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The joint impact of improved maize seeds on productivity and efficiency: implications for policy

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Abstract

Productivity and efficiency are key performance indicators of improved seeds. Efficiency differences explain part of the variation in productivity. Improved seeds may affect efficiency because farmers often do not apply inputs at optimum. Improved seeds therefore not only directly affect productivity but also indirectly through efficiency. If productivity and efficiency are not estimated jointly, it creates specification problems and it may (over)underestimate benefits of crop improvement research. Previous studies however estimate the productivity and efficiency impacts of improved seeds independently. In this paper, we estimate the joint impact of improved maize seeds on productivity and efficiency using panel data from maize farmers in Ethiopia. Selection biases associated with seeds choice are addressed by estimating production functions using endogenous switching regressions. Our findings show that improved seeds bring productivity and efficiency gains relative to recycled seeds suggesting that the benefits of improved seeds are underestimated by the amount of productivity (efficiency) gains if either of the two are ignored. Unsurprisingly, improved seeds are more productive than traditional seeds, but tradeoffs between productivity and efficiency exist because farmers are less efficient when they use improved seeds than traditional seeds. Our results may inform policy makers to design strategies that could increase productivity at most efficiency.

Keywords: productivity, efficiency, fresh improved seeds, recycled seeds, traditional seeds, maize, random effects, endogenous switching regression, Ethiopia

JEL classification: D220, D240, Q120, Q150, Q160, Q180

1 Introduction

The impact of using improved seeds on productivity and efficiency has been extensively studied in two strands of literature. The first strand focuses on the impact of improved seeds on productivity (Amare et al., 2012; Teklewold et al., 2013; Manda et al., 2016; Bezu et al., 2014; Khonje et al., 2015; Zeng et al., 2015; Walker & Alwang, 2015; Evenson & Gollin, 2003; Suri, 2011; Abro et al., 2017; Crost et al., 2007). Most of these studies underline the responsiveness of improved seeds to external inputs, but the studies do not provide direct estimates on the impact of improved seeds on efficiency. This strand of literature relies on estimating average production functions that do not account for efficiency. This is equivalent to assuming that all farmers are equally efficient even though efficiency could explain part of the variation in productivity (Coelli et al., 2005; Kumbhakar et al., 2015). The second strand of the literature estimates the efficiency impact of using improved seeds. These studies neglect the potential productivity contributions of improved seeds because various seed types, which could shift the production function, are not included as different technologies (Alene & Hassan, 2006; Battese et al., 2017; Xu & Jeffrey, 1998; Alene & Manyong, 2006; Kalirajan, 1991; Kalirajan & Shand, 2001).

Improved seeds are bred for higher productivity when they are applied at optimal amount of inputs (Vanlauwe et al., 2011). Optimal inputs use implies that farmers are efficient because they obtain the highest level of productivity per units of inputs applied. We thus expect that using improved seeds increase farmers' productivity and efficiency simultaneously. However, potential tradeoffs in productivity and efficiency may exist because of the occurrence of production stresses, which may affect farmers' ability to use inputs efficiently (Shiferaw et al., 2014; Huffman et al., 2018; Khonje et al., 2018; Fisher et al., 2015). Furthermore, farmers may not often apply inputs as recommended by scientists because they may not obtain the right quality and quantity of inputs due to inefficient input markets and other socioeconomic constraints (Bold et al., 2017; Duflo et al., 2011).

In production contexts where farmers face stringent production, socioeconomic and market constraints, the net effect of using improved seeds on productivity and efficiency is an empirical question. The previous studies however have given less focus on the simultaneous impact of using improved seeds on productivity and efficiency. If improved seeds indeed have a differential impact on productivity and efficiency, estimating them independently may overestimate or underestimate the benefits of investment on crop improvement research. From a methodological perspective, estimating productivity and efficiency independently is a specification problem because the productivity gains associated with improved efficiency as a result of using improved seeds is unaccounted. Our objective in this paper is therefore estimating the joint impact of using improved seeds on productivity and efficiency by addressing the above-mentioned shortcomings of the existing studies.

We contribute to the existing literature in two ways. First, we relax the assumption of equally efficient farmers by taking into account the role of efficiency in explaining part of the variation in productivity and the effect of using improved seeds on efficiency. Unlike the previous studies, our approach enables us to see potential benefits or tradeoffs in productivity and efficiency associated with improved seeds in the same framework. Second, we take into account the heterogeneity of farmers' seeds by classifying seeds into fresh improved seeds, recycled seeds and traditional seeds because neglecting seed heterogeneity associated with farmers seed preferences, socioeconomic, and agroecological conditions may lead to misleading policy conclusions. The fresh seeds are seeds of improved varieties purchased from seed producers and distributers.[1] Recycled seeds are saved seeds of improved varieties from the previous harvest. Traditional seeds are landraces with distinct qualities and characteristics maintained by farmers for generations. Unlike the improved versus traditional seeds classification common in the literature, our classification provides us the opportunity to understand the extent of heterogeneous seed choice of farmers and its implication on productivity and efficiency. We use a comprehensive panel household survey data collected in maize producing districts of Ethiopia. By using a detailed classification of maize seed types, we estimate endogenous switching random effects model after accounting seed selection bias emanating from both observed and unobserved factors. Our findings are relevant for designing crop improvement policies that aim to increase farm productivity at most efficiency.

The rest of this paper is structured as follows. In Section 2, we present the conceptual framework and the econometric procedure. In Section 3, we briefly describe the data and present the descriptive statistics. In Section 4, we present the empirical results. In Section 5, we make concluding remarks.

2 Conceptual and empirical framework

In this section, we present the estimation strategy we use to study the joint impact of using fresh improved seeds on productivity and efficiency. We first briefly explain the commonly used

[1] Now onwards, we interchangeably use fresh seeds, improved seeds, and fresh improved seeds.

production function in the literature and how we obtain an indicator of efficiency in the context of panel data. In subsequent sub-sections, we discuss our suggested estimation approach. The equation we estimate is a translog production function of the type in equation (1).

$$Y_{ijt} = \pi_0 FS_{ijt} + \pi_1 RS_{ijt} + \boldsymbol{X}_{ijt}\beta + u_{1j} + \varepsilon_{1ijt} \quad (1)$$

Y_{ijt} is logarithm of productivity of plot i of household j in year t, which is defined as quantity produced in kg per hectare. FS_{ijt} and RS_{ijt} are dummy variables representing the use of fresh seeds and recycled seeds, respectively. We use traditional seeds as a comparison group so that π_0 and π_1 show the effect of fresh and recycled seeds relative to the traditional seeds, respectively. $\boldsymbol{X}$ stands for a vector of inputs and their interaction terms, and other explanatory variables. π and β are parameters to be estimated. $u_j \sim N(0, \hat{\sigma}_u^2)$ stands for time invariant unobserved heterogeneity of household j. $\varepsilon_{ijt} \sim N(0, \hat{\sigma}_\varepsilon^2)$ represents classical random error terms of plot i of household j in year t.

$\widehat{u_j}$ is interpreted as a percentage deviation of observed performance of household j from its own frontier (Greene, 2005b). In the empirical literature, $\widehat{u_j}$ is used to drive measures of efficiency of decision making units, in our case, farming households (Johnes, 2006; Carey, 2000; Kumbhakar et al., 2015; Greene, 2005b; Greene, 2005a). After estimating equation (1), we obtain $\widehat{u_j}$ using the best linear unbiased predictor (BLUP) in equation (2) (Rabe-Hesketh & Skrondal, 2012; Kumbhakar et al., 2015).

$$\widehat{u_j} = \left\{\frac{n_j\hat{\sigma}_u^2}{\hat{\sigma}_\varepsilon^2 + n_j\hat{\sigma}_u^2}\right\}\frac{\sum_i (y_{ij} - \hat{y}_{ij})}{n_j} \quad (2)$$

where $\hat{\sigma}_u^2$ is the estimated variance of $\widehat{u_j}$ and $\hat{\sigma}_\varepsilon^2$ is the variance of ε_{ijt}. n_j is the number of plots within household j. $\hat{y}_{ij}$ is the predicted value of the logarithm of productivity of plot i and household j. The efficiency of farming households (TE_j) are then estimated using equation (3) (Johnes, 2006; Carey, 2000; Kumbhakar et al., 2015). TE_j shows the extent of farmers' level of efficiency in producing a maximum output given a certain quantity of inputs.

$$\widehat{TE_j} = e^{-(\max(\widehat{u_j}) - \widehat{u_j})} \quad (3)$$

The coefficient of FS_{ijt} and RS_{ijt} in equation (1) show that we assume that seed choice has only an average impact on productivity over the entire sample of farmers. Equation (1) does not allow us to analyze the effect of using fresh seeds on the productivity of conventional inputs (e.g., labor and fertilizers) (Alene & Manyong, 2007). It does not also allow us to analyze the effects of fresh seeds in terms of improving the efficiency of farmers because efficiency is obtained as a residual. Because our objective is to show that estimating productivity and efficiency independently may overestimate or underestimate the benefits of using fresh seeds, our estimation approach should enable us to estimate the impact of using fresh seeds on productivity and efficiency simultaneously. For this purpose, we estimate equation (1) in three steps. Firstly, we estimate production functions to each seed type in a switching regression framework, which could be justified by the Chow test. The Chow test results are [F(29, 6129)=4.31; p-value=0.000) for the comparison between fresh seeds and recycled seeds, and (F(29, 6119)=5.37; p-value=0.000] for the comparison between fresh seeds and traditional seeds. As the p-values indicate, we reject the null hypothesis that the coefficients of each group are identical suggesting using fresh seeds have both intercept and slope effects. Secondly, we recover an efficiency indicator from the production functions using equations (2 and 3) discussed above. Lastly, we estimate the joint impact of using fresh seeds on productivity and efficiency by establishing counterfactual outcomes following the literature on treatment effects (Kassie et al., 2015).

