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Adoption of Multiple Sustainable Agricultural Practices in Rural Ethiopia

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Abstract

The adoption and diffusion of sustainable agricultural practices (SAPs) has become an important issue in the development-policy agenda for sub-Saharan Africa, especially as a way to tackle land degradation, low agricultural productivity and poverty. However, the adoption rates of SAPs remain below expected levels. This study analyses the factors that facilitate or impede the probability and level of adoption of interrelated SAPs, using recent data from multiple plot-level observations in rural Ethiopia. Multivariate and ordered probit models are applied to the modelling of adoption decisions by farm households facing multiple SAPs, which can be adopted in various combinations. The results show that there is a significant correlation between SAPs, suggesting that adoptions of SAPs are interrelated. The analysis further shows that both the probability and the extent of adoption of SAPs are influenced by many factors: a household's trust in government support, credit constraints, spouse education, rainfall and plot-level disturbances, household wealth, social capital and networks, labour availability, plot

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and market access. These results imply that policy-makers and development practitioners should seek to strengthen local institutions and service providers, maintain or increase household asset bases and establish and strengthen social protection schemes in order to improve the adoption of SAPs.

Keywords: *Ethiopia; multiple adoption; multivariate probit; sustainable agriculture practices.*

JEL classifications: *Q01, Q12, Q16, Q18.*

1. Introduction

In sub-Saharan Africa (SSA), although significant progress has been made in increasing production over the last four decades, productivity has not increased significantly (Pretty *et al*., 2011; IFAD, 2011). The major increase in production comes from expansion of land under cultivation and shorter fallow periods (IFAD, 2011). Population growth is continuing, however, and arable land is shrinking in many areas. Thus, the extensification path and the practice of letting the land lie fallow for long periods are rapidly becoming impractical, making continuous cropping a common practice in many areas. This leads to land degradation, low productivity and poverty in the region. Increasing productivity through adoption of agricultural technologies is a key, if not the only, strategy option to increase production. The adoption and diffusion of sustainable agricultural practices (SAPs)[2] has become an important issue in the development-policy agenda for SSA (Scoones and Toulmin, 1999; Ajayi, 2007; Kassie *et al*., in press), especially as a way to tackle land degradation, low agricultural productivity and poverty.

Despite the multiple benefits of SAPs and considerable efforts by national and international organisations to encourage farmers to invest in them, the adoption rate of SAPs is still low in rural areas of developing countries (Somda *et al*., 2002; Tenge *et al*., 2004; Jansen *et al*., 2006; Kassie *et al*., 2009; Wollni *et al*., 2010). This is true for Ethiopia, where despite accelerated erosion and considerable efforts to promote various soil- and water-conservation technologies, the adoption of many recommended measures is minimal, and soil degradation continues to be a major constraint to productivity growth and sustainable intensification. A better understanding of constraints that condition farmers' adoption behaviour for these practices is therefore important for designing promising pro-poor policies that could stimulate their adoption and increase productivity.

Adoption analysis of agricultural technologies has long been emphasised for green-revolution technologies (chemical fertiliser and improved seeds) and physical soil and water conservation technologies (e.g. Gebremedhin and Scott, 2003;

[2] The Food and Agricultural Organization of the United Nations (FAO) (1989) argues that sustainable agriculture consists of five major attributes: (i) it conserves resources, (ii) it is environmentally non-degrading, (iii) it is technically appropriate, (iv) it is economically acceptable, and (v) it is socially acceptable. Accordingly, SAPs, broadly defined, include various practices such as conservation tillage, legume intercropping, legume crop rotations, improved crop varieties, the use of animal manure, the complementary use of inorganic fertilisers and soil and stone bunds for soil and water conservation (D'Souza *et al*., 1993; Lee, 2005; Kassie *et al*., 2010; Wollni *et al*., 2010).

