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### **Role of hybrid maize adoption on food security in Kenya: an application of two-step generalized method of moments (gmm2s)**

*Zachary M. Gitonga and Hugo De Groote*

*Invited paper presented at the 5th International Conference of the African Association of  
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# **Role of hybrid maize adoption on food security in Kenya: an application of two-step generalized method of moments (gmm2s)**

*Zachary M. Gitonga<sup>1</sup> and Hugo De Groote<sup>2</sup>*

*1: University of Cape Town*

*2: International Maize and Wheat Improvement Centre (CIMMYT)*

*Prepared for*

the 5th Conference of African Association Agricultural Economists (5th CAAAE) 2016 to be held at the United Nations Conference Centre - Addis Ababa, Ethiopia, 23-26 September, 2016.

## **Abstract**

Kenya has made significant strides in developing hybrid maize varieties and is considered a success story in the region. The number of hybrid varieties released per year has been increasing but average maize yields and consumption have been declining resulting to food insecurity in both urban and rural areas. Past studies evaluated the impact of hybrid maize on income inequality and poverty but none on food security impact in Kenya. This paper used representative data from 1344 households to answer this question. Three food security indicators are considered: Months of adequate household food provisioning (MAHFP), household food insecurity access scale (HFIAS) scores and household food insecurity access prevalence (HFIAP). The paper applies two step gmm2s specification and corresponding tests for relevance and validity of the instruments. Household food insecurity prevalence is assessed using generalized ordered logit model. Food security increase with hybrid maize adoption, maize sales, wealth, education, access to financial services and irrigation water but decline with household size. Food security also vary with agro ecological zones. Hybrid maize adoption reduces the risk of being moderately and severely food insecure by 5% and 13% respectively. Results suggest the need for policies that enhance hybrid seed adoption, surplus production, education, improve welfare and promote family planning.

**Keywords:** Kenya. HFIAS, Food insecurity prevalence. Ivreg2. gmm2s,

## **1. Introduction**

Maize breeding programs in Kenya is often considered a success story in the region (Mathenge, Smale, et al., 2014, Olwande and Smale, 2012). This has resulted in increased number of improved maize varieties, mostly hybrids, released over the years. This however, has not been matched by an increase in maize yields (faostat,2012), partly due to low adoption in some zones, erratic weather, poor agricultural practices and high cost of inputs (Gitu, 2006, Ogada, Mwabu, et al., 2014). Yields have stagnated below two tons per hectare and with ever increasing population, the gap between production and consumption is widening, resulting in declining consumption per capita from 120kg/person/year three decades ago to only 77kg/person/year in 2012 (Gitu, 2006).

Kenya's annual average maize production over the last decade is about 2.9 million tons with 2012 recording the highest production of 3.6 million tons (Kamau, 2013). Maize consumption however is much higher than production at 3.9 million tons, leaving a deficit that has to be bridged by importation and food aid. The country remains food insecure in both urban and rural areas and particularly in drier semi arid zones (Gitu, 2006). Maize production has also been affected by the outbreak of the maize lethal necrotic virus (MLNV) disease in Central Kenya, South and North Rift regions of the country (Kamau, 2013).

In view of this mismatch between the increasing hybrid release and declining yields and consumption per capita, there is a need to empirically analyze their impact on welfare of the farmers who adopt them. The impact of maize hybrids on income, poverty, and inequality among the Kenya's smallholder farmers has been conducted (Mathenge, Smale, et al., 2014, Mwabu, Mwangi, et al., 2007). Both studies found a positive relationship between adoption of hybrid maize varieties and welfare outcomes. Suri (2009) evaluated the relationship between hybrid maize adoption in Kenya and yields. Kassie, Jaleta, et al. (2014) evaluated impact of improved maize varieties on farm household's subjective evaluation of food security in Tanzania and found a positive relationship. The impact hybrid maize adoption on household food security in Kenya however is yet to be studied. The objective of this paper is to evaluate the impact of hybrid maize adoption on household food security using three indicators namely months of adequate household food provisioning (MAHFP), household food insecurity access scale (HFIAS) scores and household food insecurity access prevalence (HFIAP), (Bilinsky and Swindale, 2010, Coates, Swindale, et al., 2007).

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Kenya's annual maize consumption (3.9 million tons) is much higher than the production which is about 2.9 million tons (Kamau, 2013). The deficit has to be bridged by importation and food aid. The country remains food insecure in both urban and rural areas and particularly in drier semi-arid zones (Gitu, 2006).