2.1 Endogenous switching translog production functions

We estimate the production functions to the three seed types as specified in equation (4a-4c).

$$\text{Regime 1: } Y_{1ijt} = \boldsymbol{X}_{1ijt}\boldsymbol{\beta}_1 + \gamma_1\hat{\lambda}_{1ijt} + u_{1j} + \varepsilon_{1ijt} \quad \text{if } A = 1 \tag{4a}$$

$$\text{Regime 2: } Y_{2ijt} = \boldsymbol{X}_{2ijt}\boldsymbol{\beta}_2 + \gamma_2\hat{\lambda}_{2ijt} + u_{2j} + \varepsilon_{2ijt} \quad \text{if } A = 2 \tag{4b}$$

$$\text{Regime 3: } Y_{3ijt} = \boldsymbol{X}_{3ijt}\boldsymbol{\beta}_3 + \gamma_3\hat{\lambda}_{3ijt} + u_{3j} + \varepsilon_{3ijt} \quad \text{if } A = 3 \tag{4c}$$

where A=1,2,3 indicates fresh seeds, recycled seeds, and traditional seeds, respectively. $\hat{\lambda}_A$ is a proxy for unobserved factors that might affect $\hat{\lambda}_A$ and seed choice simultaneously, which are obtained from a multinomial logistic regression model (Bourguignon et al., 2006; Kassie et al., 2015; Teklewold et al., 2013). The rest are as defined in equation (1). The models are estimated using random effects. We opt to use this approach instead of Stochastic Frontier Analysis (SFA) because the productivity estimates would have been based on the *efficient* frontier in SFA approach. Hence, results would not show the impact of using fresh seeds on productivity to the *average* farmers. Our approach therefore enables us to examine the impact of seed choice on productivity and efficiency on the *average* farmers as opposed to the *efficient* farmers.

2.2 Identification strategy

Famers' seed choice is not a random assignment. Farmers use certain seed type based on their productivity expectation given the observed and unobserved attributes of their plots and various seed types. One of the key assumption in equation (4a-4c) is u_{Aj} are uncorrelated with the explanatory variables represented by $\boldsymbol{X}_A$. This seems a strong assumption because of plot-specific unobservables such as missing information regarding land quality that we cannot control for in the regression (Kassie et al., 2015; Abro et al., 2018). We relax this assumption using the Mundlak's fixed effects approach, which involves including the household averages of all time and plot-varying observations in equations (4a-4c). In the Mundlak's approach, u_{Aj} are assumed to be a linear function of the averages of time and plot-varying explanatory variables ($\bar{\boldsymbol{M}}$), u_{Aj}=$\theta\bar{\boldsymbol{M}} + \tau_j$ with $\tau_j \sim IID(0, \sigma^2)$, where $E(\gamma_j|\bar{M}) = 0$ and θ is the corresponding vector of coefficients, and τ_j is a normally distributed error term uncorrelated with $\bar{\boldsymbol{M}}$ (Di Falco & Veronesi, 2014; Mundlak, 1978). The Mundlak's approach however does not address potential endogeneity problems induced by time-varying unobserved factors (e.g., field damage by livestock) that may affect seed choice and productivity (Kassie et al., 2015; Di Falco & Veronesi, 2014). In order to control for time-varying unobserved factors, we use $\hat{\lambda}_A$ as a proxy for time-varying unobserved factors that may jointly affect both the benefits of choosing different seed types and productivity.

In addition to $\hat{\lambda}_A$, estimating equations (4a-4c) requires exclusion restrictions. The exclusion restrictions should be exogenous explanatory variables that correlate with seed choice and uncorrelated with productivity (Di Falco et al., 2011). We exclude distance to the nearest inputs and output markets in the production functions. These variables have been used as exclusion restrictions in previous impact evaluations (Zeng et al., 2015; Kassie et al., 2015; Di Falco et al., 2011; Suri, 2011). Zeng et al. (2015) argue that once the intensity of inputs and plot characteristics are controlled for in the production function, distance variables related to market access may affect productivity only through seed choice. Following Kassie et al. (2015) and the above-mentioned argument of Zeng et al. (2015), we also exclude variables on farmers' social networks and farmers' perception about the skill of government officials, which may shape farmers perception on seed choice.

We checked the statistical admissibility of the exclusion restrictions using joint tests (Di Falco et al., 2011). The joint tests show that the excluded variables are jointly statistically different from zero (χ^2(24)=42.93; p-value=0.001) in the MNL model (Table 5, in the appendix). Furthermore, a falsification test shows that the exclusion restrictions are not jointly significant in two of the three switching regressions. For the models with recycled seeds and traditional seeds, the exclusion restrictions are insignificant (χ^2(7)=6.46; p-value=0.488 and χ^2(7)=8.46; p-value=0.294, respectively) supporting the validity of the instruments. However, the significant test for fresh seeds, (χ^2(7)=16.55; p-value=0.020), may indicate that the instruments may tend to affect both seed choice and productivity (Table 6, in the appendix). As a robustness check, we estimate two variants of exogenous switching regressions. In the first variant of the exogenous switching regressions, we estimate our models without including the inverse Mill's ratio ($\hat{\lambda}$). In the second variant of the exogenous switching regressions, we exclude $\hat{\lambda}$ and include the exclusion restrictions as explanatory variables. The results from the two exogenous switching regressions are consistent with our original specification (Tables 6 and 7, Appendix).

2.3 Counterfactual analysis

After controlling for the effects of unobserved selection bias and observed explanatory variables, we obtain the actual sample and counterfactual conditional expected productivity. Equations (5a-5g) show the conditional expected outcomes for productivity (Di Falco & Veronesi, 2014).

$$E(Y_1|A = 1) = \boldsymbol{\beta}_1\boldsymbol{X}_1 + \gamma_1\hat{\lambda}_1 \tag{5a}$$

$$E(Y_2|A = 2) = \boldsymbol{\beta}_2\boldsymbol{X}_2 + \gamma_2\hat{\lambda}_2 \tag{5b}$$

$$E(Y_3|A = 3) = \boldsymbol{\beta}_3\boldsymbol{X}_3 + \gamma_3\hat{\lambda}_3 \tag{5c}$$

$$E(Y_2|A = 1) = \boldsymbol{\beta}_2\boldsymbol{X}_1 + \gamma_2\hat{\lambda}_1 \tag{5d}$$

$$E(Y_3|A = 1) = \boldsymbol{\beta}_3\boldsymbol{X}_1 + \gamma_3\hat{\lambda}_1 \tag{5e}$$

$$E(Y_1|A = 2) = \boldsymbol{\beta}_1\boldsymbol{X}_2 + \gamma_1\hat{\lambda}_2 \tag{5f}$$

$$E(Y_1|A = 3) = \boldsymbol{\beta}_1\boldsymbol{X}_3 + \gamma_1\hat{\lambda}_3 \tag{5g}$$

Equations (5a-5c) are the expected outcomes observed in the sample. Equations 5d and 5e are the expected counterfactual outcomes if farmers who used fresh seeds had used recycled and traditional seeds, respectively. In other words, the counterfactuals in equations 5d and 5e measure average expected productivity for farmers who used fresh seeds if the return to their characteristics are the same as farmers who used recycled seeds and traditional varieties, respectively. Equations (5f) and (5g) are the expected counterfactual outcomes if farmers who used recycled seeds and traditional varieties had used fresh seeds. All the other variables are as defined in equation (1). The average treatment effects on the treated (ATTs) and the average treatment effects on the untreated (ATUs) are estimated in equations (6a-6b) and (6c-6d), respectively.

$$ATT_1 = E(Y_1|A=1) - E(Y_2|A=1) = (\boldsymbol{\beta}_1 - \boldsymbol{\beta}_2)\boldsymbol{X}_1 + (\gamma_1 - \gamma_2)\hat{\lambda}_1 \quad (6a)$$

$$ATT_2 = E(Y_1|A=1) - E(Y_3|A=1) = (\boldsymbol{\beta}_1 - \boldsymbol{\beta}_3)\boldsymbol{X}_1 + (\gamma_1 - \gamma_3)\hat{\lambda}_1 \quad (6b)$$

$$ATU_1 = E(Y_1|A=2) - E(Y_2|A=2) = (\boldsymbol{\beta}_1 - \boldsymbol{\beta}_2)\boldsymbol{X}_2 + (\gamma_1 - \gamma_2)\hat{\lambda}_2 \quad (6c)$$

$$ATU_2 = E(Y_1|A=3) - E(Y_3|A=3) = (\boldsymbol{\beta}_1 - \boldsymbol{\beta}_3)\boldsymbol{X}_3 + (\gamma_1 - \gamma_3)\hat{\lambda}_3 \quad (6d)$$

ATT_1 and ATT_2 represent productivity impacts of using fresh seeds compared to using recycled seeds and traditional seeds as counterfactual outcomes, respectively. Positive values indicate that using fresh seeds improve productivity and efficiency. ATU_1 indicates the return on productivity and efficiency that farmers would have obtained if they had decided to use fresh seeds instead of recycled seeds. ATU_2 is the return on productivity and efficiency that farmers would have obtained if they had decided to use fresh seeds instead of traditional seeds. Using equations (5a-6d), we estimate the ATTs and ATUs for efficiency, and the interpretations remains the same as that of productivity.