Bluffstone and Köhlin, 2011; Isham, 2002; Kassie *et al*., 2011). However, scant attention has been paid to the factors that impede or facilitate the adoption of conservation tillage, maize–legume intercropping and crop rotations. Past research also focused on the adoption of component technologies in isolation, whereas farmers typically adopt and adapt multiple technologies as complements or substitutes that deal with their overlapping constraints. In addition, technology-adoption decisions are path dependent: the choice of technologies adopted most recently by farmers is partly dependent on their earlier technology choices. Analysis of adoption without controlling for technology interdependence and simultaneous adoption in complex farming systems may underestimate or overestimate the influence of various factors on the technology choices (Wu and Babcock, 1998).

The present study contributes to the growing adoption literature on SAPs, including, *inter alia,* Gebremedhin and Scott, 2001; Pender and Gebremedhin, 2007; Lee, 2005; Bluffstone and Köhlin, 2011; Kassie *et al*., 2009, 2010, 2012; Marenya and Barrett, 2007; and Wollni *et al*., 2010. Our contribution is in four major directions: first, our analysis uses a comprehensive large plot-level survey conducted recently of maize–legume farming systems of Ethiopia; second, we consider methods that recognise the interdependence between different practices and jointly analyse the decision to adopt multiple SAPs, including maize–legume rotation, conservation tillage, improved maize seed varieties (hereafter improved seed), inorganic fertiliser and manure. Identifying the nature of interrelationships among the set of practices is relevant to the long-standing debate of whether famers adopt technology in a piecemeal fashion or in a package and helps policy-makers and development practitioners to define their strategies for promoting agricultural technologies. Third, we concentrate on the relative importance of social capital and networks, market transaction costs, confidence in the skill of extension agents, reliance on government support, (social insurance), household wealth, individual rainfall stress and plot-level incidence stresses, in determining the probability and level of adoption of SAPs. Fourth, we extend the focus from the probability of an adoption decision to the extent of adoption as measured by the number of SAPs adopted.

The following section presents the econometric framework and estimation strategies. Section 3 presents study areas, sampling, data and description of variables, followed by a presentation of results and discussions in section 4. The last section summarises and concludes, highlighting key findings and policy implications.

2. Econometric Framework and Estimation Strategies

Farmers adopt a mix of technologies to deal with a multitude of agricultural production constraints, so the adoption decision is inherently multivariate. Attempting univariate modelling would exclude useful economic information about interdependent and simultaneous adoption decisions (Dorfman, 1996). Our econometric specification is two parts: first, farmers' choice of interrelated SAPs is modelled using a multivariate probit (MVP) model; second, we analyse the determinants of the extent of combinations of SAPs adopted, using pooled- and random-effects ordered probit models, as we have multiple plot observations per household. To overcome the possible correlation of plot-invariant unobserved heterogeneity with observed covariates, we use Mundlak's (1978) approach where the unobserved heterogeneity is parameterised by the mean values of plot-varying covariates.[3] For application of this approach using cross-sectional multiple plot observations, see Kassie *et al.* (2008) and Di Falco *et al.* (2012).

2.1. A multivariate probit model

In a single-equation statistical model, information on a farmer's adoption of one SAP does not alter the likelihood of his adopting another SAP. However, the MVP approach simultaneously models the influence of the set of explanatory variables on each of the different practices, while allowing for the potential correlation between unobserved disturbances, as well as the relationship between the adoption of different practices (Belderbos *et al.*, 2004). One source of correlation may be complementarity (positive correlation) or substitutability (negative correlation) between different practices (Belderbos *et al.*, 2004). Failure to capture unobserved factors and interrelationships among adoption decisions regarding different practices will lead to bias and inefficient estimates (Greene, 2008).

The observed outcome of SAP adoption can be modelled following a random utility formulation. Consider the ith farm household $(i = 1, \ldots, N)$ facing a decision on whether or not to adopt the available SAP on plot $p(p = 1\ldots, P)$. Let U_0 represent the benefits to the farmer from traditional management practices, and let U_k represent the benefit of adopting the kth SAP: where k denotes choice of crop rotation (R), conservation tillage (T), improved crop variety (V), inorganic fertiliser (F) and manure use (M). The farmer decides to adopt the kth SAP on plot p if $Y^*_{ipk} = U^*_k - U_0 > 0$. The net benefit ($Y^*_{ipk}$) that the farmer derives from the adoption of kth SAP is a latent variable determined by observed household, plot and location characteristics $(X_{ip})$and the error term(ε_{ip}):

$$Y^*_{ipk} = X'_{ip}\beta_k + \varepsilon_{ip} \quad (k = R, V, F, M, T). \tag{1}$$