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## 2. Methodology

### 2.1. Conceptual framework

Hybrid maize varieties are bred for higher yields. We therefore can anticipate adopting households to produce more than non-adopters. We posit that farmer's decision to grow maize hybrids is a function of both individual and household demographic and social economics factors. Individual factors include age, farming experience and education of the household head, all measured in years.

Households with educated members are more likely to be food secure because of the possibility of having alternative sources of livelihood (Bashir, Schilizzi, et al., 2012). Adoption of hybrid maize has been shown to increase with increase in education (Ogada, Mwabu, et al., 2014). Bashir, Schilizzi, et al. (2012) also found a negative relationship between age and food security. Kassie, Jaleta, et al. (2014) found a positive relationship between land area cultivated and food security. Household factors include household size, access to financial services, the distance to a passable road, wealth endowment and income. Larger families, though not always, are more likely than not to be poor and food insecure (Widyanti, Suryahadi, et al., 2009). Adoption of agricultural technologies like improved hybrids is an increasing function of wealth and income (Hamazakaza, Smale, et al., 2013) and so is the access to infrastructure and institutional services (Aloyce, Kaliba, et al., 2000, Munyua, Hellin, et al., 2010).

### 2.2. Impact of Hybrid maize adoption on food security

The impact of the hybrid maize adoption on food security could be estimated by the following ordinary least squares equation:

$$\text{Foodsecurity}_i = X_i' \beta + \delta \text{Hybrid}_i + \gamma_{\text{nonobservables}} + \mu_i \dots\dots\dots 3$$

where Hybrid is a dummy variable indicating whether or not a farmer adopted hybrid maize.

Unobservable variables are not measured and hence the estimated equation will be:

$$\text{Foodsecurity}_i = X_i' \beta + \delta \text{Hybrid}_i + \varepsilon_i \dots\dots\dots 4$$

Where  $\varepsilon_i = \gamma_{\text{nonobservables}} + \mu_i$

Assuming the rest of the regression is correctly specified, parameter  $\delta$  estimates the impact of hybrid adoption on food security outcome of household<sub>i</sub>. This parameter however would overestimate the treatment effect if the typical household that chooses to grow hybrid would

have relatively better food security outcome whether or not it adopted i.e. ( $\gamma \neq 0$ ). Selection on unobservables would result in endogeneity problem making the estimates biased and inconsistent. i.e  $E(\varepsilon|X) \neq 0$

$$\text{Let the Potential food security outcome} = \begin{cases} Y_{1i} & \text{if } D_i = 1 \\ Y_{0i} & \text{if } D_i = 0 \end{cases}$$

where D is hybrid maize adoption binary dummy variable  $D_i = \{0,1\}$  that takes value of 1 if the household adopts and 0 otherwise.

Based on the potential outcome, the observed outcome can be written as  $Y_i = Y_{0i} + (Y_{1i} - Y_{0i}) * D_i$  .....4.

The problem is that we do not simultaneously observe both  $Y_{1i}$  and  $Y_{0i}$  for the same individual. For the current study, we can only observe the food security outcome of both the adopting and non-adopting households but lack information on what the outcomes would have been had the adopting households not adopted. The challenge here therefore is that of establishing appropriate counterfactual (de Janvry, Dustan, et al., 2011, Heckman, Ichimuro, et al., 1997). In this case then, we estimate the average effect of the treatment (hybrid adoption) by comparing the mean outcomes of treated and control.

$$E(Y_i | D_i = 1) - E(Y_i | D_i = 0) = E[(Y_{1i} | D_i = 1) - (Y_{0i} | D_i = 1)] + E[(Y_{0i} | D_i = 1) - (Y_{0i} | D_i = 0)] \dots 5$$

The last term of equation 5 gives the bias of estimation. If treatment assignment is completely random, then  $E[(Y_{0i} | D_i = 1) - (Y_{0i} | D_i = 0)] = 0$  and therefore we can accurately estimate the ATT. The average treatment effect could also vary with observed characteristics (X)

$$E[(Y_i | X, D_i = 1) - (Y_i | X, D_i = 0)] = \tau_{ATT}[X] = E[Y_{1i} - Y_{0i} | X, D_i = 1]$$

Similarly, average treatment effect can be estimated as  $\tau_{ATE}[X] = E[Y_{1i} - Y_{0i} | X]$

However, even though the sample was random and representative of households, there was no deliberate targeting of treatment assignment (growing of hybrid) to subjects by the researcher. Self selection through variety choice as a result of both observable factors like wealth and access to infrastructure as well as unobservable covariates is therefore likely. This would mean that compared to non adopters, hybrid adopters are better off even before adoption. As a result  $E[(Y_{0i} | D_i = 1) - (Y_{0i} | D_i = 0)] \neq 0$  leading to over estimation of treatment effect.