3 Data and descriptive statistics

We use two rounds of panel household survey dataset jointly collected by the International Maize and Wheat Improvement Center (CIMMYT) and the Ethiopian Institute of Agricultural Research (EIAR). The survey covers the 2009/10 and 2012/13 cropping calendars. It is representative of the major rain fed maize producing districts of Ethiopia. In the first stage of the sampling procedure, 39 districts were purposively selected based on the districts' maize production potential. Sample villages and households were selected using a multistage proportionate random sampling. The number of households interviewed was 2,455 in 2009/10 and 2,298 in 2012/13. The number of plots is 28,147 in both rounds. Our analysis focuses on maize production because detailed data on seeds for other crops are unavailable. The interviewed households produced maize in 8,458 plots (4,553 plots in 2009/10 and 3,905 plots in 2012/13). We drop observations that have missing values for some of the key variables. We also drop extreme observations below the 1st or above the 99th percentile of the productivity distribution, which may affect the results in unexpected ways (Abro et al., 2018; Aguilar et al., 2015). Finally, we use unbalanced panel of 7,794 plots cultivated by 2,394 households, of which 2,226 and 2,092 households were in 2009/10 and 2012/13, respectively. The data shows that 4% of the households did not produce maize in one of the two rounds. Using structured questionnaire, detailed information on socioeconomic and demographic factors, community characteristics, volume of production, seed types, and production constraints were collected. The definition and summary statistics of the explanatory variables are reported in Table 1. For the plot level variables, we divide the households by seed types.

Figure 1 shows that farmers use fresh seeds in 59% of the plots. For the remaining plots farmers use recycled seeds and traditional seeds, each constituting nearly 21%. Figure 1 further reveals that fresh seeds use increased from 56% in 2009/10 to 62% in 2012/13. The practice of seed recycling, which is one of the most cited reasons for low productivity, has dramatically declined by 24 percentage points. In the meantime, using traditional seeds increased by 18 percentage points.

Figure 1 about here

The increase in fresh seeds use could be an indicator of the success of the Ethiopian agricultural extension system, which takes promoting fresh seeds as a key strategy for alleviating the low productivity trap in the country (Abate et al., 2015; Shiferaw et al., 2013; Sisay et al., 2017; Husmann, 2015). The increasing use of traditional seeds may however be worrisome because these seeds are not productive. High price of fresh seeds, unavailability of seeds in the market, low quality of purchased seeds or a combination of these constraints may force farmers to use more traditional seeds. Our data show that 79% of the farmers reported high price of seeds as a constraint. The price of fresh seeds increased from 19 to 23 Birr/kg, 9 to 13 Birr/kg, and 5 to 11 Birr/kg for hybrid, OPVs, and traditional seeds across survey years. The average price of maize increased from 2 to 5 birr/kg, which is lower than the increase in seed prices. Nearly 47% of the farmers reported that obtaining quality seeds were a constraint. The seed quality assessment reported is subjective, but it is in line with other studies that reported the presence of counterfeit seeds in the market in Uganda (Bold et al., 2017) and Ethiopia (Sisay et al., 2017), which may suggest that low uptake of improved seeds might be explained by low quality seeds in the market. Almost half of the farmers reported that seeds were not available on time in the market. In general, the farmers' report on seed price, quality and availability is consistent with other previous researches that reported similar constraints in seed adoption in Ethiopia and elsewhere (Fisher et al., 2015; Husmann, 2015; Abate et al., 2015; Hoogendoorn et al., 2018; Smale & Olwande, 2014).

Figure 2 about here

The average productivity of farmers is 2803, 1761 and 1636 kg/ha for fresh seeds, recycled seeds and traditional seeds, respectively (Table 1). Fresh seeds are 71% more productive than traditional seeds and 59% more productive than recycled seeds. In comparison to traditional seeds, the productivity gains from recycled seeds is fairly small, which is only 8%. The observed productivity differences might not necessarily reflect the pure effects of the seed types because of other factors that affect productivity. We defer the discussion on pure productivity gains of the three seed types to Section 4.

Table 1 about here

4 Empirical results

In this Section, we present the empirical findings. We start the discussion by presenting the estimation result of the translog production function in equation (1). The results are reported in Table 2, which shows that farmers who have used fresh seeds have approximately 19% higher productivity than farmers who used traditional seeds. After controlling for inputs and other confounding factors, the observed productivity differences between fresh seeds and traditional seeds dropped from 71% (see Section 3) to 19%. The productivity difference between recycled seeds and traditional seeds disappeared suggesting that the observed productivity differential was due to confounding factors.

Table 2 about here

Using results in Table 2, we obtain farmers' efficiency estimated based on equations (2 and 3). On average, the estimated efficiency show that farmers are 75% efficient (Figure 3). This indicates that closing the 25% level of inefficiency could help farmers to increase their productivity and overall maize production. The estimated level of inefficiency is in line with previous studies reported for maize production in Ethiopia, which documented the presence of high inefficiency (22% to 37%) (Alene & Hassan, 2006; Alene & Manyong, 2006). A recent meta-analysis of efficiency estimates on African agriculture reported 32% average inefficiency (Ogundari, 2014).

Regardless of the magnitudes, our results agree with previous studies that documented the presence of high inefficiency among smallholder farmers.

Including the seed types as dummy variables in the production function, as reported in Table 2, does not allow us to analyze the effects of using fresh seeds on farmers' efficiency. Furthermore, we are not interested in the coefficients of the explanatory variables *per se* because we wanted to establish counterfactual outcomes in order to compare the joint impact of using fresh seeds on productivity and efficiency. As outlined in Section 2, the endogenous switching regressions model enables us to do this, which we present it next.

Figure 3 about here

The results of the multinomial selection model and the random effects switching regressions are presented in Appendix Tables 5 and 6, respectively. The ATTs and ATUs of the two variants of the exogenous switching regression models discussed in Section 2 are presented in Table 7, Appendix. The results show no noticeable difference in terms of the conclusion we draw. This provides us a confidence that the variables controlled in the regressions seem to explain most of the variation in productivity. The coefficients of the inverse Mill's ratios are not also statistically significant (Table 6, Appendix). In the rest of this Section, we present the results from the endogenous switching regressions reported in Tables 3 and 4 below.

Rows A, B and C of Table 3 indicate the actual productivity of the three seed types. Row D shows the counterfactual productivity for fresh seed users if they had used recycled seeds. Row E indicates the counterfactual productivity relative to traditional seeds. Row F and G show the counterfactual productivity if farmers had decided to use fresh seeds instead of recycled seeds and traditional seeds, respectively. The ATTs and ATUs are shown in the last four rows. The results reveal that significant gains in productivity are observed when farmers use fresh seeds. In comparison to the counterfactual outcomes based on recycled seeds, fresh seeds increase productivity by 128 kg/ha. In the same way, fresh seeds have 527 kg/ha higher productivity than the counterfactual outcome based on traditional seeds. These results are in line with the expectation of the Ethiopian extension system, which is promoting fresh seeds (Abate et al., 2015). Shifting from recycled seeds plots to fresh seeds plots would have enabled farmers to fully exploit the benefits of using fresh seeds by increasing their productivity by 136 kg/ha (ATU_1, Table 3). Switching from traditional seeds plots to fresh seeds plots would have increased productivity by 111 kg/ha (ATU_2). The ATU_2 is short of nearly 400 kg/ha to reach the productivity gains of fresh seeds (ATT_2) suggesting that farmers may not obtain the full benefits of using fresh seeds if they switch from traditional seeds to fresh seeds. This might be because of poor soil quality of the plots under traditional seeds and our self-reported plot quality indicators may not fully capture unobserved plot quality differences.