Using the indicator function, the unobserved preferences in equation (1) translate into the observed binary outcome equation for each choice as follows:

$$Y_{ip_k} = \begin{cases} 1 & \text{if } Y^*_{ipk} > 0 \\ 0 & \text{otherwise} \end{cases} \qquad (k = R, V, F, M, T). \tag{2}$$

In the multivariate model, where the adoption of several SAPs is possible, the error terms jointly follow a multivariate normal distribution (MVN) with zero conditional mean and variance normalised to unity (for identification of the parameters) where: $(u_R, u_V, u_F, u_M, u_T)\tilde{}\,\mathrm{MVN}(0, \Omega)$ and the symmetric covariance matrix Ω is given by:

$$\Omega = \begin{bmatrix} 1 & \rho_{\mathrm{RV}} & \rho_{\mathrm{RF}} & \rho_{\mathrm{RM}} & \rho_{\mathrm{RT}} \\ \rho_{\mathrm{VR}} & 1 & \rho_{\mathrm{VF}} & \rho_{\mathrm{VM}} & \rho_{\mathrm{VT}} \\ \rho_{\mathrm{FR}} & \rho_{\mathrm{FV}} & 1 & \rho_{\mathrm{FM}} & \rho_{\mathrm{FT}} \\ \rho_{\mathrm{MR}} & \rho_{\mathrm{MV}} & \rho_{\mathrm{MF}} & 1 & \rho_{\mathrm{MT}} \\ \rho_{\mathrm{TR}} & \rho_{\mathrm{TV}} & \rho_{\mathrm{TF}} & \rho_{\mathrm{TM}} & 1 \end{bmatrix}. \tag{3}$$

[3] We thank an anonymous reviewer for suggesting the use of a fixed-effects model.

Of particular interest are the off-diagonal elements in the covariance matrix, which represent the unobserved correlation between the stochastic components of the different types of SAPs. This assumption means that equation (2) generates a MVP model that jointly represents decisions to adopt a particular farming practice. This specification with non-zero off-diagonal elements allows for correlation across the error terms of several latent equations, which represent unobserved characteristics that affect the choice of alternative SAPs.

When analysing the determinants of adoption, we take into account the influence of non-observable household characteristics on adoption decisions. For instance, there may be a correlation between plot-invariant characteristics (e.g. managerial ability) and the decision to adopt a technology. A pooled MVP model is consistent only under the assumption that unobserved heterogeneity is uncorrelated with observed explanatory variables. We exploited the multiple/repeated plot observations nature of our data and estimated equation (2) with and without Mundlak's (1978) approach to control for unobserved heterogeneity,[4] which involves including the means of plot-varying explanatory variables (e.g. average of plot characteristics, plot distance to residence) as additional covariates in the regression model.

2.2. Ordered probit model

The MVP model specified above only considers the probability of adoption of SAPs, with no distinction made between, for example, those farmers who adopt one practice and those who use multiple SAPs in combination. The ordered probit model allows us to analyse the factors that influence the adoption of a combination of practices (number of practices) as well as individual practices and, also the variables that affect the probability of adoption may differently affect the intensity of adoption.

In the case of multiple SAP adoption, defining a cut-off point between adopters and non-adopters is the main problem in examining the factors influencing the level of adoption of SAPs farmers (Wollni *et al.*, 2010). In our case, some farmers adopt only part of the package on their farms, but not others. As a result, for SAPs as a package, it is difficult to quantify the extent of adoption, for instance by the fraction of area under SAPs, as is usually done in adoption literature. To overcome this problem, following D'Souza *et al.* (1993) and Wollni *et al.* (2010) we use the number of SAPs adopted as our dependent variable measuring extent of adoption. Information on the number of SAPs adopted could have been treated as a count variable. Count data are usually analysed using a Poisson regression model, but the underlying assumption is that all events have the same probability of occurrence (Wollni *et al.*, 2010). However, in our application, the probability of adopting the first SAP could differ from the probability of adopting a second or third practice, given that in the latter case the farmer has already gained some experience with adoption of the first SAP and has been exposed to information about the practice. Hence, we treat the number of SAPs adopted by farmers as an ordinal variable and use an ordered probit model in the estimation, augmented with the pooled- and ran-

