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Does crop diversification reduce downside risk of external maize yield enhancing technology? Evidence from Ethiopia

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Abstract

This study provides an assessment of the role of crop diversification in minimizing the downside risks associated with the use of improved seed and chemical fertilizer in maize production using a unique household level panel data collected from the major maize producing regions of Ethiopia. Empirical results show that maize-legume intercropping and rotation increases the average maize yield and reduces downside risk as captured by the estimated yield distribution using Endogenous Switching Regression models and quintile moment approaches. Controlling for plot and household level characteristics that may induce selection bias in technology adoption, plots with maize-legume rotation or intercropping sequences had the highest yields. The contribution of crop diversification in reducing downside risk in maize yield was higher when diversification was applied to plots where improved seed and chemical fertilizers were used. In addition to technical support around external input use in smallholder maize production, Ethiopia's agricultural extension may also need to give due emphasis to both spatial and temporal crop diversification practices. This should enhance crop productivity further and reduce the potential downside risk typically hampering smallholders' external input use in maize production.

Keywords: downside risk, maize, sustainable intensification, impacts, Ethiopia.

JEL codes: C31, C34, Q12.

1. Introduction

Farming in general and rain-fed production systems such as those found in most sub-Sahara African countries are susceptible to a wide range of production risks (Barrios et al., 2008; Schlenker and Lobell, 2014; Kassie et al., 2015), including abiotic (e.g. drought, heat stress, hailstorm, excessive rain) and biotic stresses (pests and diseases; Kamanga et al., 2010; Cairns et al., 2013). (A)biotic stresses expose smallholder farmers to downside yield risks. Increasing downside risk increases the asymmetry or skewness of the risk distribution towards low outcome, holding both mean and variance constant (Di Falco and Chavas, 2006).

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Crop failures are more consequential for resource poor farmers who have limited ability to buffer/absorb production and income shocks. Hence, smallholders tend to be downside risk-averse farmers and may avoid the use of external inputs most of which exhibit high but state contingent yield outcomes. Exceptions include improved technologies directed to tackling specific risks induced through (a)biotic factors, like drought or stress tolerant varieties, and herbicides and pesticides. Thus, external input use is normally riskier and need to be accompanied complementary risk mitigating agronomic practices. Even when crop insurance schemes are available, it is important to use best crop management practices to manage production risks with only residual risks requiring some level of risk pooling (as in weather indeed insurance or food aid). Some best agronomic practices include crop rotation (alternating crops in the same field, i.e. temporal diversification) and intercropping (growing different crops in the same field at the same time, i.e. spatial diversification). Rotating crops (especially legumes after cereals) also helps in maintaining soil fertility and can help break pest and disease cycles. Intercropping also helps to increase land productivity and secure some harvest in case one crop fails. These (internal) non-cash agronomic practices could be combined with (external) cash-based improved technologies to boost productivity and at the same time reduce exposure to downside risk.

This paper analyses the potential of crop diversification to reduce the downside maize yield risk at the plot level. Emphasis will be given to plots treated with and without improved variety and chemical fertilizer, and how both spatial and temporal diversification of maize plots could contribute towards reducing the downside risk in maize productivity. Understanding the role of crop diversification in reducing the downside risk in Ethiopia's maize production systems is relevant. Maize stands as an important economic crop affecting the food security and economic wellbeing of over 10 million families in the country (Chavas and Di Falco, 2012; CSA, 2017), most of them resource poor rural families. Maize is the number one cereal in terms of production tonnage and second (after teff) in terms of area (CSA, 2017). The recent increases in production trends for maize is a testament to its growing strategic importance economic importance (Abate et al., 2015). Large amounts of resources for inputs are expended on maize production per year. Significant government programs are directed towards this crop (Alene et al., 2000; Fufa and Hassan, 2006; Spielman et al., 2012; Abate et al., 2015).

Yet there is reported considerable maize yield variability across years due to weather factors (Kassie et al., 2014). These variabilities put smallholders' income and consumption in jeopardy as maize growers directly depend on maize for consumption and cash income. Moreover, production risks also discourage smallholders from investing in external purchased agricultural inputs. Overall, any (a)biotic stress that induces maize production risks has a direct effect on the consumption and livelihoods of more of the millions of families producing maize. Given the absence of insurance in the agricultural system, the contribution of best agronomic practices (e.g. crop diversification, the focus of this paper) towards autonomous downside risk reduction is non-trivial. Mainstreaming better agronomy and production methods among maize producers is therefore an economic imperative.

The remaining paper is structured as follows. Methodologies used are presented in Section 2 and data used in section 3. Section 4 presents and discusses the results. Conclusions and implications are dealt with in Section 5.

2. Empirical Models

A package of technologies/practices may enhance average productivity, but if the variance is increased, and particularly, if the associated loss due to any downside risk is higher, smallholders may not be inclined to use such a package. Thus, one may expect farmers to consider favorably any package that both increases the productivity and reduces their risk of crop failure. Plots with different input use (internal and external) can be disaggregated to evaluate their respective average maize yield and associated variance and skewness. Skewness towards the left side of yield distribution puts the variability more to the undesirable side.

In capturing the plot level yield difference due to different combinations of purchased inputs and crop diversification, we use self-selection corrected endogenous switching regression model and obtain the average treatment effects on treated (ATT) and untreated plots (ATU) controlling for plot, household, farm and village level observed characteristics. This approach helps in controlling for a raft of observed covariates and correct for unobservable characteristics that may influence the level of crop yield. Then, yield estimates from the actual and counterfactual groups are arranged in ascending order and a quintile-based moment approach is applied to estimate the cost of risk, the contribution of variance and skewness of maize yield distribution to the cost of risk, and the contribution of downside risk to the overall cost of risk under the different combinations of purchased inputs used and crop diversification practices on maize plots. The empirical procedure we followed is discussed as follows.