Table 3 about here

The efficiency estimates are reported in Table 4. Our results reveal that farmers are 58, 51 and 72% efficient in inputs use for fresh seeds, recycled seeds and traditional seeds, respectively (rows A, B and C, Table 4). These efficiency estimates are not directly comparable because they are obtained relative to the best performing farmers within each seed type. The treatment effects approach in equations (6a and 6b) has to be used to obtain comparable efficiency estimates because the efficiency estimates obtained from these equations are relative to the same production technology.

Rows D and E of Table 4 show the estimated level of efficiency of farmers who used fresh seeds had they decided to use recycled seeds and traditional seeds, respectively. Similarly, rows F and G show the estimated level of efficiency of farmers who used recycled seeds and traditional seeds had they decided to use fresh seeds, respectively. The ATTs and ATUs for efficiency are reported in the last four rows of Table 4. ATT_1 indicates that using fresh seeds could increase efficiency by 6% compared to the counterfactual outcome based on recycled seeds. ATU_1 reveals that if farmers had chosen to use fresh seeds instead of recycled seeds, their efficiency could have had increased by almost 6%. On the other hand, ATT_2 indicates that farmers become less efficient by 16% when they use fresh seeds compared to using traditional seeds. The ATU_2 further reveals that if farmers had chosen to use fresh seeds instead of traditional seeds, they could be in a disadvantageous condition because their efficiency could have had declined by nearly 15%.[2]

The documented inefficiency disadvantage of fresh seeds relative to traditional seeds might provide another explanation why farmers' adoption of traditional seeds increased between 2009/10 and 2012/13 as we have discussed in Section 3. Probably, farmers have a good understanding of the level of responsiveness of the traditional seeds that may enable them to efficiently use inputs than fresh improved seeds, which are often are not well adapted to the local production conditions. However, we should interpret this result with caution because some studies suggest that improved seeds are more efficient than traditional seeds (Alene & Hassan, 2006). In

[2]The efficiency estimates are consistent with stochastic frontier estimates except ATU_2, which is negative. The results could be obtained up on request.

order to ascertain our findings, more empirical research on the joint impact of improved seeds in comparison to other seed types using our estimation approach might be required.

Table 4 about here

Our results in Table 3 and 4 underscore that jointly estimating the productivity and efficiency implications of using improved seeds remain crucial. Jointly estimating the two has important policy implications, which enable us to see the potential benefits of using fresh seeds in terms of increasing productivity and efficiency relative to the recycled seeds, and potential tradeoffs in comparison to traditional seeds. As observed in most previous studies, impact evaluation of improved new technologies focusing either on productivity or efficiency alone may overestimate or underestimate the benefits of investment in agriculture research in developing countries.

5 Concluding remarks

In impact evaluation of new improved seeds, researchers use productivity and efficiency as indicators of performance. The two performance indicators are conceptually related because part of the variation in productivity is explained by differences in efficiency. Improved seeds may also affect farmers efficiency depending on the performance of the varieties under various production conditions. Nonetheless, the previous studies estimate the productivity and efficiency impacts of improved seeds independently. Ignoring either efficiency or productivity effects of improved seeds is an econometric specification problem because the two related indicators has to be estimated jointly. This approach may lead to overestimation or underestimation of benefits of investment in agricultural research for crop improvement.

In this paper, we contribute to the literature by studying the joint impact of using fresh improved seeds on productivity and efficiency. In our estimation, we take advantage of advances in production function estimation techniques in the context of panel data and estimated both productivity and efficiency impacts of using fresh improved seeds in the same framework. Our approach enables us first to relax the ‘all farmers are equally efficient’ assumption of most studies on productivity. Second, we obtain the direct effects of using fresh improved seeds on farmers efficiency from the same production function. Unlike most previous studies, we use a more detailed classification of seed types in order to capture seed heterogeneity across plots. We use panel household survey data collected from maize producing households in Ethiopia. We handle endogeneity problems associated with seed choice by using endogenous switching regressions and treatment effects approach.

Our findings show that fresh improved seeds increase productivity and farmers' efficiency in comparison to recycled seeds. The productivity and efficiency gains indicate that promoting fresh improved seeds has a potential to boosting maize production using the available improved seed technologies at most efficiency. Despite the productivity advantage of fresh improved seeds, we document that the traditional seeds have higher advantage than fresh improved seeds in terms of efficiency gains. If some farmers value efficient use of inputs more than productivity gains, they may switch to traditional seeds. This might partly explain why some farmers switched to growing traditional seeds in some plots as observed in the second round of the survey. Ascertaining the evidence on the tradeoffs in productivity and efficiency of using fresh improved seeds relative to the traditional seeds needs further empirical evidence by estimating the two performance indicators jointly. Our findings further demonstrate that evaluating the impact of improved technologies using productivity (efficiency) alone may overestimate or underestimate by the amount of efficiency (productivity) gains or losses.

Regardless of the seed types, our results show that significant inefficiencies in inputs use exist. In tandem with promoting fresh improved seeds, the development community and the government may need to design complementary policy instruments that promote resource use efficiency. Furthermore, many farmers have the perception that seeds are high-priced, of low quality, and not available on time. Such perception of farmers may underscore the importance of improving the efficiency of seed production and distribution system.

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Tables and Figures

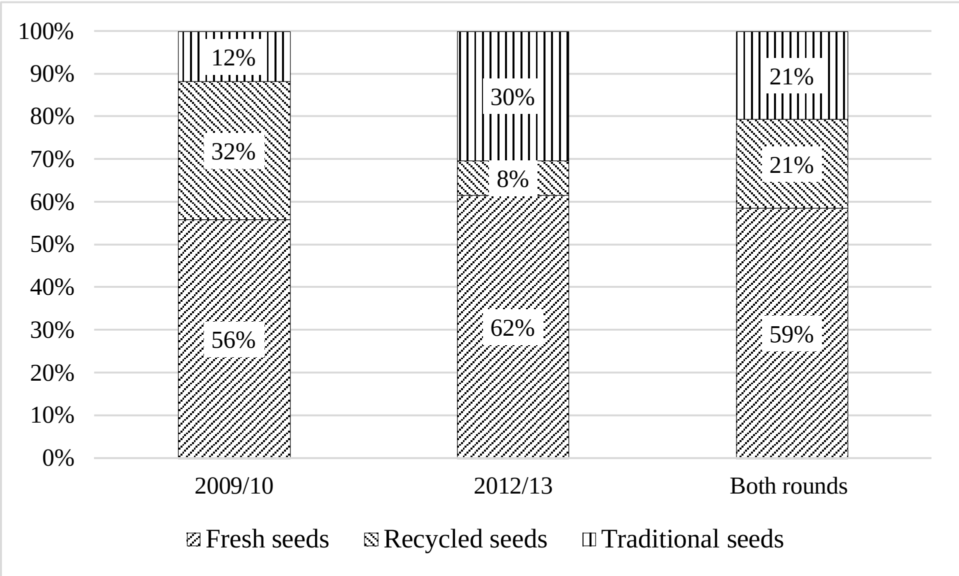

Figure 1. Fresh seeds use (2009/10-2012/13).

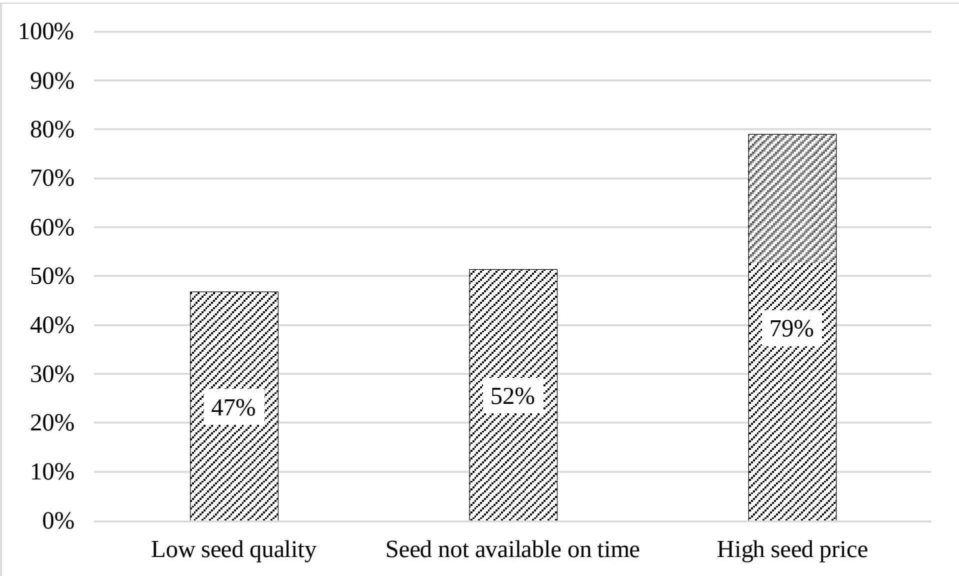

Figure 2. Farmers' report on seed purchase constraints (2009/10-2012/13).

