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

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Abstract

Unexpectedly lower yield outcomes (downside risks) challenge farmers' use of external inputs that can enhance crop productivity. Using household-level panel data collected from Ethiopia, we estimated the effects of crop diversification through maize-legume intercropping/rotation on maize yield distribution and downside risk. Results from endogenous switching regression models and quintile moment approaches show that plots with maize-legume intercropping/rotation have the highest average maize yield. Such crop diversification reduces the downside risk in maize yield more when applied to plots receiving external inputs. The results imply that, in addition to the 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 could enhance crop productivity further and reduce the potential downside risks typically hampering smallholders' external input use in maize production.

Key words: downside risk; maize; sustainable intensification; impacts; Ethiopia

1. Introduction

Farming in general, and rain-fed production systems such as those found in most sub-Sahara African countries in particular, are susceptible to a wide range of production risks (Barrios *et al*. 2008; Schlenker & 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 risk. Increasing downside risk increases the asymmetry or skewness of the risk distribution towards low outcome, holding both mean and variance constant (Di Falco & Chavas 2006).

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 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/stress-tolerant varieties, and herbicides and pesticides. Thus, external input use is normally riskier and needs to be accompanied by complementary risk-mitigating agronomic practices. Even when crop insurance schemes are available, it is important to use the best crop management practices to manage production risks, with only residual risks requiring some level of risk pooling (as in weather-indexed insurance (Tadesse *et al.* 2015) or food aid). Among some of the best agronomic practices are 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 placed on plots treated with and without an improved variety and chemical fertiliser, and how both the 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 & Di Falco 2012; Central Statistical Agency [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 increase in maize production is a testament to its growing strategic and economic importance (Abate *et al.* 2015). Large outlays are expended on maize inputs per year. Significant government programmes are directed towards this crop (Alene *et al.* 2000; Fufa & Hassan 2006; Spielman *et al.* 2012; Abate *et al.* 2015).

Yet there is considerable variability in maize yield across years due to weather factors (Kassie *et al.* 2014). This variability puts smallholders' income and consumption in jeopardy, as maize growers depend directly on maize for consumption and cash income. Moreover, production risks also discourage smallholders from investing in externally purchased agricultural inputs. Overall, any (a)biotic stress that induces maize production risks has a direct effect on the consumption and livelihoods of millions of families producing maize. Given the challenges for agricultural insurance (Tadesse *et al.* 2015), the contribution of best agronomic practices (e.g. crop diversification, the focus of this paper) to autonomous downside risk reduction offers promise. Mainstreaming better agronomy and production methods among maize producers is therefore an economic imperative.

The remaining sections are structured as follows. The methods used are presented in Section 2, and the data used in Section 3. Section 4 presents and discusses the results. The 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 downside risk is higher, smallholders may not be inclined to use such a package. Thus, one may expect farmers to consider favourably 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, i.e. increases downside risk.

In capturing the plot-level yield difference due to different combinations of purchased inputs and crop diversification, we use a self-selection corrected endogenous switching regression model and obtain the average treatment effects on treated (ATT) and untreated plots (ATU) controlling for characteristics observed on the plot, household, farm and village level. This approach helps to control 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 next.

Assuming farmer i growing maize on plot j chooses combination k of the three technologies, i.e. diversification (D), improved variety (V) and chemical fertiliser (F), if the expected benefit from combination k is higher than any of the other combinations m, i.e. $u_{ijk} > u_{ijm}$ for $K = 1,2,\ldots,8$ and $m \neq k$. Thus, considering characteristics (X_{ij}) associated with the plot, household, farm and village level and 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:

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

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

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

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

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

$$E\left[Y_{ijk} \middle| k = 1, X_{ijk}, \hat{\lambda}_{ijk}\right] = \theta_1 X_{ij1} + \sigma_1 \hat{\lambda}_{ij1} \qquad (3)$$

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

$$E\left[Y_{ijm} \middle| k = m, X_{ijm}, \hat{\lambda}_{ijm}\right] = \theta_m X_{ijm} + \sigma_m \hat{\lambda}_{ijm} \qquad (4)$$