Assuming farmer i growing maize on plot j chooses combination k of the three technologies, i.e. diversification (D), improved variety (V) and chemical fertilizer (F), if the expected benefit from combination k is better than any of the other combinations m, i.e., $u_{ijk} > u_{ijm}$ for $K = 1,2, \dots ,8$ and $m \neq k$. Thus, considering plot, household, farm, and village level characteristics (X_{ij}) affecting the choice of technology combinations on a specific maize plot j, the probability that plot j is treated with combination k by household i is specified using a multinomial logit model as:

$$p_{ijk} = pr\left(u_{ijk} > u_{ijm} \middle| X_{ij}\right) \;\; = \frac{\exp(\beta_k X_{ij})}{\sum_{m \neq k}^{K} \exp(\beta_m X_{ij})} \tag{1}$$

Then, after deriving the household and technology combination specific Inverse Mill's Ratios $(\hat{\lambda})$ from the above multinomial logit model, the self-selection bias controlled maize yield estimate (Y) from the K possible combinations of technologies/practices are specified as:

$$\begin{cases} Regime\ 1: & Y_{ij1} = \theta_1 X_{ij1} + \sigma_1 \hat{\lambda}_{ij1} + \varepsilon_{ij1} \\ \quad . & \qquad . \\ \quad . & \qquad . \\ \quad . & \qquad . \\ Regime\ K: & Y_{ijK} = \theta_K X_{ijK} + \sigma_K \hat{\lambda}_{ijK} + \varepsilon_{ijK} \end{cases} \tag{2}$$

The conditional expected maize yield under different regimes with and without adoption of combination k is given as:

If a plot is treated with a desired combination of practice, k=1; (adopter plots, actual):

$$E\left[Y_{ijk} \middle| k = 1, X_{ijk}, \hat{\lambda}_{ijk} \right] = \theta_1 X_{ij1} + \sigma_1 \hat{\lambda}_{ij1} \tag{4}$$

If a plot is not treated with a combination k=1; (non-adopter plots without adoption, actual):

$$E\left[Y_{ijm} \middle| k = m, X_{ijm}, \hat{\lambda}_{ijm} \right] = \theta_m X_{ijm} + \sigma_m \hat{\lambda}_{ijm} \tag{5}$$

If a plot treated with combination k=1 would have been not treated (adopter plots had they not adopted, counterfactual)

$$E\left[Y_{ijm}\middle|k=1, X_{ijk}, \hat{\lambda}_{ijk}\right] = \theta_m X_{ij1} + \sigma_m \hat{\lambda}_{ij1} \tag{6}$$

If a non-treated plot would have been treated with combination k=1; (non-adopter plots had they been treated with combination k=1, counterfactual)

$$E\left[Y_{ijk}\middle|k=m, X_{ijm}, \hat{\lambda}_{ijm}\right] = \theta_1 X_{ijm} + \sigma_1 \hat{\lambda}_{ijm} \tag{7}$$

Equations (4) and (5) are the actual maize yield estimates from plots treated and non-treated with the specific combination of technologies/practices, respectively. The average treatment effect on treated (ATT_k) for k=1 is given as the difference of Equation (4) and (6) and specified as:

$$ATT_k = E\left[Y_{ijk}\middle|k=1, X_{ijk}, \hat{\lambda}_{ijk}\right] - E\left[Y_{ijm}\middle|k=1, X_{ijk}, \hat{\lambda}_{ijk}\right]$$

$$= (\theta_1 - \theta_m)X_{ij1} + (\sigma_1 - \sigma_m)\hat{\lambda}_{ij1} \tag{8}$$

Similarly, the average treatment effect on the untreated (ATU_m) is computed from the difference between Equations (5) and (7) and specified as:

$$ATU_m = E\left[Y_{ijm}\middle|k=m, X_{ijm}, \hat{\lambda}_{ijm}\right] - E\left[Y_{ijk}\middle|k=1, X_{ijm}, \hat{\lambda}_{ijm}\right]$$

$$= (\theta_m - \theta_1)X_{ijm} + (\sigma_m - \sigma_1)\hat{\lambda}_{ijm} \tag{9}$$

Table 1 gives how the average maize yield estimates from the actual and counterfactual maize plots are presented and evaluated to get the average treatment effects on treated (ATT) and untreated (ATU) maize plots.

< Table 1 here >

A quintile moment approach is applied to evaluate the role of crop diversification in reducing the downside risk of investments on yield enhancing purchased inputs in maize production. Following earlier studies that used the Arrow-Pratt relative coefficient of risk in measuring the cost of risk proxied with risk premium (Kim and Chavas, 2003; Kassie, et al, 2015; Di Falco and Chavas, 2006, 2009; Kim et al., 2014), the cost of risk considering both the variance and skewness components is given as:

$$R \cong 0.5 * [F(b_k) - F(b_{k-1})] * \left\{ \frac{b(m_{k1})^{-b-1}}{\sum_{i=1}^{k} \{[F(b_k) - F(b_{k-1}) * (m_{k1})^{-b}]\}} * m_{k2} + [b(M_1)^{-1}] * [m_{k1} - M_1]^2 \right\} + (1/6) * [F(b_k) - F(b_{k-1})] * \left\{ - \frac{b(1+b)(m_{k1})^{-b-2}}{\sum_{i=k}^{k} \{[F(b_k) - F(b_{k-1}) * (m_{k1})^{-b}]\}} * m_{k3} - [b(1+b)(M_1)^{-2}] * [m_{k1} - M_1]^3 \right\} \quad (10)$$

Where $[F(b_k) - F(b_{k-1})]$ is the probability of each partial central moment to be in the quintile k; m_{k1}, m_{k2}, and m_{k3} are referring to the partial mean, variance and skewness of maize yield distribution in the specific quintile k, respectively; M is the overall central moment. All terms before (1/6) in Equation (10) are referring to the variance component of cost of risk whereas the terms starting from (1/6) are referring to the skewness component.

3. Data

In this analysis, we used two waves of panel data collected in 2010 and 2013 from major maize growing areas across five regional states in Ethiopia (Tigray, Amhara, Oromia, Benishangul-Gumuz, and SNNPR[1]). The survey covered a total of 39 maize growing districts randomly selected from the five regional states considering their maize production potential as '*high'*, '*medium'* and '*low'* based on average maize productivity and standard deviation as a cut-off points. Then, from each district, four maize growing *kebeles* (the lowest administrative unit) were randomly selected. From each selected *kebele*, 16 to 18 sample farmers growing maize were selected for interview. In case any selected sample household happened to be non-producer of maize during the specific survey season, the household was replaced by another randomly selected maize producing household. Table 2 gives the detailed overview of the sample households and number of maize plots surveyed across the two waves. Accordingly, in 2010 and 2013 respectively, a total of 2887 and 2853 maize plots operated by a sample of 1751 and 1774 farm households were surveyed and used in this analysis. Data from Tigray regional state was not collected in 2013 due to a logistic problem.