Some of the proposed approaches to solving self selection problem like difference-in-difference and experimental randomized control trials are not feasible in this case because the data is cross sectional. Quasi-experimental approaches like instrumental variable method and propensity score matching are however feasible.

We estimate a two step generalized method of moments (gmm2s) using the ivreg2 command developed by Baum, Schaffer, et al. (2007). The standard errors and test statistics reported by ivreg2 are consistent to a variety of violations of the assumption of i.i.d. errors. Specifying ivreg2 with robust two-step efficient generalized method of moments (gmm2s) ensures that the parameter estimators reported are also efficient in the presence of violation of i.i.d. errors (Baum, Schaffer, et al., 2007). We use elevation (altitude) as instrument because it has a direct effect on type and location where hybrids can thrive. Two additional instruments used in this paper distance to the nearest passable road and fertilizer use.

If  $Y = X'\beta + \mu$  where  $X$  is  $N \times k$  matrix of endogenous regressors, we can define vector matrix of instruments  $Z$  ( $N \times \ell$ ) where  $\ell \geq k$  and  $\ell$  is the number of instruments and each results in  $\ell$  moments. The instruments are assumed to be exogenous i.e.  $E(Z_i\mu_i) = 0$

Then  $g_i(\beta_{gmm}) = Z'(Y_i - X_i\beta)$

$$\bar{g}(\beta_{gmm}) = \frac{1}{N} \sum_{i=1}^N Z'(Y_i - X_i\beta)$$

The objective is to choose an estimate that solves  $\bar{g}(\hat{\beta}_{gmm}) = 0$ . Weighting matrix ( $W$ ) ensure that  $\hat{\beta}_{gmm}$  is chosen such that the elements of  $\bar{g}(\hat{\beta}_{gmm})$  are as close to zero as possible.

$$\hat{\beta}_{gmm} = (X'ZWZ'X)^{-1} X'ZWZ'Y$$

Generalied ordered logit is used to estimate the marginal probabilities of being in any of the four food insecurity prevalence categories following (Williams, 2006).

$$p(y > j) = g(X\beta_j) = \frac{\exp(\alpha_j + X_i\beta_j)}{1 + \exp(\alpha_j + X_i\beta_j)}, J=1, 2 \dots N \text{ where if the number of categories of the}$$

ordinal dependent variable. If proportional odds assumption or the parallel regression assumption is not violated, then the above equation reduces to ordinal logit. The coefficients on the explanatory variables are assumed to be the same for all the four categories, save for the intercept.



$$p(y > j) = g(X\beta_j) = \frac{\exp(\alpha_j + X_i\beta)}{1 + \exp(\alpha_j + X_i\beta)}, J=1, 2 \dots N$$

### *2.3. Sampling design and data*

Household survey, designed to cover the major maize growing zones, was conducted in 2010 using a stratified two-stage sampling procedure (Gitonga, De Groote, et al., 2013). A sampling list of sub-locations and households in each of them were obtained from Kenya National Bureau of Statistics (KNBS, 2010). Sub-locations were grouped into either of the six maize production zones. A sample of 1344 households was selected from 121 sub-locations. To obtain a self-weighted sampling (with each household in one zone having the same probability of being selected), sub-locations were selected proportion to size in number of households (De Groote, 1996).

[Table 1]

[Figure 1]

### *2.4. Measurement of food security outcomes*

Three indicators of food security were constructed. These include months of adequate household food provisioning (MAHFP) (Bilinsky and Swindale, 2010), household food insecurity access scale (HFIAS) and household food insecurity access prevalence (HFIAP) (Coates, Swindale, et al., 2007).

To measure MAHFP, the respondent was first asked if in the last 12 months there were months the household did not have enough food to meet their needs. If yes, the respondent was then asked to specify the months this occurred, and the months tallied to calculate the number of months of inadequate and adequate food provisioning.

For HFIAS, respondents were asked nine binary-response questions with a yes or no answer, designed to assess increasing levels of the severity of household food insecurity from anxiety about not having enough food to feed the family to severe food insufficiency. Each was followed by a frequency-of-occurrence

question. Respondents were asked how often during the past four weeks had the severity condition happened with responses ranging from Never (=0), rarely (=1), sometimes (=2), and often (=3). The questions were asked to the person in the household mostly responsible for preparing meals especially the female spouse to the household head (Coates, Swindale, et al., 2007). A continuous measure (0-27) of the degree of food insecurity was then computed for each household with higher numbers implying greater food insecurity.