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

$$E\left[Y_{ijm} \middle| k = 1, X_{ijk}, \hat{\lambda}_{ijk}\right] = \theta_m X_{ij1} + \sigma_m \hat{\lambda}_{ij1} \qquad (5)$$

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):

$$E\left[Y_{ijk} \middle| k = m, X_{ijm}, \hat{\lambda}_{ijm}\right] = \theta_1 X_{ijm} + \sigma_1 \hat{\lambda}_{ijm} \qquad (6)$$

Equations (3) and (4) are the actual maize yield estimates from plots treated and not 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 (3) and (5), and specified as:

$$\begin{aligned} ATT_k &= E\left[Y_{ijk} \middle| k=1, X_{ijk}, \hat{\lambda}_{ijk}\right] - E\left[Y_{ijm} \middle| k=1, X_{ijk}, \hat{\lambda}_{ijk}\right] \\ &= (\theta_1 - \theta_m)X_{ij1} + (\sigma_1 - \sigma_m)\hat{\lambda}_{ij1} \end{aligned} \tag{7}$$

Similarly, the average treatment effect on the untreated (ATU_m) is computed from the difference between Equations (4) and (6), and specified as:

$$\begin{aligned} ATU_m &= E\left[Y_{ijm} \middle| k=m, X_{ijm}, \hat{\lambda}_{ijm}\right] - E\left[Y_{ijk} \middle| k=1, X_{ijm}, \hat{\lambda}_{ijm}\right] \\ &= (\theta_m - \theta_1)X_{ijm} + (\sigma_m - \sigma_1)\hat{\lambda}_{ijm} \end{aligned} \tag{8}$$

Table 1 shows 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: 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 $D_0V_1F_1$

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 to measure the cost of risk proxied with risk premium (Kim & Chavas 2003; Kassie *et al.* 2015; Di Falco & Chavas 2006, 2009; Kim *et al.* 2014), the cost of risk considering both the variance and skewness components is given as:

$$\begin{aligned} R \cong\ & 0.5 * [F(b_k) - F(b_{k-1})] * \left\{\frac{b(m_{k1})^{-b-1}}{\sum_{i=1}^{k}\{[F(b_k) - F(b_{k-1}) * (m_{k1})^{-b}]\}} * m_{k2} + [b(M_1)^{-1}] * [m_{k1} - \right. \\ & \left. M_1]^2\right\} + (1/6) * [F(b_k) - F(b_{k-1})] * \left\{- \frac{b(1+b)(m_{k1})^{-b-2}}{\sum_{i=k}^{k}\{[F(b_k) - F(b_{k-1}) * (m_{k1})^{-b}]\}} * m_{k3} - [b(1 + \right. \\ & \left. b)(M_1)^{-2}] * [m_{k1} - M_1]^3\right\}, \end{aligned} \tag{9}$$

where $[F(b_k) - F(b_{k-1})]$ is the probability that each partial central moment will be in quintile k; m_{k1}, m_{k2} and m_{k3} refer to the partial mean, variance and skewness of maize yield distribution in the specific quintile k, respectively; and M is the overall central moment. All terms before (1/6) in Equation (9) are referring to the variance component of the 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 national regional states in Ethiopia (Tigray, Amhara, Oromia, Benishangul-Gumuz and SNNPR[1]). The survey covered a total of 39 maize-growing districts selected randomly from the five regional states and considering their maize production potential as 'high', 'medium' and 'low', based on average maize productivity and standard deviation as cut-off points. Then, from each district, four maize-growing *kebeles* (the lowest administrative unit) were selected randomly. From each selected *kebele*, 16 to 18 sample farmers growing maize were selected for interviews. In case any selected sample household happened to be a non-producer of maize during the specific survey season, the household was replaced by another randomly selected maize-producing household. Table 2 gives a detailed overview of the sample households and the number of maize plots surveyed across the two waves. Accordingly, a total of 2 887 and 2 853 maize plots operated by a sample of 1 751 and 1 774 farm households were surveyed in 2010 and 2013 respectively and used in this analysis. Data from Tigray national regional state was not collected in 2013 due to a logistical problem.