< Table 2 here >

The data are panel at the household level and each year details of maize plots for each sample households were collected. However, due to crop rotation and change in plot size resulting from splitting and merging of plots each season, the datasets we have could not be a panel at the plot level.

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[1] Southern Nations Nationalities and Peoples Regional State.

The survey had details of plot level physical characteristics (soil type, color, slope, and soil depth), farmer specific subjective judgment on plot level soil fertility, inputs used and production from all maize plots operated by each sample household. In addition, for all the surveyed plots, the amount of labor, seed and fertilizer used, herbicide and pesticides applied, whether the production was exposed to any kind of (a)biotic stresses (like drought, flood, disease, pest, etc.) were documented. Finally, maize and beans productivity accounting for the type of harvest (whether harvested when green/fresh or dry) were collected. Using a standard conversion factor, the green harvests were converted to dry weight equivalent for yield accounting purpose.

Table 3 gives summary of plot level characteristics and average maize yield for the two survey years. Accordingly, there was a slight improvement in the average maize productivity of the sample households from 2.3 to 2.5 tons/ha. The increase in the level of maize productivity is in line with the nationally representative data released by the Ethiopian Central Statistical Agency for these specific cropping seasons. Fertilizer use in maize production increased somewhat between the two survey years, as did pesticide and labor use. The share of plots using improved hybrid maize varieties increased from 54 to 63%.

< Table 3 here >

During both years, drought was the major farmer reported stress: reported for 15% and 12% of the maize plots in 2010 and 2013, respectively. Drought discourages smallholder use of purchased inputs in maize production but it encourages crop diversification, particularly intercropping of maize with legumes or shifting to alternate crops to diversify risks.

Table 4 gives the number of maize plots under different combinations of purchased inputs use (improved Variety, V, and chemical Fertilizer, F) and crop Diversification, D. During both survey years, most of the maize plots used both improved varieties and chemical fertilizer ($D_0V_1F_1$ and $D_1V_1F_1$). Interestingly, the data also show that these combinations of technology use have shown better maize productivity. The level of skewness is higher when maize plots did not use improved varieties and chemical fertilizer regardless of diversification ($D_0V_0F_0$ and $D_1V_0F_0$).

< Table 4 here >

4. Results and Discussions

4.1. *Explaining variations in maize yield*

Controlling for the district level variations, Table 5 presents estimation results explaining variations in maize yield for the total sample and the two survey years. Accordingly, household head characteristics and key inputs in maize production (seed rate, fertilizer rate and use of seeds of improved hybrid and openly pollinated maize varieties) have explained the variation in maize yield as expected. Considering the total sample (pooled data) and controlling for other factors, estimated maize yield is higher for male headed households by 164.7 kg/ha. In addition, the estimated maize yield per ha decreased with the age of household head and increased with the level of education of the household head. Plots with common bean intercropped with maize increased yields (638.1 kg/ha for the pooled data). The rate of maize seed and chemical fertilizer used in maize production during both survey years have shown positive effects on maize yield. On the other hand, the effects of (a)biotic factors reported by farmers had significant negative effects on maize yield. Compared to other stress factors, water logging and drought effects were relatively larger. These are extreme cases related to the amount of rainfall received at a given time and its distribution across the cropping season reducing maize yields.

< Table 5 here >

4.2. Average treatment effects on maize yield

Results from the conditional expected maize yield derived from endogenous switching regression analysis for the actual and counterfactual maize plots under different treatments are presented in Table 6. Results show that the largest average treatment effect on maize yield (1.36 t/ha) was observed when plots treated with diversification combined with both in improved seed and chemical fertilizer ($D_1V_1F_1$) and compared to when these plots had been treated only with diversification but no improved seed and chemical fertilizer use ($D_1V_0F_0$). On the other hand, plots with no diversification and no use of improved seed and chemical fertilizer ($D_0V_0F_0$) would have attained higher returns in maize yield (average increment of 0.28 t/ha) if they had been treated with diversification and the two purchased inputs ($D_1V_1F_1$). Moreover, if plots treated with both improved variety and chemical fertilizer but no diversification ($D_0V_1F_1$) would have been treated with the combination of these three technologies/practices ($D_1V_1F_1$), the average maize yield increases by 0.1 t/ha. Overall, the association of diversification with either of the two purchased inputs or both have shown better increment in average maize yield. This confirms the assertion that smallholders' investment in these two purchased inputs is more secure in terms of average maize yield obtained if plots treated with these two technologies also receive some sort of crop diversification, i.e. either intercropping maize with legumes or rotating maize with legumes.

< Table 6 here >

Figures 1a and 1b also show the actual and estimated maize yield distribution from the sub-set of plots treated with three different combinations of technologies/practices ($D_1V_1F_1$, $D_0V_1F_1$., and $D_0V_0F_0$). It is apparent that maize yield is lower for plots treated with maize-after-maize and at the same time not receiving improved seeds and chemical fertilizer. For those plots that received improved seed and chemical fertilizer, better yield distribution is observed for those treated with crop diversification.

< Figure 1a and 1b here >

4.3.Cost of risk

Subdividing the estimated maize yield distribution from the actual and counterfactual estimates under the different combinations of practices into four quintiles, the level of average maize yield, skewness, risk premium at randomly considered coefficient of relative risk factor (CRRA), and the contribution of downside risk to the risk premium are evaluated. As shown in below in Table 7, both the risk premium farmers should pay to avoid the associated yield reduction and the contribution of downside risk to the cost of risk are higher for the lowest quintile (quintile 1) in both survey years. This implies that, the cost of risk (proxied by the level of maize yield loss) is higher on the left side of the maize yield distribution. Smallholders in the lowest quintile are mainly resource poor and they need any sort of cushion (crop management practices or risk reducing or sharing arrangements) while encouraging them to adopt improved maize technologies demanding external inputs and thus cash outlays (like purchased improved seeds and chemical fertilizers).

