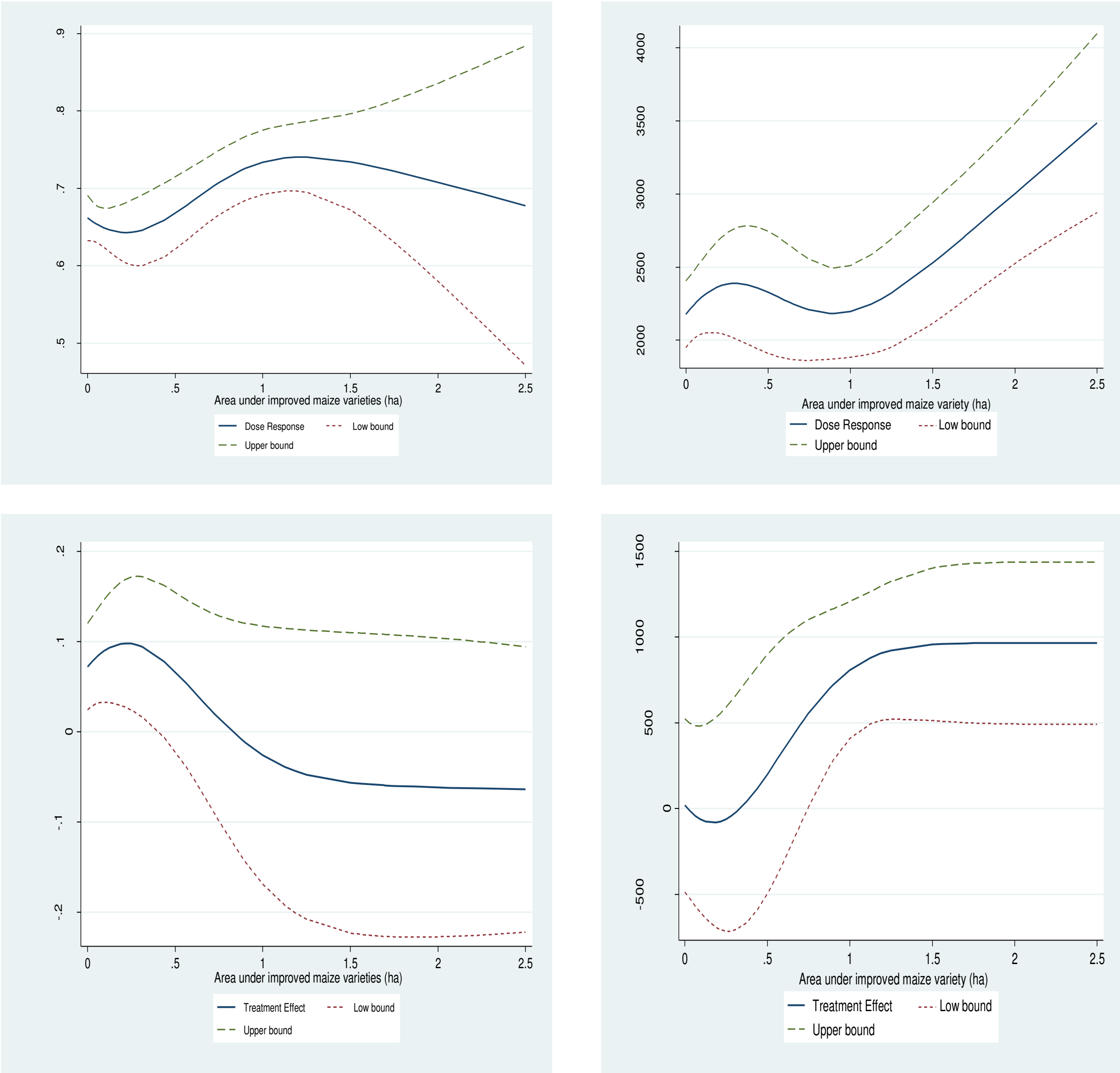

Figure 3. Dose response and marginal treatment effects on the probability of food security and per-capita food consumption expenditure.