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

	National regional state										**Total**	
	Tigray		**Amhara**		**Oromia**		**Benishangul-Gumuz**		**SNNPR**			
Year	**HHs**	**Maize plots**	**HHs**	**Maize plots**	**HHs**	**Maize plots**	**HHs**	**Maize plots**	**HHs**	**Maize plots**	**HHs**	**Maize plots**
2010	27	30	259	446	992	1 666	55	72	418	673	1 751	2 887
2013	nd	nd	235	369	1 068	1 802	64	78	407	604	1 774	2 853
Total	27	30	494	815	2 060	3 468	119	150	825	1 277	3 525	5 740

SNNPR = Southern Nations, Nationalities, and Peoples' Region; HHs = sample households; nd = no data

The data are panel data at the household level and details of maize plots for each sample household were collected each year. However, due to crop rotation and changes in plot size resulting from the splitting and merging of plots each season, the datasets may not be panel at the plot level. The survey asked for details of plot-level physical characteristics (soil type, soil colour, slope and soil depth), farmer-specific subjective judgement of plot-level soil fertility, inputs used and production on all maize plots operated by each sample household. In addition, for all the surveyed plots, the amount of labour, seed and fertiliser used, herbicide and pesticides applied, and whether the production was exposed to any kind of (a)biotic stresses (like drought, flood, disease, pests, etc.) were documented. Finally, data on maize and bean productivity (accounting for whether harvested green/fresh or dry) was collected. Using a standard conversion factor, the green harvests were converted to dry weight equivalent for yield accounting purposes.

Table 3 gives a 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 country-representative data released by the Ethiopian Central Statistical Agency for these specific cropping seasons. Fertiliser use in maize production increased between the two survey years, as did pesticide and labour use. The share of plots using improved hybrid maize varieties increased from 54% to 63%.

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[1] Southern Nations, Nationalities, and Peoples' Region.

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

Variables	2010 (*N* = 2 887)		2013 (*N* = 2 853)		Total (*N* = 5 740)	
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
Maize yield *(kg/ha)*	2 325	1 533	2 496	1 513	2 410	1 525
Seed *(kg/ha)*	26.9	15.6	25.8	12.7	26.4	14.2
Fertiliser *(kg/ha)*	87.3	105.1	109.5	114.1	98.3	110.2
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
Labour *(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
Benishangul-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

During both years, drought was the major stress reported by the farmers, being reported for 15% and 12% of the maize plots in 2010 and 2013 respectively. Drought discourages smallholders from using purchased inputs in maize production, but may encourage 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 used (improved variety, V, and chemical fertiliser, F) and crop diversification, D. During both survey years, most of the maize plots used both improved varieties and chemical fertiliser ($D_0V_1F_1$ and $D_1V_1F_1$). Interestingly, the data also show that these combinations of technology use were shown to give rise to higher maize productivity. The level of skewness is higher when improved varieties and chemical fertiliser were not used on the maize plots, regardless of diversification ($D_0V_0F_0$ and $D_1V_0F_0$).

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

Technology combinations	2010 *(N = 2 887)*				2013 *(N = 2 853)*				Total *(N = 5 740)*			
	Obs	**Mean**	**Std. dev.**	**Skew-ness**	**Obs**	**Mean**	**Std. dev.**	**Skew-ness**	**Obs**	**Mean**	**Std. dev.**	**Skew-ness**
$D_0V_0F_0$	461	1 631	1 114	1.65	400	1 751	1 098	1.49	861	1 687	1 108	1.57
$D_0V_1F_0$	232	1 889	1 228	0.79	239	2 005	1 239	1.06	471	1 948	1 233	0.93
$D_0V_0F_1$	120	2 094	1 452	1.51	147	2 103	1 286	0.75	267	2 099	1 360	1.17
$D_0V_1F_1$	621	2 714	1 515	0.81	798	2 805	1 502	0.77	1 419	2 765	1 508	0.79
$D_1V_0F_0$	395	1 721	1 233	1.65	255	1 652	1 016	1.43	650	1 694	1 152	1.62
$D_1V_1F_0$	185	2 140	1 397	1.05	154	2 177	1 377	0.95	339	2 157	1 386	1.01
$D_1V_0F_1$	157	2 309	1 425	1.42	119	2 451	1 598	1.31	276	2 370	1 501	1.38
$D_1V_1F_1$	716	2 999	1 701	0.87	741	3 167	1 593	0.69	1457	3 085	1 649	0.78