< Table 7 here >

Comparing $D_1V_1F_1$ and $D_0V_1F_1$, where the difference is mainly the diversification component, both at moderate (b=2) to low (b=1) constant relative risk aversion coefficients (CRRA), the proportion of risk emanating from variance and skewness of maize yield distribution at the lower quintile (i.e., 1st quintile) ranges between 55 to 64% and 73 to 82% for plots with and without diversification (Table 8). Looking at the skewness component alone, the risk premium is positive for plots without diversification whereas plots treated with diversification have negative risk premium which indicates that the level of risk from diversified plots not a challenge. However, the risk premium from the skewness component when looked at the specific quintiles is not the same. Though smaller than the risk premium of plots without diversification, plots treated with diversification also have some positive premium at the lower quintiles (1st and 2nd quintiles).

< Table 8 here >

In Figure 2, the risk premium from plots treated with diversification and purchased inputs ($D_1V_1F_1$) is lower than the risk premium of other plots with different combination of practices for all ranges of constant relative risk aversion coefficients (from the lowest 0.5 to the highest 3). The cost of risk is higher for plots with no diversification ($D_0V_1F_1$) compared to any of the other combinations of purchased inputs used with crop diversification ($D_0V_1F_1$, $D_0V_1F_1$, or $D_0V_1F_1$).

< Figure 2 here >

5. Conclusions

(A)biotic stress factors put smallholders' production under risk. The resulting consequence on income, food and nutrition security is detrimental when farmers have little information to make informed decisions on (downside) risk mitigating production and input use decisions. In situations where there are no functional insurance markets to buffer smallholders from production risks, the introduction of improved agronomic practices could help in reducing (at least partly) the production and consumption shocks associated weather with (a)biotic stress related yield depression or crop failures. This paper analyzed the case of intensifying maize-based systems in Ethiopia using a unique two years of household panel data collected at both plot and household level. It assessed the contribution of crop diversification in improving average maize yield, and reducing the potential left-side move of maize yield distribution, i.e. reducing the skewness of maize yield distribution to the left and the associated downside risk in maize production.

Estimation results confirmed the role of crop diversification in increasing the average maize productivity and the effects are higher when diversification practices were used with yield enhancing external inputs, particularly improved maize varieties and chemical fertilizer in this specific study. In addition, the cost of risk, as measured by the possible maize yield farmers are willing to pay to ensure their production under different combinations of practices/technologies, is higher for plots with no diversification but using both improved seed and chemical fertilizer.

The current agricultural extension system in Ethiopia justifiably emphasizes on smallholders' intensification of maize production using external inputs (improved seed and chemical fertilizer). Results from this study imply that concomitant emphasis needs to be placed on training and encouraging smallholders to use crop diversification such as maize-legume intercropping or crop rotation. This should enhance maize productivity further and reduce the potential downside risk typically hampering smallholders' external input use in maize production.

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Tables

Table 1. Expected conditional and average treatment effects (considering $D_1V_1F_1$ and $D_0V_1F_1$ as an example)

	Treated plots	Non-treated plots	Average treatment effect on treated (ATT) and untreated (ATU)
Adopted D ($D_1V_1F_1$)	(a_{111}) $E\left[Y_{ijk} \middle| k = 1, X_{ijk}, \hat{\lambda}_{ijk}\right]$	($c_{111,\,011}$) $E\left[Y_{ijm} \middle| k = m, X_{ijk}, \hat{\lambda}_{ijk}\right]$	ATT=a-c
Not adopted D ($D_0V_1F_1$)	($d_{011,\,111}$) $E\left[Y_{ijk} \middle| k = 1, X_{ijm}, \hat{\lambda}_{ijm}\right]$	(b_{011}) $E\left[Y_{ijm} \middle| k = m, X_{ijm}, \hat{\lambda}_{ijm}\right]$	ATU=b-d

a_{111} = *Actual maize yield from plots treated with* $D_1V_1F_1$.
b_{011} = *Actual maize yield from plots treated with* $D_1V_1F_1$.
$c_{111,\,011}$ = *Estimated maize yield if the counterfactual plots* ($D_0V_1F_1$) *were treated with* $D_1V_1F_1$.
$d_{011,\,111}$ = *Estimated maize yield if the counterfactual plots* ($D_1V_1F_1$) *were treated with* $D_0V_1F_1$.

Table 2. Distribution of sample households and number of surveyed maize plots across the two waves

	Region										Total	
	Tigray		Amhara		Oromia		B/Gumuz		SNNPR			
Year	Sample HHs	Maize plots	Sample HHs	Maize plots	Sample HHs	Maize plots	Sample HHs	Maize plots	Sample HHs	Maize plots	Sample HHs	Maize plots
2010	27	30	259	446	992	1666	55	72	418	673	1751	2887
2013	*nd*	*Nd*	235	369	1068	1802	64	78	407	604	1774	2853
Total	27	30	494	815	2060	3468	119	150	825	1277	3525	5740

nd=Data was not collected from Tigray region in 2013 due to logistic problem.

Table 3. Plot level characteristics and maize yield statistics (kg/ha)