[4] Alternatively, a fixed-effects model could have been used. However, with this approach and the nature of our data, it would not be feasible to estimate plot-invariant covariates as the model relies on data transformation to remove unobserved heterogeneity.

dom-effect specification and Mundlak's (1978) approach by including the mean of plot-varying covariates to capture the correlation between observed covariates and unobserved heterogeneity.

3. Study Areas, Sampling, Data and Description of Variables

The data used for this study are derived from a farm household survey in Ethiopia conducted during the period October–December 2010 by the Ethiopian Institute of Agricultural Research (EIAR) in collaboration with the International Maize and Wheat Improvement Center (CIMMYT), to identify the key factors influencing the simultaneous adoption of several agricultural technologies and practices, and the impact of these on household welfare in the maize–legume cropping system zones. The sample covers a total of 898 farm households and 4,050 farming plots. In this study, we focused on maize plots (1,616) because maize is the largest cereal commodity in terms of its share of total cultivated area, total production and role in direct human consumption. In the study area, maize accounts for over 50% and 76% of the total cultivated land and consumption of own production, respectively.

A multistage sampling procedure was employed to select peasant associations (PAs)[5] from each district, and households from each PA. First, based on their maize–legume production potential, nine districts were selected from three regional states of Ethiopia: Amhara, Oromia and SNNRP Region. Second, based on proportionate random sampling, three to six PAs in each district and 16–24 farm households in each PA were selected.

3.1. Data and descriptive statistics

A structured questionnaire was prepared, and the sampled respondents were interviewed by experienced interviewers under close supervision by researchers from CIMMYT and EIAR. The questionnaire consisted of detailed items about household, plot, and village data including input and output market access, household composition, education, asset ownership, herd size, various sources of income, participation in credit markets, membership of formal and informal organisations, trust, stresses, participation and confidence in extension services, cropping pattern, crop production, land tenure, adoption of SAPs and a wide range of plot-specific attributes.

3.2. Dependent variables

The dependent variables (SAPs) we consider are maize–legume rotation; conservation tillage; animal manure use; improved seed; inorganic fertiliser use.

The maize–legume rotation system (temporal biodiversification) is one option for sustainable intensification that can help farmers to increase crop productivity through Nitrogen fixation and also helps to maintain productivity in a changing climate that could bring new pests and diseases due to warmer weather (Delgado *et al*., 2011). Maize–legume crop rotation was practiced on 23.2% of the plots during the cropping season used for this analysis.

[5] These are the lowest administrative structures in Ethiopia.

Conservation tillage is part of a sustainable agricultural system, as soil disturbance is minimised and crop residue or stubble is allowed to remain on the ground with the accompanying benefits of better soil aeration and improved soil fertility. Minimum soil disturbance requires less traction power and less C emissions from the soil (Delgado *et al.*, 2011). In our case, conservation tillage practices entail reduced tillage (only one pass) and/or zero tillage and letting the stubble lie on the plot. Conservation tillage is used on 36.3% of maize plots.

Manure use refers to the application of livestock waste to the farming plot. It is a major component of a sustainable agricultural system with the potential benefits of long-term maintenance of soil fertility, organic matter content and supply of nutrients, especially nitrogen (N), phosphorus (P) and potassium (K). The average quantity of manure used in our sample was 1.25 t/ha, although, those using manure (27.3% of plots) typically use 5 t/ha.

The introduction of modern maize varieties could improve food security and income for the rapidly growing population by improving productivity. The National Maize Research Project of Ethiopia has recommended a number of improved maize varieties adapted to the different maize agro-ecologies of the country. However, the total area planted with modern maize varieties is still about 50% in our sample and only 52.5% of maize plots are planted with improved maize varieties.