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

4. Results and discussions

4.1 Explaining variations in maize yield

Controlling for variations at the district level, Table 5 presents estimation results explaining variations in maize yield for the total sample and the two survey years. Accordingly, and as expected, household head characteristics and key inputs in maize production (seed rate, fertiliser rate and use of seeds of improved hybrid and openly pollinated varieties (OPVs)) have explained the variation in maize yield. Considering the total sample (pooled data) and controlling for other factors, estimated maize yield is higher for male-headed households by 166 kg/ha. In addition, the estimated maize yield per hectare decreased with the age of household head and increased with the level of education of the household head. On average, maize plots intercropped with common bean showed a higher yield (641 kg/ha for the pooled data). The rate of maize seed and chemical fertiliser used in maize production during both survey years has shown positive effects on maize yield. On the other hand, the effects of (a)biotic factors reported by the 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, which can reduce maize yields.

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

Explanatory variables	**Total (pooled)**		**2010**		**2013**	
	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
Fertiliser (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
Labour (AE/ha)	6.98***	0.56	5.32***	0.81	9.00***	0.79
Hybrid variety (dummy, 1 = Yes)	291.01***	48.07	256.44***	70.45	350.37***	65.98
Improved OPV (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)						

Explanatory variables	**Total (pooled)**		**2010**		**2013**	
	Coef.	**Std err**	**Coef.**	**Std err**	**Coef.**	**Std err**
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	1 057.16***	276.82	1 234.69***	300.12	570.44**	268.63
Gonder	726.17**	307.60	1 353.33***	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	1 436.37***	270.79	1081.74***	316.94	1 465.73***	213.02
Jimma Rare	420.93	278.53	830.33**	333.98	44.56	230.81
Hagere Maryam	1 014.73***	283.94	919.28**	399.61	737.07***	222.58
Arero	641.92**	288.62	948.82***	363.52	281.47	244.94
Kersa/East Hararge	1 488.93***	282.42	1 356.36***	312.72	1 622.72***	266.13
Kuni	1 568.30***	281.22	1 171.76***	307.22	2 258.85***	278.11
Chole	1 252.77***	293.99	922.27**	366.25	1 343.99***	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	2 322.69***	271.70	2 512.13***	300.41	1 978.48***	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
Meskan and Mareko	871.36***	268.15	1 007.59***	296.84	578.39***	216.66

Explanatory variables	**Total (pooled)**		**2010**		**2013**	
	Coef.	**Std err**	**Coef.**	**Std err**	**Coef.**	**Std err**
Kacha Bira	-12.55	281.89	206.44	318.71	-439.57*	254.11
Shebedino	1 134.05***	272.14	1 550.56***	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	1 307.58***	259.05	1 178.23***	278.40	1 250.73***	192.55
Misrak Badawacho	590.62**	260.50	584.45**	281.35	387.01*	198.54
Meskan	1 032.67****	259.93	875.56***	282.02	969.73***	195.60
Hawassa Zurya	1 113.77***	262.04	1 000.66***	283.62	1 017.29***	205.75
Dugda	839.79***	265.10	850.04***	293.95	645.00***	205.09
Adamitulu Jidokombolcha	851.51***	260.09	1 078.74***	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 observations	*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*	
Adjusted 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's 2010 estimation, as Guangua is for 2013. There was no survey data from Tahtay Maychew in 2013. References were selected randomly.