	2010 *(N=2887)*		2013 *(N=2853)*		Total *(N=5740)*	
Variables	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Maize yield *(kg/ha)*	2325.2	1532.7	2496.3	1512.7	2410.2	1525.1
Seed *(kg/ha)*	26.92	15.58	25.80	12.69	26.36	14.23
Fertilizer *(kg/ha)*	87.29	105.07	109.47	114.11	98.31	110.21
Pesticide *(Birr/ha)*	2.55	14.96	1.40	25.40	1.98	20.83
Herbicide *(Birr/ha)*	6.48	69.58	11.32	90.52	8.89	80.71
Labor *(person-days/ha)*	72.41	31.60	79.26	32.06	75.81	32.01
Improved hybrid variety *(dummy, 1=Yes)*	0.53	0.50	0.64	0.48	0.59	0.49
Improved OPV variety *(dummy, 1=Yes)*	0.08	0.27	0.03	0.18	0.06	0.23
Soil fertility *(1=Good, 2=Medium, 3=Poor)*	2.40	0.60	2.48	0.62	2.44	0.61
Soil slope *(1=Flat, 2=Medium, 3=Steep)*	2.65	0.53	2.67	0.55	2.66	0.54
Soil Depth *(1=Shallow, 2=Medium, 3=Deep)*	2.23	0.77	2.40	0.77	2.31	0.77
Plot distance from homestead *(Minutes)*	12.20	23.31	11.04	19.82	11.63	21.65
Plot under rotation *(dummy, 1=Yes)*	0.43	0.49	0.29	0.46	0.36	0.48
Intercrop with common bean *(dummy, 1=Yes)*	0.06	0.24	0.12	0.33	0.09	0.29
Rotation and bean intercrop *(dummy, 1=Yes)*	0.02	0.14	0.02	0.15	0.02	0.14
Stress effect reported on the plots (dummy)						
Pest *(1=Yes)*	0.04	0.20	0.06	0.23	0.05	0.22
Disease *(1=Yes)*	0.05	0.21	0.05	0.23	0.05	0.22
Water logging *(1=Yes)*	0.03	0.18	0.05	0.22	0.04	0.20
Drought *(1=Yes)*	0.15	0.35	0.12	0.32	0.13	0.34
Hailstorm *(1=Yes)*	0.03	0.17	0.03	0.17	0.03	0.17
Other stresses *(1=Yes)*	0.02	0.13	0.06	0.24	0.04	0.20
Regional dummy						
Tigray *(1=Yes)*	0.01	0.10	0	0	0.01	0.07
Amhara *(1=Yes)*	0.15	0.36	0.13	0.34	0.14	0.35
Oromia *(1=Yes)*	0.58	0.49	0.63	0.48	0.60	0.49
B/Gumuz *(1=Yes)*)	0.03	0.16	0.03	0.16	0.03	0.16
SNNPR *(1=Yes)*	0.23	0.42	0.21	0.41	0.22	0.42

Table 4. Maize yield distribution by combination of practices (kg/ha)

Technology combinations	2010 *(N=2887)*				2013 *(N=2853)*				Total *(N=5740)*			
	Obs	Mean	*Std. Dev*	Skewness	Obs	Mean	*Std. Dev*	Skewness	Obs	Mean	*Std. Dev*	*Skewness*
$D_0V_0F_0$	461	1630.5	1113.7	1.65	400	1751.1	1098.3	1.49	861	1686.5	1107.6	1.57
$D_0V_1F_0$	232	1888.8	1227.7	0.79	239	2005.4	1238.5	1.06	471	1947.9	1233.3	0.93
$D_0V_0F_1$	120	2094.3	1452.0	1.51	147	2102.5	1285.7	0.75	267	2098.8	1360.3	1.17
$D_0V_1F_1$	621	2714.3	1515.4	0.81	798	2804.5	1501.5	0.77	1419	2765.1	1507.7	0.79
$D_1V_0F_0$	395	1721.3	1232.7	1.65	255	1652.0	1016.2	1.43	650	1694.1	1152.3	1.62
$D_1V_1F_0$	185	2140.4	1397.0	1.05	154	2176.5	1376.6	0.95	339	2156.8	1385.8	1.01
$D_1V_0F_1$	157	2309.4	1424.5	1.42	119	2450.9	1598.1	1.31	276	2370.4	1500.6	1.38
$D_1V_1F_1$	716	2999.4	1700.9	0.87	741	3167.4	1593.0	0.69	1457	3084.9	1648.5	0.78

Note: D=Diversification, V= Improved variety, F= Chemical fertilizer

Table 5. Factors explaining the variations in maize yield *(kg/ha)*

	Total		2010		2013	
Explanatory Variables	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
Sex of HH head *(1=male, 0=female)*	165.99**	71.86	252.79**	102.85	128.60	97.75
Age of HH head *(years)*	-5.02***	1.41	-4.97**	1.98	-3.48*	1.96
Education of HH head *(years)*	39.61***	5.68	38.79***	8.21	39.83***	7.69
Seed *(kg/ha)*	9.31***	1.29	9.06***	1.74	7.67***	1.94
Fertilizer *(kg/ha)*	4.59***	0.21	5.07***	0.32	4.07***	0.27
Pesticide *(Birr/ha)*	0.96	0.80	2.36	1.70	0.10	0.87
Herbicide *(Birr/ha)*	0.00	0.21	-0.21	0.35	0.24	0.25
Labor *(AE/ha)*	6.98***	0.56	5.32***	0.81	9.00***	0.79
Improved hybrid variety *(dummy, 1=Yes)*	291.01***	48.07	256.44***	70.45	350.37***	65.98
Improved OPV variety *(dummy, 1=Yes)*	193.84**	84.50	313.66***	107.90	184.19	146.29
Soil fertility (Ref.: Poor)						
Medium *(dummy, 1=Yes)*	83.70	72.69	-48.85	107.76	203.93**	96.17
Good *(dummy, 1=Yes)*	229.49***	73.68	36.56	110.79	380.99***	96.88
Plot slope (Ref.: steep)						
Medium *(dummy, 1=Yes)*	43.04	94.29	-142.24	148.02	198.95*	119.52
Flat *(dummy, 1=Yes)*	99.41	93.27	-28.86	146.04	171.46	119.87
Soil depth (Ref.: Shallow)						
Medium *(dummy, 1=Yes)*	6.48	50.88	147.26**	72.34	-118.45	72.19
Deep (*dummy, 1=Yes)*	-40.92	46.25	52.75	66.02	-92.91	65.05
Plot distance from homestead *(Minutes)*	-1.29	0.81	-2.08*	1.10	-0.85	1.17
Plot under rotation *(dummy, 1=Yes)*	77.78**	37.12	67.42	51.55	35.60	53.75
Intercrop with common bean *(dummy, 1=Yes)*	640.54***	73.78	908.06***	129.93	567.96***	88.79
Rotation and HB intercrop *(dummy, 1=Yes)*	-128.07	134.48	-401.17*	215.80	-24.62	171.13