A categorical indicator of household food insecurity severity (HFIAP) was constructed from the HFIAS scores. Households are categorized and coded as either food secure (1), mildly (2), moderately (3) or severely food insecure (4) (Coates, Swindale, et al., 2007). Households categorized as food secure experience none of the food insecurity conditions and/or just rarely worried that they may not have enough food. Mildly food insecure are those that were unable to eat their preferred foods or ate food considered undesirable but did so only rarely. Moderately insecure households sacrificed quality more often by eating monotonous diets or undesirable food, and/or had started cutting back on food quantity by eating less or skipping meals although rarely or sometimes. Severely food insecure households on the other hand were cutting back on meals more often, either spent the whole day without food or went to bed hungry. The impact of hybrid adoption on this last food security outcome indicator will be estimated by ordinal logit regression. The parallel regression assumption will be tested.

### **3. Results & Discussion**

#### *3.1.Descriptive Comparison of adopters and non-adopters on observables*

Hybrid maize adopters are relatively younger, more educated, have more cultivated land and allocated more area to maize than non-adopters (Table2). Most the households are headed by males for both adopters of hybrids and users of other varieties. Adopters of hybrids have on average two more years of formal education than non-adopters. The average household size is about the same for both groups of households. The proportion of households with bank accounts is however higher among hybrid adopters than their counterparts. Almost two thirds of adopters of hybrids use commercial fertilizer compared to only a fifth among non-adopting households. The average fertilizer rate among hybrid users is 110kg/ha compared to 23.5kg/ha for users of other varieties. Consequently, adopters of maize hybrids have higher yields at 2.85kg/ha than users of other varieties who have 1.9kg/ha.

[Table 2]

### *3.2. Adoption of maize varieties in different agro ecological zones*

Adoption of maize hybrids, OPVs and local varieties differs by zone (Table3). Adoption of hybrids is highest in areas of high agricultural potential (high tropics and moist transitional) and lowest in low tropics and moist mid altitude zones. Local varieties are common in of low agricultural potential zones.

Most farmers in high tropics (85%), moist transitional (82.5%) and dry transitional zones grow hybrids. Hybrid adoption is lowest in Moist mid altitude at 27% where most (65%) grow local varieties. Half of the farmers in dry mid altitude grow hybrid maize and 55% grow local varieties. Significant proportion (45.6%) of households in low tropics still grow local varieties and only 52% grew hybrids. OPV are more common in dry areas but generally only a small proportion of farmers (14%) grow them.

Area allocation to hybrid maize is highest in high tropics at 90% of the total maize area. This is followed by moist transitional (79%) and dry transitional (72%). Moist mid altitude has the lowest area allocation to hybrid maize (29%) followed by dry mid altitude (42%) and low tropics (43%). Area allocation to local varieties is highest in moist mid altitude at 59% followed by low tropics (51%) and dry mid altitude (44%).

[Table 3]

### *3.3. Two-step GMM estimation of impact of hybrids adoption and other determinants of household food insecurity*

Adoption of hybrid maize seed by rural households leads to a reduction in food insecurity severity by a score of 6.6 equivalent to 24 % (Table 4). It also reduced duration of inadequate food by at least a month more for adopters than non-adopters.

Household food insecurity decreases with increasing years of education of the household head for both indicators. Larger households are more food insecure with each additional person in the family leading to an increase in food insecurity severity by one score. Duration

of inadequate household food provisioning also increases by more than a week (9days) for every additional member of the family

Households with non-farm income are less food insecure and experience food shortage for shorter periods than households that only rely on farm income.

Selling of maize was an indication of surplus maize. As expected, households that had surplus and sold maize were less food insecure than households that didn't. Duration of inadequate food provisioning was 2 weeks less than non-selling households. Households that have access to financial services by way of having bank account are less food insecure by a score of 2.3. Duration of inadequate food is also less by almost two weeks (12days) for households that have bank accounts. Household food insecurity also reduced with increase in total cultivated land by a household.

Ownership of livestock assets is associated with shorter duration of inadequate food compared to households that do not have such assets. Small farm implements seem to have little impact if any on household welfare. Assets like radio, television, solar pane and ownership of plough are good indicators of social/ wealth status. Households that owned these assets were less food insecure than households that lacked them. Motorbike for instance has become an important source of income for many households and a common mode of transport in rural areas. Households that own ploughs earn some extra income by renting them to other households

Food insecurity increase with increase in distance to the nearest town and water source but decrease with availability of irrigation water in local community. Food insecurity severity was found to be higher in all other zones than in high tropics where agricultural potential is high.