The average inorganic fertiliser used for maize in the study areas was 43 kg N/ha and 13 kg P/ha. Of the maize plots, 67% received fertiliser, and farmers who use fertiliser applied 57 kg N/ha and 18 kg P/ha. This is very low compared to the official extension recommendation of 92 kg N/ha and 69 kg P/ha. 67.3% of the maize sample plots were treated with inorganic fertiliser.

3.3. Independent variables

The adoption models include several explanatory variables based on the economic theory and empirical literature on the adoption of sustainable land management and integrated natural resource management (D'Souza *et al.*, 1993; Neill and Lee, 2001; Isham, 2002; Arellanes and Lee, 2003; Gebremedhin and Scott, 2003; Lee, 2005; Marenya and Barrett, 2007; Knowler and Bradshaw, 2007; Kassie *et al.*, 2008, 2009, 2010, 2012; Wollni *et al.*, 2010). The description and summary statistics of the variables are given in Table 1. Detailed descriptions of the explanatory variables are as follows.

3.4. Farm and household characteristics

We include several plot-specific attributes, including soil fertility,[6] soil depth,[7] plot slope,[8] plot tenure status and spatial distance of the plot from the farmer's home (walking distance in minutes). On average, landowners operate on four plots of 0.5 ha each, and these plots are often not spatially adjacent (as far as 5 hours walking time away). Distance of plots to residence is an important determinant of the adoption of SAPs because of increased transaction costs on the farthest plot, partic-

[6] The farmer ranked each plot as 'poor', 'medium' or 'good'.

[7] The farmer ranked each plot as 'deep', 'medium deep' or 'shallow'.

[8] The farmer ranked each plot as 'flat', 'medium slope' or 'steep slope'.

Table 1
Definitions and summary statistics of the variables used in the analysis

Variables	Description	Mean	Std. Dev.
Household and farm characteristics			
FAMILYSIZE	Family size	6.84	2.83
SEX	1 = household head is male	0.92	0.28
AGE	Age of the household head	42	13
EDUCATHEAD	Years of education of the household head	3.42	3.42
EDUCATSPOUS	Years of education of the spouse	1.41	2.85
PLOTDIST	Plot distance from home, minutes	11.3	27.4
RENTDPLT	1 = rented plot	0.15	–
SHALDEPT	1 = shallow depth of soil	0.20	–
MEDMDEPT	1 = medium depth of soil	0.44	–
GODSOIL	1 = good soil quality	0.40	–
MEDMSOIL	1 = medium soil quality	0.51	–
FLATSLOP	1 = flat plot slope	0.62	–
MEDMSLOP	1 = medium slope plot	0.33	–
Resource constraints			
FARMSIZE	Farm size, ha	2.22	2.88
ASSETVALUE	Total value of assets, Birr*	19,543	50,331
OTHERINCOM	1 = the household earns other income and transfers	0.65	–
TLU	Livestock herd size (tropical livestock units; TLU)	12.38	12.18
CREDIT	1 = credit is a constraint (credit is needed, but unable to get)	0.30	–
Market access			
MEANSTRANS	1 = walking to market as means of transportation	0.44	–
WALKDIST	Walking distance to input markets, minutes	59.8	56.6
Social capital network			
RELATIVE	Number of close relatives living in and outside the village	10	11
KNOWTRUST	Number of grain traders that farmers know and trust	2.45	4.00
MEMBER	1 = member in input/marketing/ labour rural institutions/group	0.24	–
Extension service			
EXTMAZLEG	Frequency of extension contact on maize/legume varieties, days/year	7.3	18.1
EXTPEST	Frequency of extension contact on pest control, days/year	3.0	9.1
EXTROTAT	Frequency of extension contact on crop rotation, days/year	2.9	8.1
EXTTILAGE	Frequency of extension contact on tillage practices, days/year	3.4	12.4
CONFDNT	1 = confident with skills of extension workers	0.82	–

Table 1
(*Continued*)