Stress effect reported on the plots (dummy)						
Pest *(1=Yes)*	-373.20***	77.98	-385.45***	121.29	-303.40***	99.50
Disease *(1=Yes)*	-465.55***	77.76	-371.18***	116.21	-391.02***	102.62
Water logging *(1=Yes)*	-632.99***	84.24	-580.30***	133.60	-650.52***	105.26
Drought *(1=Yes)*	-587.80***	53.89	-667.53***	80.15	-526.14***	74.26
Hailstorm *(1=Yes)*	-401.74***	100.97	-387.13***	141.91	-341.75**	142.30
Other stresses *(1=Yes)*	-530.85***	87.18	-403.57**	180.90	-571.57***	97.47
Survey year *(dummy, 1= if 2013)*	12.08	35.73				
Districts Dummy [a]						
Guangua	380.27	274.25	598.59*	306.68		
Dangila	144.60	264.99	564.92*	289.64	-538.03**	209.32
Fogera	428.13	270.60	678.08**	299.80	7.33	221.34
Dawa Chefa	1057.16***	276.82	1234.69***	300.12	570.44**	268.63
Gonder	726.17**	307.60	1353.33***	371.31	-107.23	292.20
Sekela	-47.70	288.71	162.44	324.17	-590.98**	275.66
Merawi	583.06**	269.59	908.82***	299.00	8.69	221.50
Omo Nada	123.31	271.02	757.79**	309.48	-515.32**	220.98
Kersa/Jimma	223.62	267.44	651.10**	304.70	-306.98	211.04
Gutu Wayo/gidda	1436.37***	270.79	1081.74***	316.94	1465.73***	213.02
Jimma Rare	420.93	278.53	830.33**	333.98	44.56	230.81
Hagere Maryam	1014.73***	283.94	919.28**	399.61	737.07***	222.58
Arero	641.92**	288.62	948.82***	363.52	281.47	244.94
Kersa/EH	1488.93***	282.42	1356.36***	312.72	1622.72***	266.13
Kuni	1568.30***	281.22	1171.76***	307.22	2258.85***	278.11
Chole	1252.77***	293.99	922.27**	366.25	1343.99***	257.58
Ada'a Chukala	655.43**	285.64	547.54	341.35	642.26**	247.55
Darimu	198.97	267.49	86.55	293.06	84.98	227.90

Mana	104.58	275.05	407.77	307.60	-451.95*	242.31
Setema	95.62	274.81	257.05	304.23	-238.47	244.73
Limu Kosa	703.16**	274.96	966.75***	321.74	301.16	224.08
Nono	2322.69***	271.70	2512.13***	300.41	1978.48***	227.05
Dano	898.92***	264.78	618.82**	295.26	967.01***	206.86
Sayyo	501.45*	271.83	870.45***	301.71	-87.91	229.56
Gimbi	311.41	278.73	406.14	313.06	20.29	249.09
Meskanena Mareko	871.36***	268.15	1007.59***	296.84	578.39***	216.66
Kacha Bira	-12.55	281.89	206.44	318.71	-439.57*	254.11
Shebedino	1134.05***	272.14	1550.56***	305.00	472.74**	222.88
Damot Weyde	7.30	279.91	212.19	321.30	-400.67*	235.24
Gubu Sayyo	854.34***	263.86	986.10***	285.95	363.92*	215.79
Bako Tibbe	735.98***	254.63	466.85*	271.58	744.35***	188.43
Shalla	1307.58***	259.05	1178.23***	278.40	1250.73***	192.55
Misrak Badawacho	590.62**	260.50	584.45**	281.35	387.01*	198.54
Meskan	1032.67****	259.93	875.56***	282.02	969.73***	195.60
Hawassa Zurya	1113.77***	262.04	1000.66***	283.62	1017.29***	205.75
Dugda	839.79***	265.10	850.04***	293.95	645.00***	205.09
Adami Tulu	851.51***	260.09	1078.74***	280.58	484.63**	193.98
Pawe	848.50***	267.71	975.90***	296.02	549.42**	217.60
Constant	65.47	288.84	214.48	337.54	56.88	270.55
Number of Obs.	*5,620*		*2,842*		*2,778*	
F(k, n-k)	*46.34*		*22.8*		*30.8*	
Prob > F	*0.000*		*0.000*		*0.000*	
R-square	*0.352*		*0.345*		*0.417*	
Adj R-square	*0.344*		*0.329*		*0.403*	

****, **, and * are significant at 1%, 5%, and 10%, respectively.*

[a] *Tahtay Maychew is a reference district for the total sample 2010 estimation as Guangua is for 2013. There was no survey data from Tahtay Maychew in 2013. References were selected randomly.*

Table 6. Average treatment effects (ATT and ATU) moving from untreated ($D_0V_0F_0$) to fully treated ($D_1V_1F_1$) plots and vice versa.

Combinations compared	Adopted plots	Non-adopted plots	Adoption Effect (a-c) (b-d)	Rank in Impacts (ATT)	Rank in Impacts (ATU)
$D_1V_1F_1$ - $D_0V_1F_1$	(a_{111}) 3083.8(25.7)	($c_{111,011}$) 2262.3(31.8)	821.5***	4	
	($d_{011, 111}$) 2848.4(23.3)	(b_{011}) 2748.3(21.8)	100.1***		6
$D_1V_1F_1$ – $D_0V_0F_1$	(a_{111}) 3083.8(25.7)	($c_{111,001}$) 2415.6(26.0)	668.2***	6	
	($d_{001, 111}$) 2312.3(80.0)	(b_{001}) 2084.8(56.6)	227.6***		4
$D_1V_1F_1$ – $D_0V_1F_0$	(a_{111}) 3083.8(25.7)	($c_{111,010}$) 1979.9(26.4)	1103.9***	3	
	($d_{010, 111}$) 2219.1(36.4)	(b_{010}) 1953.5(31.5)	265.6***		2
$D_1V_1F_1$ – $D_0V_0F_0$	(a_{111}) 3083.8(25.7)	($c_{111,000}$) 1760.4(16.6)	1323.4***	2	
	($d_{000, 111}$) 1965.1(31.5)	(b_{000}) 1685.1(19.0)	279.9***		1
$D_1V_1F_1$ – $D_1V_0F_1$	(a_{111}) 3083.8(25.7)	($c_{111,101}$) 2643.9(26.5)	439.9***	7	
	($d_{101, 111}$) 2512.7(79.2)	(b_{101}) 2382.0(60.0)	130.6*		5
$D_1V_1F_1$ – $D_1V_1F_0$	(a_{111}) 3083.8(25.7)	($c_{111,110}$) 2299.8(29.0)	784.0***	5	
	($d_{110, 111}$) 2092.8(45.3)	(b_{110}) 2149.0(41.6)	(56.2)		7
$D_1V_1F_1$ – $D_1V_0F_0$	(a_{111}) 3083.8(25.7)	($c_{111,100}$) 1718.9(16.2)	1364.9***	1	
	($d_{100, 111}$) 1944.9(36.3)	(b_{100}) 1688.0(22.6)	256.9***		3