4.2 Average treatment effects on maize yield

The results from the conditional expected maize yield derived from an endogenous switching regression analysis for the actual and counterfactual maize plots under different treatments are presented in Table 6. These 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 improved seed and chemical fertiliser ($D_1V_1F_1$) were compared to the situation in which these plots were treated only with diversification but no improved seed and chemical fertiliser use ($D_1V_0F_0$). On the other hand, plots with no diversification and no use of improved seed and chemical fertiliser ($D_0V_0F_0$) would have obtained higher returns in maize yield (average increment of 0.28 t/ha) if they had been treated with diversification and the two purchased inputs ($D_1V_1F_1$), i.e. the average treatment effect on the untreated (ATU). Moreover, if plots treated with both improved variety and chemical fertiliser but no diversification ($D_0V_1F_1$) would have been treated with a combination of these three technologies/ practices ($D_1V_1F_1$), the average maize yield would have increased by 0.1 t/ha. Overall, the association of diversification with either of the two purchased inputs, or both, has shown better a 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: 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}) 3 083.8 (25.7)	$(c_{111,011})$ 2 262.3 (31.8)	821.5***	4	
	$(d_{011,111})$ 2 848.4 (23.3)	(b_{011}) 2 748.3 (21.8)	100.1***		6
$D_1V_1F_1 - D_0V_0F_1$	(a_{111}) 3 083.8 (25.7)	$(c_{111,001})$ 2 415.6 (26.0)	668.2***	6	
	$(d_{001,111})$ 2 312.3 (80.0)	(b_{001}) 2 084.8 (56.6)	227.6***		4
$D_1V_1F_1 - D_0V_1F_0$	(a_{111}) 3 083.8 (25.7)	$(c_{111,010})$ 1 979.9 (26.4)	1 103.9***	3	
	$(d_{010,111})$ 2 219.1 (36.4)	(b_{010}) 1 953.5 (31.5)	265.6***		2
$D_1V_1F_1 - D_0V_0F_0$	(a_{111}) 3 083.8 (25.7)	$(c_{111,000})$ 1 760.4 (16.6)	1 323.4***	2	
	$(d_{000,111})$ 1 965.1 (31.5)	(b_{000}) 1 685.1 (19.0)	279.9***		1
$D_1V_1F_1 - D_1V_0F_1$	(a_{111}) 3 083.8 (25.7)	$(c_{111,101})$ 2 643.9 (26.5)	439.9***	7	
	$(d_{101,111})$ 2 512.7 (79.2)	(b_{101}) 2 382.0 (60.0)	130.6*		5
$D_1V_1F_1 - D_1V_1F_0$	(a_{111}) 3 083.8 (25.7)	$(c_{111,110})$ 2 299.8 (29.0)	784.0***	5	
	$(d_{110,111})$ 2 092.8 (45.3)	(b_{110}) 2 149.0 (41.6)	(56.2)		7
$D_1V_1F_1 - D_1V_0F_0$	(a_{111}) 3 083.8 (25.7)	$(c_{111,100})$ 1 718.9 (16.2)	1 364.9***	1	
	$(d_{100,111})$ 1 944.9 (36.3)	(b_{100}) 1 688.0 (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 the 1%, 5% and 10% level respectively

Figures 1a and 1b 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 fertiliser. For those plots that received improved seed and chemical fertiliser, a higher yield was observed when treated with crop diversification. This implies that crop diversification is an affordable complement to external inputs in enhancing maize yield. External inputs are costly, but their returns are worth the expense. On the other hand, the cost of not using purchased external inputs is also high in terms of forgone yield. Thus, for higher production and greater productivity in maize, the extension system needs to place emphasis on external inputs and on proper agronomic literacy, so that maize-growing farmers consistently apply crop diversification.