Households in dry mid altitude zone are the most food insecure with a score of four, more than those in high tropics, the reference category. Households located in moist mid altitude are the second most food insecure followed by those in dry transitional and low tropics.

[Table 4 here]

### *3.4. Marginal probabilities of being in any of the food insecurity prevalence categories*

Adoption of hybrid maize varieties increases the probability of a household being in food secure category by 11.9% and of being in mild food insecure category by 2.9% (Table.5). Mild food insecure household are the ones that just worry of not having enough food. Adopting households are less likely to be moderately food insecure by 2.1% and the probability of being in severely food insecure category reduces significantly with by 12.7%.

Having surplus maize to sell Large families are more likely to be food insecure than small families. An additional member to the household reduces the probability of being in the food secure category by 5.4% and 1.3% of being in mildly food insecure. Probability of being moderately food insecure increase by 1% and of being severely food insecure by 6% for every additional member of a household.

probability of being in food secure category increase by 3% with non-farm income. Household that have source of off-farm income are less likely to be in severy food insecure category by 3.2%. increased the likelihood of a Household being in food secure category by 5.5%. This also reduced the probability of being mildly food insecure and severy food insecure categories by 1% and 6% respectively.

Households that have a bank account are more likely to be in food secure category than those without by 10.7%. Having a bank account increases the probability of being mild food insecure by 1.9%. Having a bank account also reduced the likelihood of being in moderately and severe food insecure categories by 2% and 11.4% respectively.

Increasing area under cultivation by a hactare increased the probability of being in food secure category by one percent while reducing household's likelihood of being in severe food insecure category by similar magnitude. Owning a motorbike reduces the probability of being serevely food insecure by 7%. Motorbikes are commonly used for transport hence a source of livelihood for many families. Ownership of radio, television and ploughs is associated with reduced food insecurity

Households in other zones are more likely to be in moderately and severe food insecure categories than those residing in high tropics. For instance, a house in dry mid altitude zone has 11% less chance of being food secure and 12% more chance of being severely food insecure than a household in high tropics. similarly, the likelihood of being food secure is 14% less and that of being severy food insecure 15% more for a household in dry transitional than one in high tropics.

[Table 5 here]

[Figure 2. Here]

on average, probability of a hybrid-adopting household being food secure is 46% compared to only 28% among non-adopters (Figure2). Adopting hybrid maize reduces the risk of a household being food secure by 18%. the likelihood of being moderately food insecure is 43% for non adopters and 38% for adopters. The likelihood of being severely food insecure is 29% for nonadopters and only 16% for adopters. This means adoption of hybrid reduces the risk of being moderately and severely food insecure by 5% and 13% respectively.

## 1. Conclusion

Kenya remains food insecure in both urban and rural areas and particularly in drier semi-arid areas except for the years with reliable rain (Gitu, 2006). Erratic rains and increased food prices have resulted in a 15% increase in the number of people requiring food assistance from 850,000 in 2013 to an estimated 1.5 million people that are acutely food insecure in 2014 (Lawrence-Brown, 2014).

Kenya's annual average maize production (about 2.9 million tons) is much lower than consumption estimated at 3.9 million tons. Maize yields have stagnated at below two tons per hectare and per capita maize consumption has been on the decline from 120kg/person/year in 1960s to 79kg/person/year in 2009. This is despite of the robust maize breeding program, often considered a success story in the region. The mismatch between increase hybrids and production however leads to pertinent questions like whether farmers are aware of these improved hybrid varieties, what adoption levels are and the welfare impacts among adopting households.

Past studies have looked at the impact of maize hybrids adoption on yields, income, poverty, and inequality among the Kenya's smallholder farmers (Mathenge, Smale, et al., 2012, Mwabu, Mwangi, et al., 2007, Suri, 2011). The studies found a positive relationship between adoption of hybrid maize varieties and welfare outcomes.

In this study, we use a national representative data collected from 1344 households in six main agro-ecological zones of Kenya to evaluate the impact of hybrid maize adoption on household food security. We employ a two-stage generalized methods of moments using the *Ivreg2* command with corresponding tests for relevance and validity of the instruments. Generalized ordinal logit (Williams, 2006), was used to assess the determinants of household food insecurity access prevalence.

Hybrid maize adoption differed by zones and food insecurity was more severe and prevalent in areas with low adoption. Adoption of hybrid seeds reduced the food insecurity index by a score of 6.6 and increased duration of adequate household food supply by over a month. Food insecurity is found to be a decreasing function of education, maize sales, access to irrigation water, cultivated land size, wealth, off-farm income, access to financial services and livestock asset. Food insecurity however increases with family size, distance to nearest town and water source. Areas that use local varieties and OPV mainly low tropics, moist mid altitude and dry mid altitude are more food insecure than zones where farmers grow hybrids.