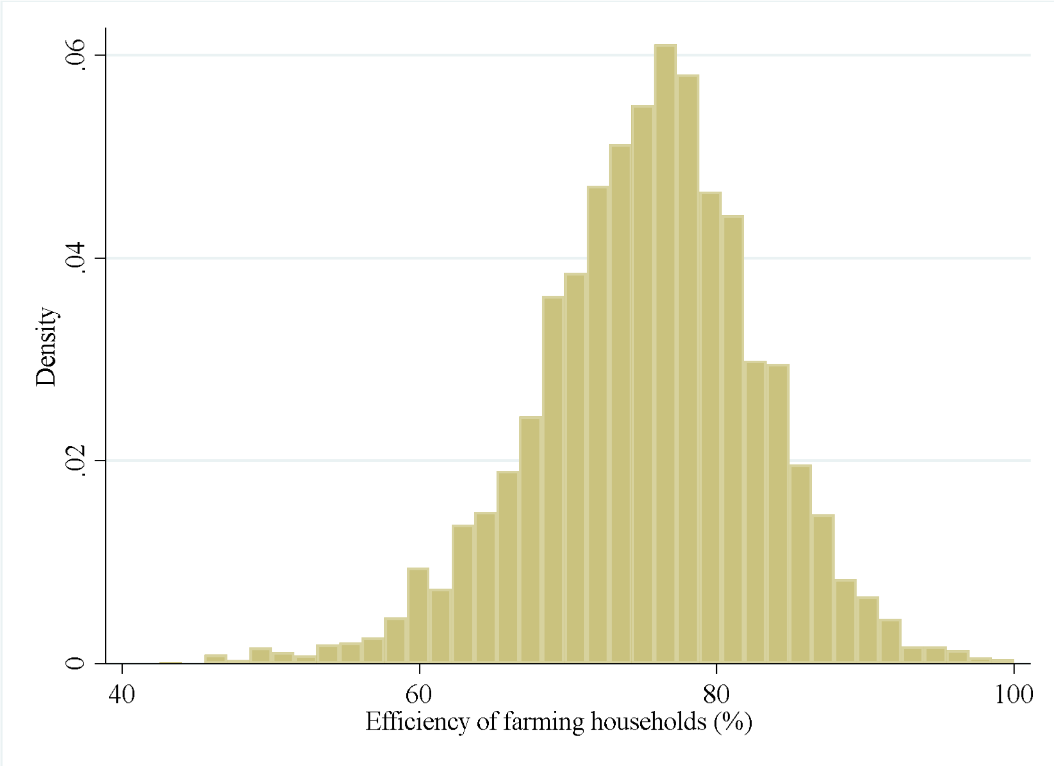

Figure 3. Distribution of efficiency.

Table 1. Descriptions and summary statistics of variables used in the production functions.

Description of the explanatory variables	Variables	Fresh seeds Mean	Fresh seeds Std. Dev.	Recycled seeds Mean	Recycled seeds Std. Dev.	Traditional seeds Mean	Traditional seeds Std. Dev.
Maize yield (kg/ha)	Yield	2,803***	(1,953)	1,761**	(1,530)	1,636	(1,541)
1 if the sex of the household head is male, 0 if female	Male	0.94					
Age of the head of the household (years)	Age	43					
1 if the head of the household is illiterate, 0 otherwise	Illiterate	0.38					
1 if the head of the household attended school between two and six years, 0 otherwise	School >=2 & <6	0.44					
1 if the head of the household completed more than six years of schooling, 0 otherwise	School >=6	0.17					
1 if farmers received any training in the previous season, 0 otherwise	Training	0.97					
1 if the household is in low asset quartile, 0 otherwise	Low asset	0.47					
1 if the household is in middle asset quartile, 0 otherwise	Middle asset	0.21					
1 if the household is in high asset quartile, 0 otherwise	High asset	0.32					
1 if the household owns one or more ploughing oxen, 0 otherwise	Oxen ownership	0.83					
Distance to the nearest input markets (walking minutes)	Distance to input markets	56	(49)				
Distance to the nearest output markets (walking minutes)	Distance to output markets	95	(77)				
Distance to the nearest agricultural extension office (walking minutes)	Distance to agri ext office	30	(29)				
1 if friends or relatives are in leadership position in or outside the village, 0 otherwise	Leadership	0.55					
Number of relatives and non-relatives the head of the household relies on	Kinship	31	(51)				
Number of traders the head of the household knows	No of traders	5	(7)				
1 if the head of the household is confident on the skills of government officials, 0 otherwise	Confidence	0.69					
Plot size (ha)	Plot size	0.47***	(0.41)	0.35***	(0.39)	0.30	(0.33)
1 if the plot was rented in, 0 otherwise	Rented	0.07***		0.01***		0.04	
Plot distance from home (walking minutes)	Plot distance	13***	(24)	9	(19)	9	(18)
1 if intercropping was practiced in the plot, 0 otherwise	Intercropping	0.14***		0.16***		0.19	
1 if rotation was practiced, 0 otherwise	No rotation	0.62***		0.69 ***		0.74	
1 if rotating with legumes were practiced, 0 otherwise	Legume rotation	0.07***		0.04		0.04	
1 if rotating with cereals were practiced, 0 otherwise	Cereals rotation	0.32***		0.27***		0.22	
1 if crop residues & stubble left on the plot, 0 otherwise	Crop residue	0.20***		0.29***		0.23	
1 if the farmers used their own seeds, 0 otherwise	Own seed	0.04***		0.88***		0.82***	
1 if the plot is gently sloped (flat), 0 otherwise	Flat slope	0.69***		0.67		0.64	
1 if the plot is medium sloped, 0 otherwise	Medium slope	0.27***		0.31		0.31	
1 if the plot is steep sloped, 0 otherwise	Steep slope	0.04***		0.03***		0.05	
1 if the depth of the soil is shallow, 0 otherwise	Shallow	0.18***		0.26***		0.22	
1 if the depth of the soil is medium, 0 otherwise	Medium depth	0.32***		0.29		0.27	
1 if the depth of the soil is deep, 0 otherwise	Deep	0.50		0.45***		0.51	
1 if the color of the soil is black, 0 otherwise	Black	0.24***		0.32***		0.28	

Description of the explanatory variables	Variables	Fresh seeds		Recycled seeds		Traditional seeds	
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
1 if the color of the soil is brown, 0 otherwise	Brown	0.26***		0.24***		0.20	
1 if the color of the soil is red, 0 otherwise	Red	0.39***		0.38***		0.49	
1 if the color of the soil is grey and others, 0 otherwise	Gray	0.11***		0.06***		0.04	
1 if the fertility of the soil is good, 0 otherwise	Good soil fertility	0.47***		0.54		0.53	
1 if the fertility of the soil is medium, 0 otherwise	Medium soil fertility	0.45***		0.41		0.41	
1 if the fertility of the soil is poor, 0 otherwise	Poor soil fertility	0.08 ***		0.05		0.06	
1 if the farmer faced incidence of drought in the plot, 0 otherwise	Drought	0.22***		0.11***		0.25	
1 if the farmer faced incidence of waterlogging in the plot, 0 otherwise	Waterlogging	0.02***		0.02***		0.00	
1 if the farmer faced incidence of other abiotic stresses (e.g., frost), 0 otherwise	Abiotic stress	0.02***		0.03		0.03	
1 if the farmer faced incidence of pests in the plot, 0 otherwise	Pests	0.21***		0.10***		0.25	
1 if the farmer faced incidence of maize diseases in the plot, 0 otherwise	Disease	0.03***		0.03***		0.01	
Total labor (days/ha)	Labor	104***	(66)	101***	(70)	118	(79)
Expenses on fertilizers (Birr/ha) †	Fertilizers	2,197***	(1,696)	1,295***	(1,382)	1,948	(1,947)
Expenses on herbicides and pesticides (Birr/ha) †	Agrochemicals	166	(294)	82***	(147)	152	(306)
Quantity of manure (dry equivalent kg/ha)	Manure	1,339***	(1,374)	1,594	(1,467)	1,668	(1,420)
1 if compost was used in the plot, 0 otherwise	Compost	0.04		0.02		0.05	
Number of plots	Number of plots	4570		1617		1607	
% of total plots		59		21		21	
Number of households	Number of households	1837		1088		1021	

Notes: (i) * p<0.1, ** p<0.005, *** p<0.01. (ii) the comparison group for the T-test is traditional seeds. (ii) †the input expenses are in real terms deflated by zone level price index .

Table 2. Results of the translog production function.