Variables	Description	Mean	Std. Dev.
Stresses			
RAININDEX	Rainfall index (1 = best)	0.52	0.30
PESTSTRES	1 = pest and disease stress	0.12	–
WATRLOGG	1 = waterlogging/drought stress	0.22	–
FROSTSTRES	1 = frost/hailstorm stress	0.06	–
RELYGOVT	1 = rely on government support in case of crop failure	0.39	–
Location dummies			
WESTSHOA	1 = west Shewa zone	0.21	–
EASTWELEGA	1 = east Welega zone	0.07	–
WESTARSI	1 = west Arsi zone	0.13	–
HADYA	1 = Hadiya zone	0.11	–
GURAGE	1 = Gurage zone	0.09	–
SIDAMA	1 = Sidama zone	0.10	–
EASTSHOA	1 = east Shewa zone	0.22	–
METEKEL	1 = Metekel	0.08	–
Plot observations		1,616	
Household observations		898	

Note: *1 Birr = 0.059 USD at the time of survey.

ularly the cost of transporting bulky materials/inputs. For instance, plots treated with manure are closer to the residence (about 6 minutes walking time) than plots that are not treated with manure (about 13 minutes walking time). Distant plots usually receive less attention and less frequent monitoring in terms of, for example, watching and guarding. This is especially true for maize and legume crops, which are edible at green stage and hence farmers are less likely to adopt SAPs on such plots.

We control for socio-demographic characteristics relevant to the adoption decision, such as family size, age, gender and education level of the household head and spouse. Of the sample households, 92% have a male head. The number of years of education range from 2 to 4 years across the study areas with only 55% of the household heads having at least primary education. Farm technology-adoption decisions may not only be made by the head of the household, but can be part of an overall household strategy (Zepeda and Castillo, 1997). Therefore, we also include the education level of the spouse when we examine the role of human capital in the adoption of SAPs. The average level of education of the spouses in the study area is 1.3 years; with only 30% of spouses having at least primary education.

3.5. *Input–output market access*

Access to market variables are directly associated with the transaction costs associated with input and output marketing activities, and can negatively influence the smallholder's adoption of SAPs, through increasing travel time and transport costs. Transaction costs are barriers to market participation by resource-poor smallholders, and are factors responsible for significant market failures in developing countries (Sadoulet and de Janvry, 1995). Market access is measured here by distance to the input markets (in minutes walking time) and by means of transportation used to the output markets, a dummy variable equal to one if farmers are walking to the market, and zero if farmers use other transportation systems (such as a public transport, bicycle or donkey/horse and cart). The average walking distance to input markets is about 1 hour, and only 56% of households use different transportation means (public transport, bicycle or donkey/horse and cart) to visit the market.

3.6. Resource constraints

As a measure of wealth of the household, we include the total value of all non-land assets, livestock ownership (in tropical livestock units; TLU) and farm size. We also include a dummy variable equal to one if the household receives a remittance in the form of cash and/or participates in off-farm work as an indicator for working capital. Farm size is often thought to be a prerequisite for obtaining credit. In Ethiopia, farmers must have at least 0.5 ha under maize to participate in the credit scheme for maize (Doss, 2006).

Credit constraints are frequently mentioned in technology-adoption literature. To measure whether a farmer has access to credit, we follow the Feder *et al.* (1990) approach of constructing a credit-access variable. This measure of credit tries to distinguish between farmers who choose not to use available credit, and farmers who do not have access to credit, as many non-borrowers do not borrow because they actually have sufficient liquidity from their own resources, and not because they cannot obtain credit, whereas some cannot borrow because they are not creditworthy, do not have collateral or fear risk (Feder *et al.*, 1990; Doss, 2006). In this study, the respondent is asked to answer two sequential questions: whether credit is needed or not, and if yes, whether credit is obtained for farming operations or not. The credit-constrained farmers are then defined as those who need credit, but are unable to get it (30%). Accordingly, the credit-unconstrained farmers are those who do not need credit (40%) and those who need credit and are able to get it (30%).