This study concludes that use of hybrid maize can improve food security in the country but adoption rates remains low in many areas. Policies that enhance off farm economic activities, access to irrigation water, surplus production and postharvest storage, education and population growth control like provision of birth control to rural families can further enhance realization of this goal.



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Table 1. Sampling design by agro-ecological zones

AEZ	Number of sub-locations	Number of households per sub-location	Number of households
Lowland Tropics	15	6	90
Dry mid-altitudes	18	12	217
Dry transitional	17	12	203
Moist Transitional	30	12	354
Moist Mid-altitudes	20	12	240
Highlands	20	12	240
<b>Total</b>	120		1344

Table 2. Variable definition and mean comparison between adopters and non-adopters of hybrid maize

Variable	Hybrid adopters (n=869)		Non-adopters (n=475)		t-test for Equality of Means	
	Mean	Std. Error Mean	Mean	Std. Error Mean	Mean Difference	Sig. (2-tailed)
Age of the household head (years)	52.34	0.49	55.30	0.77	-2.95	0.001
Male headed household (%)	83.89	0.012	0.77	0.020	83.12	0.003
Household head education (years)	7.73	0.14	5.90	0.20	1.82	0.000
Farming experience (years)	26.19	0.51	30.54	0.79	-4.35	0.000
Household size (number of members)	6.09	0.09	5.93	0.13	0.15	0.32
Having savings /bank account (1=yes; 0=No)	0.55	0.02	0.32	0.02	0.22	0.000
Distance to the passable road (km)	3.09	0.19	3.12	0.33	-0.02	0.945
Total land cultivated (ha)	2.02	0.09	1.57	0.07	0.45	0.0004
Maize area (ha)	0.78	0.04	0.62	0.03	0.17	0.002
Fertilizer use intensity (kg/ha)	110.33	13.28	23.49	3.70	86.84	0.000
Use of commercial fertilizer (1=Yes, 0=No)	0.62	0.02	0.23	0.02	0.39	0.000
Yields (ton/ha)	2.85	0.12	1.90	0.11	0.95	0.000
Loss due to storage pests (%)	9.12	0.45	9.52	0.65	-0.40	0.604
Frequent expenses (000'KES)	3.09	0.19	1.90	0.14	1.19	0.000
Less frequent expenses (000'KES)	40.96	2.64	25.39	2.48	15.57	0.0001
Farm income (000'KES)	137.74	31.85	27.43	3.06	110.31	0.012
Nonfarm income (000'KES)	96.36	9.49	45.70	3.74	50.66	0.000
Total income ('000 Ksh.)	234.10	33.99	73.14	4.75	160.96	0.001

Table 3. Adoption of hybrids by zones

	Hybrid maize adoption							Area allocation (ha)				Mean difference	
	% households			Total maize area (ha)	% Area share			Hybrids		Other varieties		Mean	sig
	Hybrids	OPV	Loca		Hybrids	OPV	Loca	Mean (ha)	Std. Dev.	Mean (ha)	Std. Dev.		
Low tropics	52.22	12.2	45.6	171.7	43	6	51	1.04	0.796	1.33	1.64	-0.29	0.288
Dry mid altitude	50.00	23.0	54.8	363.9	42	14	44	0.89	0.785	0.71	0.64	0.18	0.065
Dry transitional	73.27	19.0	26.8	292.7	72	12	16	0.71	0.678	0.45	0.39	0.26	0.009
Moist transitional	82.49	9.3	17.5	348.4	79	11	10	0.67	1.146	0.53	0.75	0.14	0.362
High tropics	85.42	2.5	19.6	213.6	90	2	9	0.85	1.316	0.31	0.33	0.54	0.017
Moist mid altitude	27.92	17.5	64.6	246.7	29	12	59	0.71	0.602	0.51	0.39	0.20	0.003
ALL	64.6	13.5	35.6	1637	60	10	30	0.77	1.037	0.61	0.74	-0.16	0.003