Explanatory variables	**Coefficients**	**Standard errors**
Fresh seeds use dummy [b]	0.186***	(0.046)
Recycled seeds use dummy	0.028	(0.038)
Labor	0.246***	(0.045)
Fertilizers	0.268***	(0.021)
Manure	0.022	(0.021)
Agrochemicals	0.017	(0.040)
Compost	0.050	(0.066)
Oxen ownership	0.095***	(0.032)
Intercropping	0.069*	(0.040)
Legume rotation [c]	0.048	(0.062)
Cereals rotation	0.084***	(0.027)
Crop residue	0.021	(0.036)
Own seed	-0.017	(0.042)
Medium slope [d]	0.019	(0.034)
Steep slope	0.079	(0.079)
Medium depth [e]	0.018	(0.044)
Deep depth	-0.028	(0.042)
Brown [f]	0.018	(0.044)
Red	0.021	(0.042)
Gray	0.073	(0.064)
Medium soil fertility [g]	-0.013	(0.028)
Poor soil fertility	-0.044	(0.049)
Rented	0.046	(0.045)
Plot size	0.067**	(0.031)
Plot distance	0.000	(0.001)
Drought	-0.030	(0.152)
Waterlogging	-0.339***	(0.112)
Abiotic stress	-0.206*	(0.106)
Pests	-0.174	(0.155)
Disease	-0.141	(0.088)
Male	0.088*	(0.051)
Age	-0.003***	(0.001)
School >=2 & <6 [h]	0.027	(0.026)
School >=6	0.143***	(0.034)
Training	0.002	(0.059)
Middle asset quartile [i]	-0.166	(0.109)
High asset quartile	-0.079**	(0.033)
Survey year dummy	0.059	(0.111)
Input interaction terms included	Yes	
District fixed effects controlled	Yes	
Mundlak's fixed effects controlled	Yes	
Battese intercept shifting variables controlled	Yes	
Constant	-0.433***	(0.158)
Number of plots	7,794	

Notes: (i) * p<0.1, ** p<0.005, *** p<0.01. (ii). For brevity, input interaction terms are suppressed. (iii). [b, c,d,e,f,g,h,i] the base categories are traditional seeds, no rotation, flat slope, shallow depth, black, good soil fertility, illiterate and high asset quartile, respectively.

Table 3. The impact of using fresh seeds on productivity.

Expected outcomes	Productivity (kg/ha)	Standard errors
Fresh seeds (A)	2278.06	(14.54)
Recycled seeds (B)	1350.73	(18.45)
Traditional seeds (C)	1219.19	(17.23)
If farmers who used fresh seeds had used recycled seeds (D)	2150.1	(15.08)
If farmers who used fresh seeds had used traditional seeds (E)	1750.73	(13.41)
If farmers who used recycled seeds had used fresh seeds (F)	1486.36	(20.58)
If farmers who used traditional seeds had used fresh seeds (G)	1330.47	(18.33)
ATT_1 (row A minus row D)	127.97***	(20.95)
ATT_2 (row A minus row E)	527.34***	(19.78)
ATU_1 (row F minus row B)	135.63***	(27.64)
ATU_2 (row G minus row C)	111.28***	(25.16)

Notes: (i) ** p<0.005, *** p<0.01. (ii) Standard errors in brackets. (iii) Since the dependent variable, productivity, was modeled in logarithm, converting the predicted logarithm of productivity into levels may lead to inaccuracies (Kabunga et al., 2012). We also reported the ATTs and ATUs using the predicted logarithm of productivity in Table 8.

Table 4. The impact of using fresh seeds on efficiency.

Expected outcomes	Efficiency (%)	Standard errors
Fresh seeds (A)	57.55	(0.24)
Recycled seeds (B)	51.36	(0.35)
Traditional seeds (C)	71.85	(0.14)
If farmers who used fresh seeds had used recycled seeds (D)	51.74	(0.28)
If farmers who used fresh seeds had used traditional seeds (E)	73.08	(0.11)
If farmers who used recycled seeds had used fresh seeds (F)	57.56	(0.32)
If farmers who used traditional seeds had used fresh seeds (G)	57.21	(0.35)
ATT_1 (row A minus row D)	5.81***	(0.37)
ATT_2 (row A minus row E)	-15.52***	(0.26)
ATU_1 (row F minus row B)	6.20***	(0.48)
ATU_2 (row G minus row C)	-14.63***	(0.38)

Notes: (i) *** p<0.01. (ii) Standard errors in brackets.

Appendix

Table 5. The multinomial logit selection model for seeds use.

	Seed types: traditional seeds are the base for comparison			
	Fresh seeds [a]		Recycled seeds [a]	
Explanatory variables	Coefficients	Standard errors	Coefficients	Standard errors
Labor	0.142	(0.239)	0.450**	(0.223)
Fertilizers	0.745***	(0.108)	0.322***	(0.109)
Manure	0.121	(0.103)	0.012	(0.093)
Agrochemicals	0.202	(0.211)	0.520**	(0.223)
Compost	0.508	(0.330)	0.348	(0.316)
Oxen ownership	0.427***	(0.140)	0.374***	(0.127)
Labor × Labor	-0.075	(0.083)	-0.058	(0.067)
Labor × Fertilizers	0.008	(0.029)	0.035	(0.028)
Labor × Manure	-0.017	(0.031)	0.023	(0.024)
Labor × Agrochemicals	0.024	(0.090)	0.188**	(0.085)
Fertilizers × Fertilizers	-0.037	(0.050)	0.026	(0.027)
Fertilizers × Manure	-0.005	(0.006)	0.005	(0.006)
Fertilizers × Agrochemicals	0.031*	(0.017)	0.022	(0.016)
Manure × Manure	-0.064*	(0.037)	-0.058*	(0.032)
Manure × Agrochemicals	-0.015	(0.018)	-0.015	(0.016)
Agrochemicals × Agrochemicals	-0.057	(0.055)	-0.172**	(0.067)
Intercropping	-0.350*	(0.206)	0.077	(0.168)
Legume rotation [b]	-0.416	(0.324)	-0.692**	(0.306)
Cereals rotation	-0.007	(0.154)	-0.073	(0.131)
Crop residue	0.170	(0.190)	0.173	(0.155)
Own seed	-4.373***	(0.130)	0.596***	(0.130)
Medium slope [c]	-0.460**	(0.187)	-0.194	(0.157)
Steep slope	-0.306	(0.376)	-0.146	(0.322)
Medium depth [d]	0.264	(0.218)	-0.244	(0.184)
Deep depth	0.200	(0.202)	-0.212	(0.170)
Brown [e]	0.202	(0.230)	-0.101	(0.192)
Red	0.192	(0.215)	0.004	(0.171)
Gray	1.119***	(0.348)	1.434***	(0.313)
Medium soil fertility [f]	-0.052	(0.159)	-0.133	(0.135)
Poor soil fertility	0.217	(0.303)	0.159	(0.260)
Rented	0.181	(0.298)	0.012	(0.324)
Plot size	0.719***	(0.175)	0.079	(0.159)
Plot distance	-0.004	(0.004)	-0.005	(0.004)
Drought	-2.301***	(0.661)	-0.886	(0.586)
Waterlogging	1.141	(0.754)	0.421	(0.606)
Abiotic stress	-0.822*	(0.451)	-0.706*	(0.370)
Pests	2.539***	(0.676)	0.923	(0.603)
Disease	0.713	(0.523)	0.361	(0.446)
Male	0.229	(0.201)	0.091	(0.184)

Explanatory variables	Seed types: traditional seeds are the base for comparison			
	Fresh seeds [a]		Recycled seeds [a]	
	Coefficients	Standard errors	Coefficients	Standard errors
Age	0.007	(0.005)	-0.002	(0.004)
School >=2 & <6 [g]	0.043	(0.125)	-0.101	(0.106)
School >=6	0.152	(0.178)	-0.181	(0.150)
Training	0.785***	(0.265)	0.894***	(0.273)
Middle asset quartile [h]	-0.666	(0.953)	0.244	(0.978)
High asset quartile	-0.093	(0.163)	0.021	(0.125)
Survey year dummy	-1.062	(0.962)	-3.126***	(0.985)
Distance to input markets	0.001	(0.001)	-0.001	(0.001)
Distance to output markets	-0.002	(0.002)	0.001	(0.002)
Distance to agri ext office	-0.002***	(0.001)	-0.003***	(0.001)
Leadership	-0.057	(0.111)	0.041	(0.094)
Kinship	0.002	(0.001)	0.002*	(0.001)
No of traders	0.017**	(0.008)	0.001	(0.006)
Confidence	0.036	(0.117)	-0.240**	(0.098)
District fixed effects	Yes		Yes	
Mundlak's fixed effects	Yes		Yes	
Battese variables	Yes		Yes	
Constant	2.456***	(0.930)	1.594*	(0.819)
Wald test	8688.93***			
Log likelihood	-3175.8044			
Joint Wald test statistic: H_0 is coefficients of the instruments are jointly zero	42.93***			
Joint Wald test statistic: H_0 is coefficients of input interaction terms are jointly zero	31.65**			
Number of plots	7,794			

Notes: (i) *** p<0.01, ** p<0.05, * p<0.1. (ii) Clustered standard errors at household level in brackets. (iii) [a] FS and 1-3 RS refer fresh seeds and recycled seeds (1-3 seasons), respectively. The base group is recycled seeds (>3 seasons). (iv) [b, c,d,e,f,g,h] the base categories, no rotation, flat slope, shallow depth, black, good soil fertility, illiterate and high asset, respectively.

Table 6. The random effects switching regressions.