3.7. Stresses

Smallholder farming in Ethiopia is often subject to environmental disturbances such as drought, waterlogging, floods, untimely or uneven distribution of rainfall, incidence of pest and diseases, and frost. Understanding the impact of these disturbances on the adoption of SAPs is relatively neglected, but these stresses contribute to an erosion of farmers' confidence in adopting technology. We include self-reported rainfall and plot-level crop-production disturbances to account for the farm-specific environmental disturbance experience. We follow the Quisumbing (2003) approach to construct the rainfall disturbance variable based on respondents' subjective rainfall satisfaction in terms of timeliness, amount and distribution. The individual rainfall index relates to rainfall in the preceding three seasons, based on such questions as whether rainfall came and stopped on time, whether there was enough rain at the beginning and during the growing season and whether it rained at harvest time. Responses to each of these questions (either yes or no) were coded as favourable or unfavourable rainfall outcomes, and averaged over the number of questions asked (five questions) so that the best outcome would be close to one and the worst close to zero.[9] Plot-level disturbance is captured by the three most common stresses affecting crop production: attacks by pests and diseases, water logging and drought, frost and hailstorm stress. The effect of these plot-level disturbances on the adoption of SAPs depends on the type of SAP. For instance, credit-constrained farmers may be less likely to adopt SAPs that involve cash expenditure, such as fertiliser and seed varieties, compared to other SAPs, such as manure, or crop rotation, that do not require cash outlays.

3.8. Government support

In Ethiopia, it is common for government and international organisations to provide aid/or subsidies (productive safety nets programme) when crop production fails. We include a dummy variable equal to one if farmers believe they can rely on government support during crop failure and zero otherwise. Social safety nets/insurance, if properly implemented, can build farmer confidence so that he invests despite uncertainty, and can help farm households to smooth consumption and maintain productive capacity by reducing the need to liquidate assets that might otherwise occur (Barrett, 2005). Thus, farmers' confidence in public support can positively influence the adoption of SAPs.

3.9. Social capital network

In addition to the conventional household characteristics and endowment variables, the survey also collected variables related to social capital and networks that can influence technology-adoption decisions (Isham, 2002; Bandiera and Rasul, 2006; Marenya and Barrett, 2007). Social capital literature treats social networks as a means to access information, secure a job, obtain credit, protect against unforeseen events, exchange price information, reduce information asymmetries and enforce contracts (Barrett, 2005; Fafchamps and Minten, 2002; Di Falco and Bulte, 2011).

In this study, detailed questions were asked to identify different social networks. We distinguished three social networks and capital: first, a household's relationship with rural institutions in the village, defined as whether the household is a member of a rural institution or association, such as input supply and labour sharing; second, a household's relationship with trustworthy traders, measured by the number of trusted traders inside and outside the village that the respondent knows; and third, a household's kinship network, defined as the number of close relatives that the farmer can rely on for critical support in times of need. This classification is important, as different forms of social capital and networks may affect the adoption of SAPs in various ways, such as through information sharing, stable market outlets, labour sharing, the relaxing of liquidity constraints and mitigation of risks. In most developing countries, households with a greater number of relatives are more likely to adopt new technologies because they are able to experiment with technologies while spreading the risks over more people and resources (Di Falco and Bulte, 2011; Kassie *et al.*, in press). On the other hand, farmers with more relatives may

[9] Actual rainfall data are preferable, but getting reliable data in most developing countries, including Ethiopia, is difficult.

have lower opportunity costs for family labour, so farmers may invest less, including in new technologies (Di Falco and Bulte, 2011).

3.10. Extension

Extension is one source of information for many farmers through contact with extension agents. Farmers' access to information through extension agents is measured by the frequency of extension contact related to SAP activities. Given that many of the extension agents are also involved in other activities, such as input delivery service, administering credit provision and collection of repayment, farmers may question the skill of extension agents to provide reliable and updated information. We assess the perception of farmers regarding the skill of extension workers through attitudinal questions, with a value of 1 if the respondents are confident with the qualification of extension agents and 0 otherwise.

4. Results and Discussion

4.1. Conditional and unconditional adoption

The joint and marginal probability distribution of plots for the five SAPs is presented in Table 2. Of the 1,616 plots considered in the analysis, about 1,509 plots benefited from one or more SAP although all five SAPs were applied in only ten plots. Inorganic fertiliser was the most common SAP used by the sample households. It was used as a single technology on 11% of plots, in combination with improved seed on 16% of plots and in combination with conservation tillage and improved seed on 10% of plots. Manure alone was adopted on 4.9% of plots, in combination with inorganic fertiliser on 3.5% of plots and jointly with improved seed and inorganic fertiliser on 4.3% of plots. Of the plots, 1.6% received only the legume–maize rotation practice. Similarly, 4.3% of the plots benefited from adoption of crop rotation, improved seed and inorganic fertiliser jointly, and 3.5% of plots jointly adopted legume–maize rotation, improved seed, inorganic fertiliser and conservation tillage.