a-c, reduction in yield if plots treated by $D_1V_1F_1$ *would have been treated by their counterfactuals*

b-d, yield gain if plots not fully treated would have been fully treated by $D_1V_1F_1$*.*

****, **, and * are significant at 1%, 5%, and 10% level, respectively.*

Table 7. Comparison of risk premium (cost of risk) by quintile of yield distribution (with and without diversification on plots treated with both improved seed and chemical fertilizer)

	$D_1V_1F_1$					$D_oV_1F_1$				
Quintile	Obs.	Mean Yield (kg/ha)	Skewness	Risk Premium (at 2 CRRA)	Contribution of downside risk to the premium	Obs.	Mean Yield (kg/ha)	Skewness	Risk Premium (at 2 CRRA)	Contribution of downside risk to the premium
1	355	1932.3	-1.288	188.0	21.3	337	990.6	-0.365	494.6	24.8
2	356	2704.5	-0.103	15.8	9.1	338	2147.7	-0.238	11.4	6.7
3	356	3324.7	0.155	6.5	-5.6	338	2792.7	0.280	14.0	-17.6
4	356	4362.8	1.147	85.6	-64.7	336	3705.2	0.882	82.9	-113.1
Total	1423	3083.8	0.395	295.9	63.5	1349	2408.2	-0.181	602.9	82.1

Table 8. Risk premium (R) and its decomposition by quintiles (comparing V_1 and F_1 use with and without diversification, D)

CRRA Coefficient (b)	Total		1st Quintile		2nd Quintile		3rd Quintile		4th Quintile	
	$D_1V_1F_1$	$D_0V_1F_1$	$D_1V_1F_1$	$D_0V_1F_1$	$D_1V_1F_1$	$D_0V_1F_1$	$D_1V_1F_1$	$D_0V_1F_1$	$D_1V_1F_1$	$D_0V_1F_1$
Variance + Skewness components										
2	295.90(1.00)	602.85(1.00)	187.97(0.64)	494.64(0.82)	15.80(0.05)	11.36(0.02)	6.50(0.02)	13.98(0.02)	85.58(0.29)	82.88(0.14)
1	148.10(1.00)	273.74(1.00)	82.15(0.55)	200.44(0.73)	7.72(0.05)	6.38(0.02)	3.65(0.02)	7.87(0.03)	54.58(0.37)	59.05(0.22)
Variance component										
2	310.13(1.00)	575.54(1.00)	147.91(0.48)	371.92(0.65)	14.37(0.05)	10.60(0.02)	6.91(0.02)	16.43(0.03)	140.94(0.45)	176.60(0.31)
1	152.84(1.00)	264.64(1.00)	68.79(0.45)	159.54(0.60)	7.25(0.05)	6.12(0.02)	3.77(0.02)	8.69(0.03)	73.03(0.48)	90.29(0.34)
Skewness component										
2	-14.23(1.00)	27.31(1.00)	40.06(-2.82)	122.72(4.49)	1.43(-0.10)	0.76(0.03)	-0.37(0.03)	-2.46(-0.09)	-55.35(3.89)	-93.72(-3.43)
1	-4.74(1.00)	9.10(1.00)	13.52(-2.85)	40.91(4.50)	0.48(-0.10)	0.25(0.03)	-0.12(0.03)	-0.82(-0.09)	-18.45(3.89)	-31.24(-3.43)

Note: Ratios of risk premium in each quintile are in parenthesis.

Figures

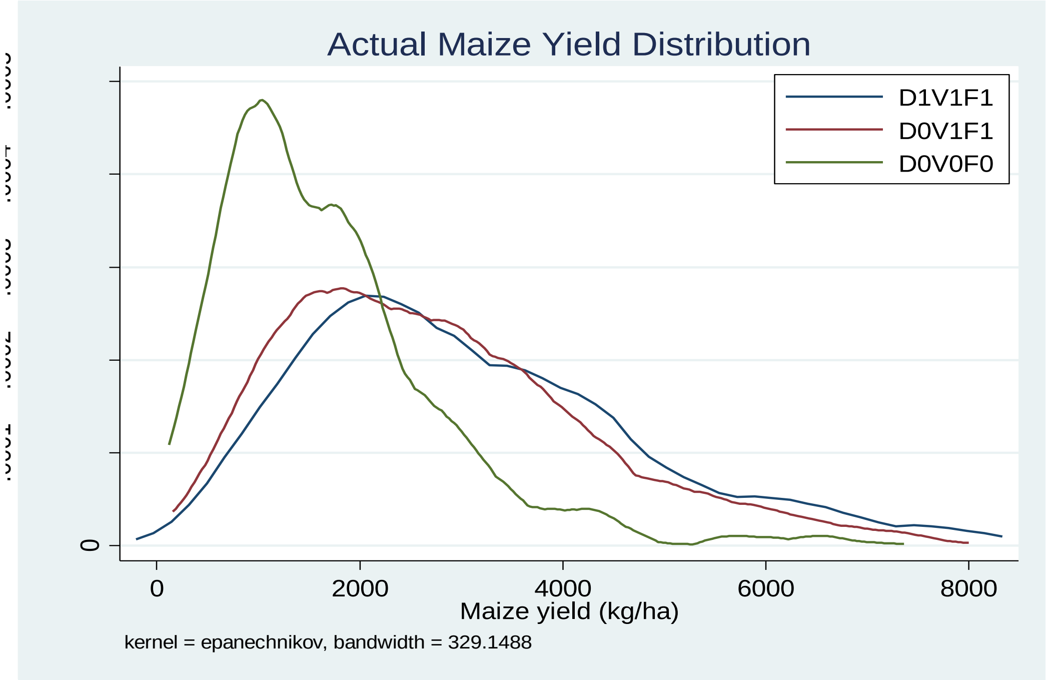

Figure 1a. Actual maize yield distributions under different combination of practices