	Log of productivity (kg/ha) models with:								
	Exogenous switching regressions 1 †			Exogenous switching regressions 2 ‡			Endoogenous switching regressions		
	Fresh seeds	**Recycled seeds**	**Traditional seeds**	**Fresh seeds**	**Recycled seeds**	**Traditional seeds**	**Fresh seeds**	**Recycled seeds**	**Traditional seeds**
Explanatory variables	**coef/se**	**coef/se**	**coef/se**	**coef/se**	**coef/se**	**coef/se**	**coef/se**	**coef/se**	**coef/se**
Labor	0.242***	0.226**	0.448***	0.241***	0.217**	0.444***	0.242***	0.212*	0.448***
	(0.064)	(0.097)	(0.112)	(0.063)	(0.097)	(0.113)	(0.065)	(0.110)	(0.123)
Fertilizers	0.282***	0.266***	0.220***	0.282***	0.268***	0.216***	0.281***	0.246***	0.219***
	(0.028)	(0.055)	(0.053)	(0.027)	(0.055)	(0.053)	(0.030)	(0.068)	(0.055)
Manure	0.008	0.042	0.023	0.006	0.041	0.018	0.008	0.040	0.023
	(0.025)	(0.049)	(0.048)	(0.025)	(0.049)	(0.047)	(0.028)	(0.067)	(0.050)
Agrochemicals	0.052	-0.144	-0.042	0.045	-0.155	-0.035	0.052	-0.168	-0.044
	(0.050)	(0.103)	(0.099)	(0.050)	(0.108)	(0.099)	(0.061)	(0.134)	(0.132)
Compost	-0.041	-0.032	0.164	-0.033	-0.025	0.184	-0.042	-0.063	0.164
	(0.083)	(0.204)	(0.161)	(0.083)	(0.209)	(0.165)	(0.088)	(0.225)	(0.152)
Oxen ownership	0.069*	-0.004	0.184***	0.068	-0.028	0.195***	0.069	-0.031	0.184***
	(0.042)	(0.071)	(0.059)	(0.041)	(0.073)	(0.059)	(0.049)	(0.075)	(0.060)
Labor × Labor	-0.011	-0.109**	-0.133***	-0.010	-0.108**	-0.135***	-0.011	-0.106**	-0.133***
	(0.029)	(0.042)	(0.040)	(0.029)	(0.042)	(0.040)	(0.030)	(0.048)	(0.033)
Labor × Fertilizers	-0.059***	-0.032**	0.002	-0.059***	-0.033**	0.003	-0.059***	-0.034**	0.002
	(0.010)	(0.014)	(0.015)	(0.010)	(0.014)	(0.015)	(0.011)	(0.016)	(0.015)
Labor × Manure	-0.014	-0.008	0.003	-0.013	-0.007	0.004	-0.014	-0.010	0.003
	(0.012)	(0.013)	(0.014)	(0.012)	(0.013)	(0.014)	(0.012)	(0.015)	(0.012)
Labor × Agrochemicals	0.022	-0.015	-0.039	0.022	-0.016	-0.038	0.023	-0.022	-0.039
	(0.015)	(0.036)	(0.035)	(0.015)	(0.036)	(0.036)	(0.016)	(0.039)	(0.047)
Fertilizers × Fertilizers	0.038***	0.029***	0.030	0.040***	0.029***	0.024	0.038***	0.027	0.030
	(0.013)	(0.011)	(0.027)	(0.013)	(0.011)	(0.027)	(0.013)	(0.021)	(0.029)
Fertilizers × Manure	0.004**	0.004	-0.001	0.004**	0.005	-0.001	0.004*	0.004	-0.001
	(0.002)	(0.003)	(0.003)	(0.002)	(0.003)	(0.003)	(0.002)	(0.003)	(0.003)
Fertilizers × Agrochemicals	-0.007	-0.025***	0.006	-0.007	-0.026***	0.006	-0.007	-0.026**	0.006
	(0.005)	(0.008)	(0.007)	(0.005)	(0.008)	(0.007)	(0.005)	(0.011)	(0.009)
Manure × Manure	0.004	0.025	0.043***	0.003	0.022	0.044***	0.004	0.028	0.043***

	(0.010)	(0.019)	(0.015)	(0.010)	(0.019)	(0.015)	(0.012)	(0.028)	(0.016)
Manure × Agrochemicals	-0.001	0.001	0.006	-0.001	0.001	0.006	-0.001	0.002	0.006
	(0.004)	(0.008)	(0.007)	(0.004)	(0.008)	(0.007)	(0.004)	(0.008)	(0.009)
Agrochemicals × Agrochemicals	-0.004	0.038	0.016	-0.002	0.044	0.014	-0.004	0.044	0.016
	(0.011)	(0.035)	(0.027)	(0.011)	(0.036)	(0.027)	(0.013)	(0.055)	(0.035)
Intercropping	0.112**	0.080	0.036	0.113**	0.075	0.046	0.112**	0.077	0.035
	(0.048)	(0.096)	(0.090)	(0.048)	(0.097)	(0.090)	(0.047)	(0.111)	(0.082)
Legume rotation [b]	0.018	-0.069	0.403***	0.016	-0.056	0.410***	0.018	-0.035	0.405***
	(0.057)	(0.211)	(0.139)	(0.058)	(0.209)	(0.138)	(0.057)	(0.226)	(0.156)
Cereals rotation	0.055*	0.157***	0.036	0.060*	0.166***	0.030	0.055*	0.159**	0.037
	(0.032)	(0.061)	(0.071)	(0.032)	(0.060)	(0.071)	(0.032)	(0.067)	(0.068)
Crop residue	0.068	0.004	-0.009	0.073*	0.007	-0.006	0.068	-0.012	-0.010
	(0.044)	(0.091)	(0.082)	(0.044)	(0.091)	(0.081)	(0.047)	(0.116)	(0.076)
Own seed	-0.064	-0.077	0.032	-0.077	-0.076	0.028	-0.058	-0.116	0.031
	(0.071)	(0.077)	(0.068)	(0.070)	(0.077)	(0.068)	(0.104)	(0.097)	(0.064)
Medium slope [c]	-0.007	0.075	0.063	-0.006	0.080	0.058	-0.007	0.089	0.064
	(0.041)	(0.088)	(0.081)	(0.041)	(0.087)	(0.081)	(0.041)	(0.098)	(0.079)
Steep slope	0.166*	0.003	-0.033	0.165*	0.030	-0.049	0.166*	0.010	-0.034
	(0.095)	(0.220)	(0.156)	(0.095)	(0.218)	(0.156)	(0.099)	(0.251)	(0.140)
Medium depth [d]	0.097*	-0.228**	-0.056	0.094*	-0.208*	-0.041	0.097**	-0.215	-0.055
	(0.051)	(0.116)	(0.097)	(0.051)	(0.114)	(0.097)	(0.049)	(0.135)	(0.092)
Deep depth	0.027	-0.138	-0.090	0.025	-0.129	-0.089	0.027	-0.124	-0.090
	(0.052)	(0.110)	(0.087)	(0.052)	(0.110)	(0.087)	(0.049)	(0.141)	(0.085)
Brown [e]	-0.001	0.175	-0.074	0.008	0.174	-0.061	-0.002	0.183	-0.074
	(0.054)	(0.113)	(0.101)	(0.054)	(0.113)	(0.101)	(0.055)	(0.139)	(0.097)
Red	-0.023	0.186**	-0.060	-0.013	0.179*	-0.058	-0.023	0.184*	-0.060
	(0.057)	(0.094)	(0.082)	(0.057)	(0.094)	(0.082)	(0.058)	(0.100)	(0.082)
Gray	0.044	0.177	0.093	0.051	0.193	0.121	0.044	0.079	0.090
	(0.070)	(0.194)	(0.168)	(0.070)	(0.197)	(0.167)	(0.072)	(0.263)	(0.185)
Medium soil fertility [f]	-0.030	0.033	0.028	-0.026	0.036	0.026	-0.030	0.046	0.028