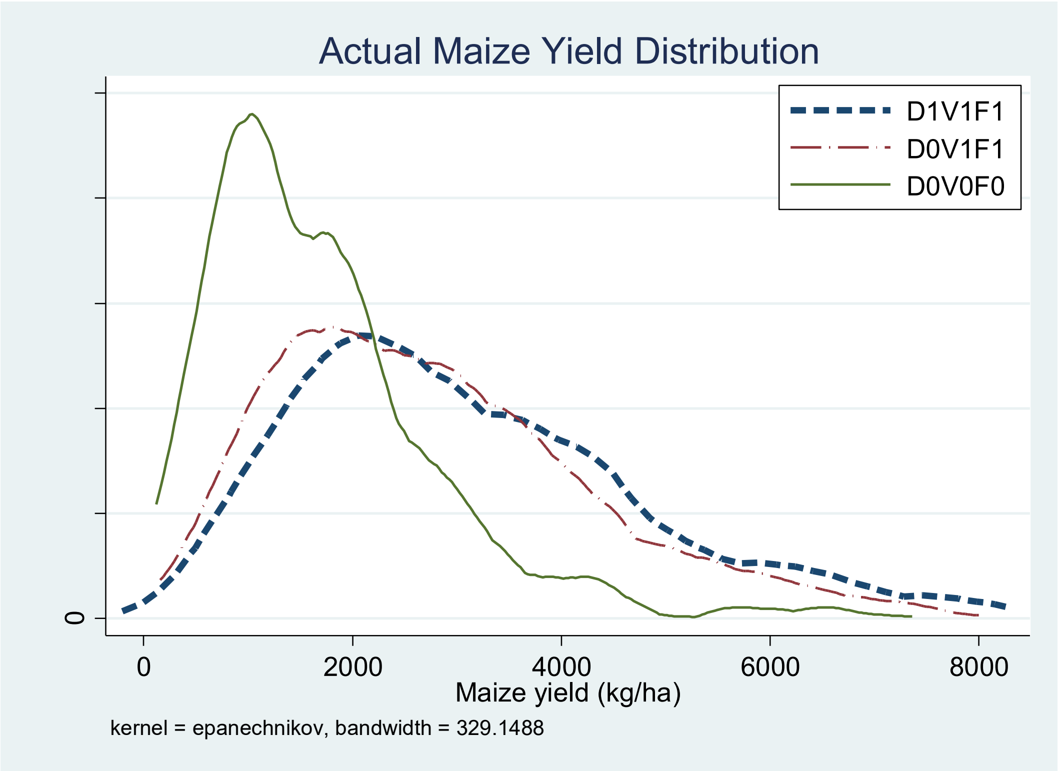

Figure 1a: Actual maize yield distributions under different combinations of practices