Table 4. 2-Step GMM estimation of determinants of household food insecurity

	HFAS		MIHFP	
	Coef.	Robust Std. Err.	Coef.	Robust Std. Err.
Food insecurity				
Hybrid maize adoption (1=adopters,0 =non-adoptors)	-6.569***	1.426	-1.131**	0.544
Age of the head (years)	0.006	0.013	-0.001	0.005
Gender of the household head (1=male)	0.097	0.432	0.11	0.171
Education of the head (years)	-0.076*	0.045	-0.046***	0.018
Adult Equivalent	1.002***	0.162	0.300***	0.066
Non farm income (00,000KES)	-0.151***	0.052	-0.036*	0.02
Household sold maize (1=sold)	-0.764**	0.364	-0.491***	0.126
Bank savings account	-2.259***	0.379	-0.430***	0.15
Total cultivated land (ha)	-0.183***	0.069	-0.075***	0.028
FertUse	0.569	0.455	0.029	0.169
Total livestock units (TLU)	-0.078*	0.045	-0.032**	0.015
Animal Cart	0.192	0.629	0.298	0.246
Wheelbarrow	-0.125	0.366	0.036	0.139
Hoe	-0.529	0.842	0.045	0.321
Bicycle	-0.236	0.342	-0.142	0.13
Motorbike	-0.369	0.678	-0.404**	0.202
Radio	-1.982***	0.51	-0.902***	0.209
Television	-0.810*	0.491	-0.602***	0.172
Cell phone	-0.641	0.455	-0.203	0.181
Solar panel	-1.022**	0.486	-0.102	0.172
Plough	-1.344***	0.461	-0.472***	0.162
Agric Extension services	-0.582	0.463	-0.089	0.173
Agrovet in community	0.878**	0.404	0.128	0.153
Distance to nearest town (km)	0.030***	0.011	0.002	0.004
Irrigation water in community	-1.061**	0.412	-0.112	0.153
Distance to nearest water source (km)	0.156	0.115	0.116***	0.043
Dry mid altitude	5.043***	1.237	0.733	0.471
Low tropics	3.386**	1.373	0.282	0.516
Dry transitional	4.309***	1.069	0.702*	0.399
Moist transitional	3.280***	0.956	0.402	0.358
Moist mid altitude	4.289***	1.198	0.739*	0.436
Constant	11.622***	1.255	3.760***	0.484
Number of obs	1336.0		1336	
Prob > F	0.000		0.000	
Kleibergen-Paap rk LM statistic (Chi-sq(2) P-val) <sup>1</sup> :	0.000		0.000	
overidentification (J-test ) test (Chi-sq(1) P-val) <sup>2</sup>	0.814		0.874	
(Cragg-DonaldWaldFstatistic):	145.36		145.36	
Centered R2	0.253		0.227	

<sup>1</sup> First stage test that the instruments are relevant (correlated with endogenous regressor). The null hypothesis that the equation is under identified is strongly rejected in this case

<sup>2</sup> The Hansen's J statistic test of (validity) over-identifying restrictions. The joint null hypothesis is maintained and conclude that the instruments are uncorrelated with the error term. The altitude and distance to passable road are correctly excluded from the estimated equation.

Table.5 Generalied ordered logit Marginal probabilities of being in any of the food insecurity prevalence categories

Pr(HFIAP==i)	Food secure		Mild food insecure		Moderate food insecure		Severe food insecure	
VARIABLES	Coefficient	Se	Coefficient.	se	Coefficient.	se	Coefficient.	se
Hybrid1	0.119***	0.026	0.029***	0.007	-0.021***	0.006	-0.127***	0.028
Adult equivalent	-0.056***	0.008	-0.013***	0.002	0.010***	0.002	0.060***	0.008
Gender of head	0.007	0.022	0.002	0.005	-0.001	0.004	-0.008	0.023
Age of head	-0.001	0.003	-0.000	0.001	0.000	0.001	0.001	0.003
Education of the head	0.004	0.002	0.001	0.001	-0.001	0.000	-0.004	0.003
Nonfarm income	0.030***	0.008	0.007***	0.002	-0.005***	0.002	-0.032***	0.009
Bank Savings A/C	0.106***	0.019	0.025***	0.005	-0.019***	0.005	-0.113***	0.020
Total cultivated land (ha)	0.013***	0.005	0.003***	0.001	-0.002**	0.001	-0.013***	0.005
Livestock asset (tlu)	0.005**	0.002	0.001**	0.001	-0.001**	0.000	-0.006**	0.003
Animal cart	-0.032	0.032	-0.008	0.008	0.006	0.006	0.034	0.034
Wheelbarrow	0.009	0.019	0.002	0.004	-0.002	0.003	-0.010	0.020
Hoe	0.010	0.043	0.002	0.010	-0.002	0.008	-0.011	0.046
Bicycle	-0.006	0.017	-0.001	0.004	0.001	0.003	0.006	0.018
Motorbike	0.069*	0.040	0.016*	0.010	-0.012*	0.007	-0.073*	0.042
Radio	0.120***	0.024	0.029***	0.006	-0.021***	0.006	-0.128***	0.025
Television	0.077***	0.024	0.019***	0.006	-0.014***	0.005	-0.082***	0.026
Cell phone	0.024	0.022	0.006	0.005	-0.004	0.004	-0.025	0.023
Solar panel	0.044*	0.027	0.010	0.006	-0.008	0.005	-0.047	0.028
Plough	0.044**	0.022	0.011**	0.005	-0.008*	0.004	-0.047**	0.023
Extension	0.019	0.023	0.005	0.006	-0.003	0.004	-0.020	0.024
Availability of agrovet	-0.001	0.018	-0.000	0.004	0.000	0.003	0.001	0.019
Irrigation water	0.007	0.018	0.002	0.004	-0.001	0.003	-0.007	0.019
Dry mid altitude	-0.121***	0.036	-0.029***	0.009	0.022***	0.007	0.129***	0.038
Low tropics	-0.029	0.050	-0.007	0.012	0.005	0.009	0.031	0.053
Dry transitional	-0.149***	0.032	-0.036***	0.008	0.026***	0.007	0.158***	0.035
Moist transitional	-0.024	0.027	-0.006	0.007	0.004	0.005	0.026	0.029
Moist Mid Altitude	-0.083**	0.041	-0.020**	0.010	0.015*	0.008	0.088**	0.044
Observations	1.339		1.339		1.339		1.339	
Wald test of parallel lines assumption for the final model <sup>3</sup> : $\chi^2(44) = 41.59$ Prob > $\chi^2 = 0.5756$ *** p<0.01, ** p<0.05, * p<0.1								