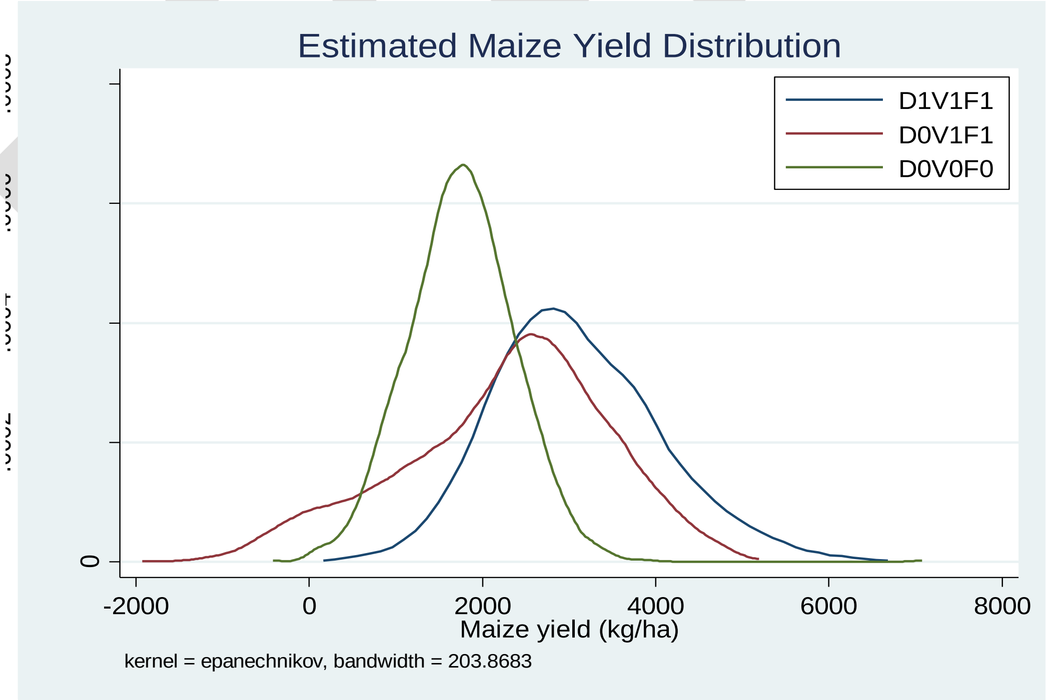

Figure 1b. Estimated maize yield distributions under different combination of practices

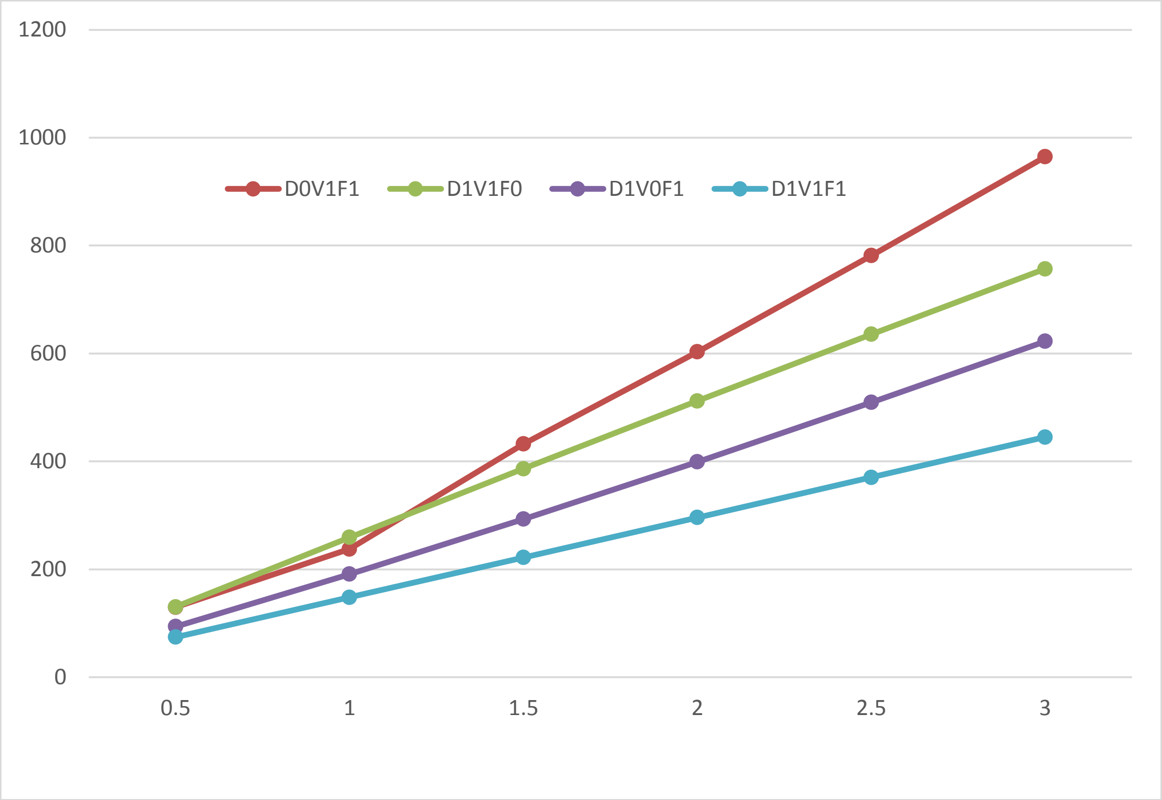

Figure 2. Risk premium (cost of risk) due to selected combinations of maize intensification practices (Diversification, use of improved Variety/seed and chemical Fertilizer)