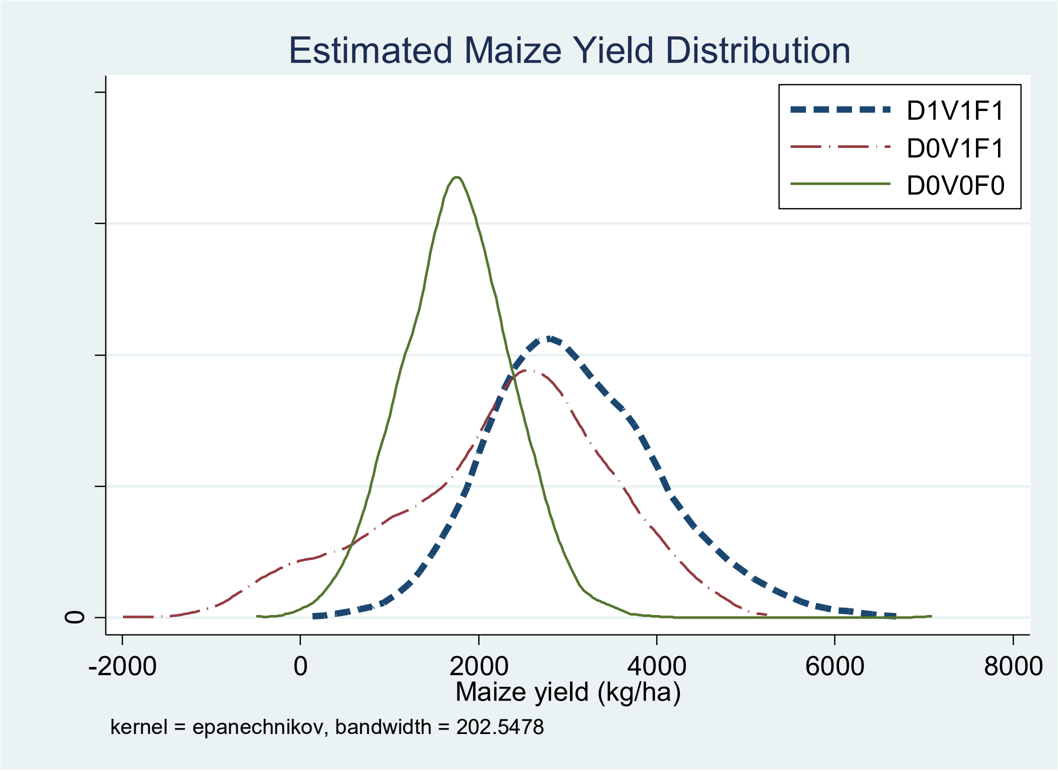

Figure 1b: Estimated maize yield distributions under different combinations of practices

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 levels of coefficient of relative risk aversion (CRRA), and the contribution of downside risk to the risk premium were evaluated. As shown in Table 7, the estimated risk premium farmers would have to pay to avoid the associated lower yield outcome is 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 forgone) 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 risk-sharing arrangements), while having to be encouraged to adopt improved maize technologies that demand external inputs and thus cash outlays (like purchased improved seeds and chemical fertilisers).

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 fertiliser)

	$D_1V_1F_1$					**$D_0V_1F_1$**				
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	1 932.3	-1.288	188.0	21.3	337	990.6	-0.365	494.6	24.8
2	356	2 704.5	-0.103	15.8	9.1	338	2 147.7	-0.238	11.4	6.7
3	356	3 324.7	0.155	6.5	-5.6	338	2 792.7	0.280	14.0	-17.6
4	356	4 362.8	1.147	85.6	-64.7	336	3 705.2	0.882	82.9	-113.1
Total	1 423	3 083.8	0.395	295.9	63.5	1 349	2 408.2	-0.181	602.9	82.1

Comparing $D_1V_1F_1$ and $D_0V_1F_1$, where the difference is mainly the diversification component, both at moderate ($b = 2$) and low ($b = 1$) constant relative risk-aversion coefficients (CRRA), the proportion of risk emanating from the variance and skewness of the maize yield distribution in the lower quintile (i.e. 1st quintile) ranges from 55% to 64% and from 73% to 82% for plots with and without diversification (Table 8). Looking at the skewness component alone, the yield penalty (as measured by the amount of yield farmers would have to pay to avoid the lower yield outcome) is positive for plots not treated with any form of diversification, whereas plots treated with diversification have a negative cost of risk, which indicates that downside risk is not a challenge. Decomposing the yield distribution by quintiles also confirms the same finding, where plots treated with diversification are always better off in terms of reducing the probability of a lower yield outcome in each quintile of the yield distribution.

In Figure 2, the estimated cost of risk from plots treated with diversification and purchased inputs ($D_1V_1F_1$) is lower compared to the cost of risk estimates for any of the other plots with different combinations of practices across a range of relative risk-aversion coefficients (CRRA). On the other hand, compared to any of the other combinations of purchased inputs used with crop diversification ($D_1V_1F_0$, $D_1V_0F_1$ or $D_1V_1F_1$), the estimated cost of risk is higher for plots with no diversification but treated with purchased inputs ($D_0V_1F_1$). This implies the important role crop diversification could play in reducing the downside risk of maize yield distribution when yield-enhancing purchased inputs are used in maize production.