<sup>3</sup> The test statistic in this case is not significant and hence the model does not violate the proportional odds/ parallel lines assumption (see Williams, R. 2006. Generalized ordered logit/partial proportional odds models for ordinal dependent variables. The Stata Journal 6: 58-82.).

## Figures

Figure 1. Map with selected sublocations for the adoption survey

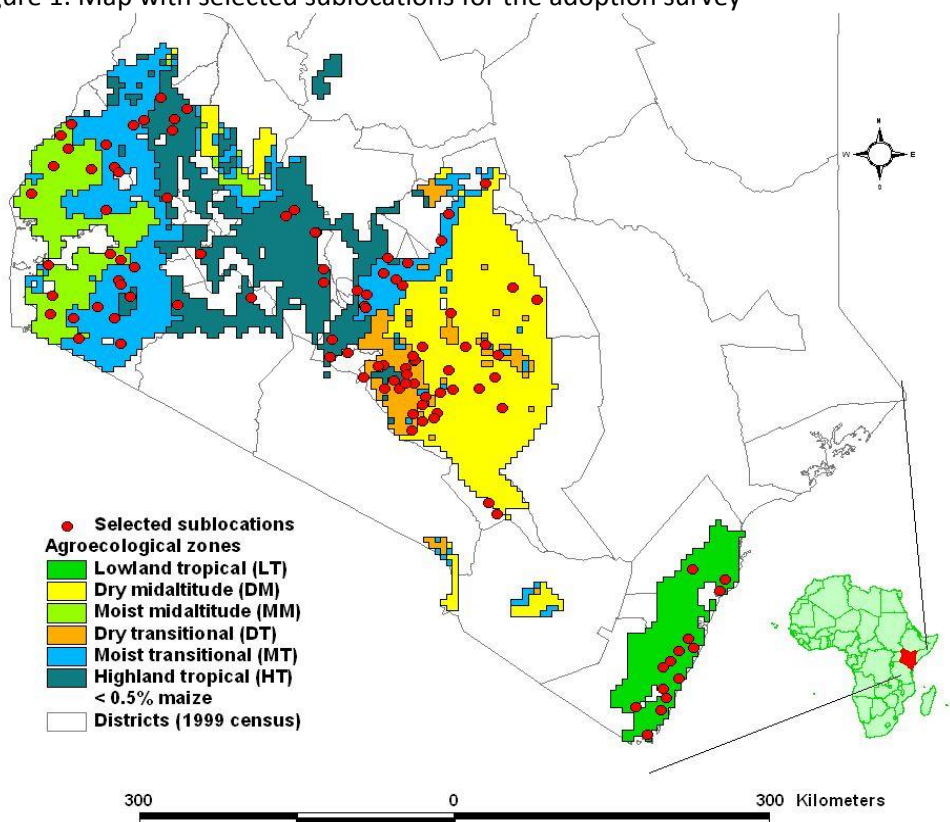




Figure2: Margins plot of probability of being in either of the HFPAS categories