	(0.034)	(0.072)	(0.066)	(0.034)	(0.072)	(0.065)	(0.034)	(0.083)	(0.068)
Poor soil fertility	-0.127**	0.115	0.067	-0.130**	0.099	0.060	-0.127**	0.108	0.066
	(0.056)	(0.132)	(0.138)	(0.056)	(0.131)	(0.138)	(0.056)	(0.138)	(0.127)
Rented	-0.027	0.137	0.337***	-0.029	0.157	0.328***	-0.027	0.133	0.337**
	(0.049)	(0.196)	(0.126)	(0.049)	(0.198)	(0.126)	(0.050)	(0.236)	(0.138)
Plot size	-0.003	0.104*	0.220**	-0.003	0.114*	0.209**	-0.004	0.098	0.220**
	(0.036)	(0.062)	(0.105)	(0.036)	(0.062)	(0.104)	(0.037)	(0.090)	(0.091)
Plot distance	0.000	0.002	-0.001	0.000	0.002	-0.001	0.000	0.002	-0.001
	(0.001)	(0.002)	(0.002)	(0.001)	(0.002)	(0.002)	(0.001)	(0.002)	(0.002)
Drought	0.059	-0.381*	0.135	0.064	-0.385*	0.124	0.059	-0.331	0.139
	(0.182)	(0.202)	(0.376)	(0.182)	(0.209)	(0.380)	(0.179)	(0.272)	(0.343)
Waterlogging	-0.216*	-0.661**	-0.634**	-0.224*	-0.649**	-0.630**	-0.216*	-0.673**	-0.635*
	(0.118)	(0.271)	(0.293)	(0.117)	(0.274)	(0.301)	(0.112)	(0.328)	(0.379)
Abiotic stress	-0.104	-0.450	-0.240	-0.098	-0.439	-0.233	-0.104	-0.430	-0.236
	(0.137)	(0.275)	(0.192)	(0.137)	(0.273)	(0.190)	(0.150)	(0.303)	(0.192)
Pests	-0.198	0.018	-0.370	-0.204	0.022	-0.354	-0.198	-0.037	-0.374
	(0.185)	(0.226)	(0.379)	(0.185)	(0.237)	(0.382)	(0.182)	(0.300)	(0.345)
Disease	-0.272**	0.204	-0.305	-0.266**	0.224	-0.290	-0.272**	0.190	-0.306
	(0.118)	(0.174)	(0.321)	(0.117)	(0.175)	(0.325)	(0.120)	(0.229)	(0.284)
Male	0.143**	0.089	0.008	0.127*	0.094	0.012	0.142**	0.087	0.008
	(0.068)	(0.107)	(0.084)	(0.067)	(0.106)	(0.085)	(0.068)	(0.110)	(0.093)
Age	-0.003***	-0.004*	-0.002	-0.003***	-0.004*	-0.002	-0.003***	-0.004*	-0.002
	(0.001)	(0.002)	(0.002)	(0.001)	(0.002)	(0.002)	(0.001)	(0.002)	(0.002)
School >=2 & <6 [g]	0.014	-0.021	0.045	0.003	-0.034	0.035	0.014	-0.016	0.045
	(0.032)	(0.056)	(0.052)	(0.033)	(0.056)	(0.052)	(0.034)	(0.063)	(0.055)
School >=6	0.182***	0.037	0.120	0.165***	0.008	0.115	0.182***	0.044	0.120
	(0.039)	(0.086)	(0.077)	(0.040)	(0.087)	(0.077)	(0.038)	(0.083)	(0.079)
Training	0.033	-0.084	0.064	0.026	-0.107	0.030	0.033	-0.150	0.063
	(0.070)	(0.212)	(0.102)	(0.069)	(0.213)	(0.101)	(0.072)	(0.304)	(0.108)
Middle asset quartile [h]	-0.216*	-0.544	0.360	-0.237**	-0.626	0.384	-0.216	-0.576	0.358

	(0.125)	(0.344)	(0.414)	(0.119)	(0.410)	(0.425)	(0.161)	(0.532)	(0.518)
High asset quartile	-0.116***	-0.032	0.047	-0.117***	-0.025	0.077	-0.116**	-0.035	0.048
	(0.042)	(0.057)	(0.091)	(0.041)	(0.057)	(0.090)	(0.045)	(0.062)	(0.087)
Survey year dummy	0.053	0.621*	-0.412	0.068	0.702*	-0.393	0.054	0.849	-0.402
	(0.127)	(0.355)	(0.419)	(0.122)	(0.422)	(0.429)	(0.163)	(0.626)	(0.540)
Distance to input markets				-0.001**	-0.001*	0.000			
				(0.000)	(0.001)	(0.001)			
Distance to output markets				-0.000	-0.000	-0.000			
				(0.000)	(0.000)	(0.000)			
Distance to agri ext office				0.001	0.001	0.000			
				(0.001)	(0.001)	(0.001)			
Leadership				0.089***	0.114**	0.073			
				(0.029)	(0.053)	(0.049)			
Kinship				0.000	-0.001	-0.001**			
				(0.000)	(0.001)	(0.001)			
No of traders				0.001	0.003	0.010***			
				(0.002)	(0.004)	(0.004)			
Confidence				-0.004	-0.031	-0.020			
				(0.029)	(0.054)	(0.053)			
Inverse Mills' ratio							-0.004	-0.137	0.006
							(0.063)	(0.160)	(0.087)
District fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mundlak's fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Battese variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-0.140	-0.154	-0.423	-0.109	-0.122	-0.452	-0.140	-0.035	-0.437
	(0.217)	(0.316)	(0.702)	(0.225)	(0.328)	(0.677)	(0.211)	(0.420)	(0.624)
Wald test	1777.45***	804.15***	1112.74***	1817.84***	809.54***	1139.27***	2559.87***	991.6***	1502.31***
Log likelihood	-5253.8729	-2066.949	-2046.7577	-5242.5398	-2061.1658	-2040.824	-5242.5389	-2060.7977	-2040.824
Joint Wald test statistic: H_0 is coefficients of the instruments are jointly zero							16.55**	6.46	8.46

Joint Wald test statistic: H_0 is coefficients of input interaction terms are jointly zero							38.75***	25.57***	15.52***
Number of plots	4,570	1,617	1,607	4,570	1,617	1,607	4,570	1,617	1,607

Notes: (i) *** p<0.01, ** p<0.05, * p<0.1. (ii) Bootstrapped standard errors and clustered at household level in brackets. (iii) [a] FS, 1-3 RS, and > 3 RS refer the fresh seeds and recycled seeds (1-3 seasons), and recycled seeds (>3 seasons), respectively. (iv) [b, c,d,e,f,g,h] the base categories, no rotation, flat slope, shallow depth, black, good soil fertility, illiterate and high asset, respectively. (v) [†] We estimate this model without including the inverse Mill's ratio. [‡] We estimate this model by including the exclusion restrictions as explanatory variables and excluding the inverse Mill's ratio.

Table 7. The impact of using fresh seeds on productivity and efficiency: results from the two variants of the exogenous switching regression models

Expected outcomes	Productivity (kg/ha)				Efficiency (%)			
	Exogenous switching regressions 1 †	Standard errors	Exogenous switching regressions 2 b	Standard errors	Exogenous switching regressions 1	Standard errors	Exogenous switching regressions 2	Standard errors
Fresh seeds (A)	2278.09	(14.54)	2282.72	(14.66)	57.68	(0.24)	59.09	(0.24)
Recycled seeds (B)	1350.59	(18.42)	1359.25	(18.97)	50.10	(0.34)	51.53	(0.35)
Traditional seeds (C)	1219.16	(17.23)	1221.16	(17.42)	71.81	(0.14)	76.46	(0.13)
If farmers who used fresh seeds had used recycled seeds (D)	2167.4	(15.18)	2150.11	(15.15)	50.51	(0.27)	52.03	(0.28)
If farmers who used fresh seeds had used traditional seeds (E)	1750.16	(13.41)	1767.44	(13.65)	73.04	(0.11)	77.53	(0.10)
If farmers who used recycled seeds had used fresh seeds (F)	1489.19	(20.53)	1492.51	(20.7)	57.65	(0.32)	59.03	(0.32)
If farmers who used traditional seeds had used fresh seeds (G)	1338.22	(18.35)	1338.5	(18.53)	57.28	(0.35)	58.71	(0.35)
ATT_1 (row A minus row D)	110.69***	(21.02)	132.61***	(21.08)	7.17***	(0.36)	7.06***	(0.37)
ATT_2 (row A minus row E)	527.94***	(19.78)	515.27***	(20.03)	-15.36***	(0.26)	-18.44***	(0.26)
ATU_1 (row F minus row B)	138.61***	(27.58)	133.27***	(28.08)	7.55***	(0.47)	7.49***	(0.48)
ATU_2 (row G minus row C)	119.07***	(25.17)	117.33***	(25.43)	-14.53***	(0.38)	-17.75***	(0.38)

Notes: (i) *** p<0.01, ** p<0.05, * p<0.1. (ii) Standard errors in brackets. (iii) † We estimate this model without including the inverse Mill's ratio. ‡ We estimate this model by including the exclusion restrictions as explanatory variables and excluding the inverse Mill's ratio.

Table 8. Impact of using fresh seeds on log of productivity (kg/ha): results from the endogenous switching regression model.

Expected outcomes	Log of Productivity (kg/ha)	Standard errors
Fresh seeds (A)	7.64	(0.01)
Recycled seeds (B)	7.07	(0.01)
Traditional seeds (C)	6.97	(0.01)
If farmers who used fresh seeds had used recycled seeds (D)	7.56	(0.01)
If farmers who used fresh seeds had used traditional seeds (E)	7.34	(0.01)
If farmers who used recycled seeds had used fresh seeds (F)	7.16	(0.01)
If farmers who used traditional seeds had used fresh seeds (G)	7.05	(0.01)
ATT_1 (row A minus row D)	0.08***	(0.01)
ATT_2 (row A minus row E)	0.30***	(0.01)
ATU_1 (row F minus row B)	0.09***	(0.02)
ATU_2 (row G minus row C)	0.09***	(0.02)

Notes: (i) *** p<0.01. (ii) standard errors in brackets.