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 parentheses

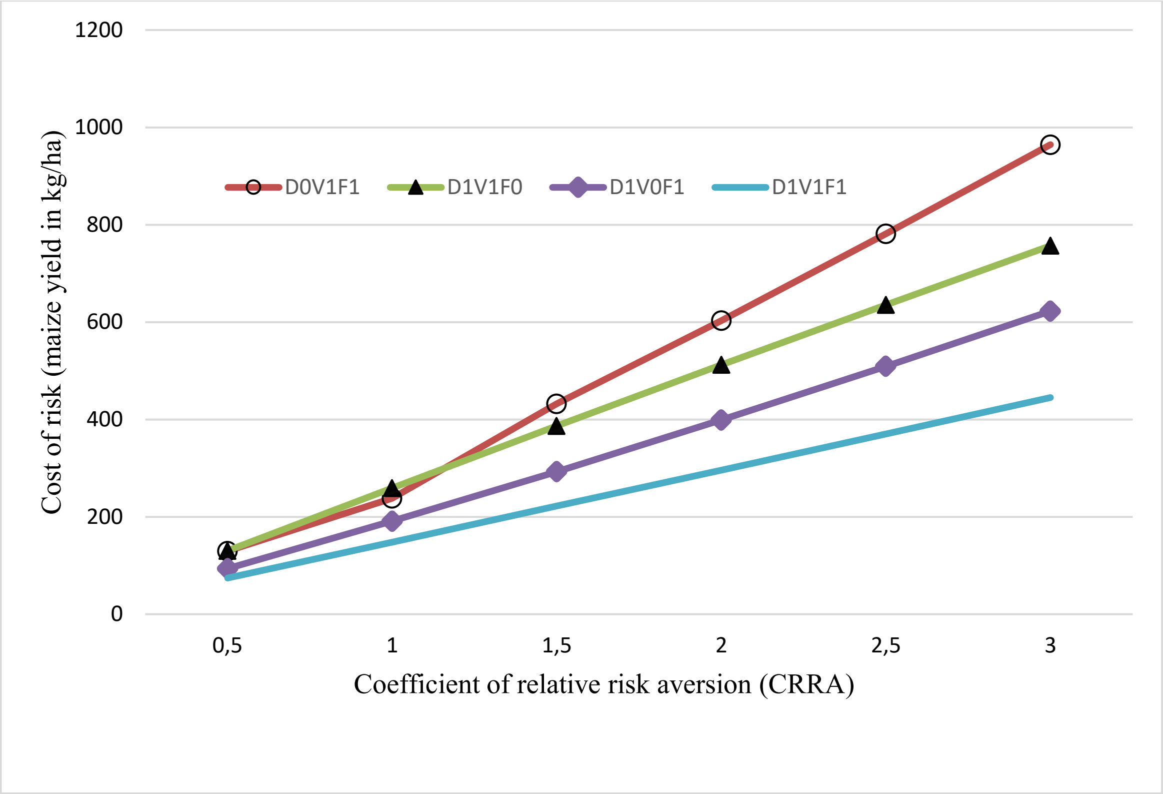

Figure 2: Risk premium (cost of risk) for selected combinations of maize intensification practices (*D*iversification, use of improved *V*ariety/seed and chemical *F*ertiliser) at different relative risk-aversion coefficients (CRRA)

5. Conclusions

(A)biotic stress factors give rise to maize production risk and can adversely affect income, food and nutritional security for smallholders. Farmers often have too 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 with (a)biotic stresses. This paper has analysed the case of intensifying maize-based systems in Ethiopia using a unique two years of household panel data collected at both plot and household levels. It assessed the contribution of crop diversification in improving average maize yield, and in 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 average maize productivity, particularly when combined with yield-enhancing external inputs such as improved maize varieties and chemical fertiliser. In addition, the cost of risk, as estimated by the maize yield farmers may be 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 fertiliser.

The current agricultural extension system in Ethiopia emphasises the intensification of maize production using external inputs (improved seed and chemical fertiliser) among smallholders. The results from this study imply that a concomitant emphasis needs to be placed on training and encouraging smallholders to use crop diversification, such as maize-legume intercropping or crop rotation. The application of the full package of external input use, combined with diversification, provided the highest maize yield and lowest downside risk. Policies should therefore support and encourage the use of the full package, using those farmers already implementing it as exemplars for their farming communities. Moreover, these policies should support non-users to apply the missing components to generate additional yield and income benefits at a reduced downside risk. Going forward, research and development may want to further explore and promote appropriate package approaches, rather than focusing on component technologies one at a time. This appears to be a promising avenue to both enhance maize productivity further, and to reduce the potential downside risk typically hampering smallholders' external input use in maize production.

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