Although the statistics on the joint and marginal probabilities provide interesting results, the sample unconditional and conditional probabilities of adoption also provide an indication of the existence of possible interdependence across the five SAPs (Table 3). The unconditional probability of a plot receiving inorganic fertiliser is 67.3%. However, this increases to 78.1%, 73.2% and 76.4% conditional on adoption of one practice (improved seed), two practices (rotation and improved seed) and three practices (rotation, improved seed and conservation tillage), respectively. Interestingly, the conditional probability of adopting inorganic fertiliser on plots is significantly lower on plots when farmers adopt only manure (48.2%), jointly manure and conservation tillage (38.3%) and three practices (manure, improved seed and conservation tillage, 49.2%). The likelihood of inorganic fertiliser use is reduced by more than 19% when households applied manure to a plot, suggesting substitutability between manure and inorganic fertiliser.

While a more in-depth multivariate analysis is required, a non-parametric maize net-income[10] distribution analysis shows that SAPs affect the net value of maize

[10] Net of fertiliser, seed and pesticides costs.

Table 2

Joint and marginal probabilities of adoption of sustainable agricultural practices (%)

Percent adopting in:	Joint probability	Marginal				
		Rotation	Variety	Fertiliser	Manure	Tillage
Rotation only	1.58	1.58	–	–	–	–
Improved maize variety only	2.37	–	2.37	–	–	–
Inorganic fertiliser only	10.62	–	–	10.62	–	–
Manure only	4.92	–	–	–	4.92	–
Conservation tillage only	2.31	–	–	–	–	2.31
Rotation and improved seed	1.70	1.70	1.70	–	–	–
Rotation and fertiliser	2.31	2.31	–	2.31	–	–
Rotation and manure	1.03	1.03	–	–	1.03	–
Rotation and tillage	1.09	1.09	–	–	–	1.09
Improved seed and fertiliser	16.02	–	16.02	16.02	–	–
Improved seed and manure	2.00	–	2.00	–	2.00	
Improved seed and tillage	2.18	–	2.18	–	–	2.18
Fertiliser and manure	3.52	–	–	3.52	3.52	–
Fertiliser and tillage	5.58	–	–	5.58	–	5.58
Manure and tillage	3.16	–	–	–	3.16	3.16
Rotation, improved seed, fertiliser	4.25	4.25	4.25	4.25	–	–
Rotation, improved seed, manure	0.61	0.61	0.61	–	0.61	–
Rotation, improved seed, tillage	0.73	0.73	0.73	–	–	0.73
Rotation, improved seed, manure	0.49	0.49	–	0.49	0.49	–
Rotation, fertiliser, tillage	2.18	2.18	–	2.18	–	2.18
Rotation, manure, tillage	0.49	0.49	–	–	0.49	0.49
Improved seed, manure, tillage	1.40	–	1.40	–	1.40	1.40
Improved seed, fertiliser, manure	4.31	–	4.31	4.31	4.31	–
Improved seed, fertiliser, tillage	9.65	–	9.65	9.65	–	9.65
Fertiliser, manure, tillage	0.91	–	–	0.91	0.91	0.91
Rotation, improved seed, manure, tillage	0.55	0.55	0.55	–	0.55	0.55
Rotation, improved seed, fertiliser, manure	1.40	1.40	1.40	1.40	1.40	–
Rotation, improved seed, fertiliser, tillage	3.52	3.52	3.52	3.52	–	3.52
Rotation, fertiliser, manure, tillage	0.67	0.67	–	0.67	0.67	0.67
Improved seed, fertiliser, manure, tillage	1.27	–	1.27	1.27	1.27	1.27
All five	0.61	0.61	0.61	0.61	0.61	0.61
None (plot did not receive any of the practices)	6.61	–	–	–	–	–
Total	100.00	23.21	52.57	67.31	27.34	36.30

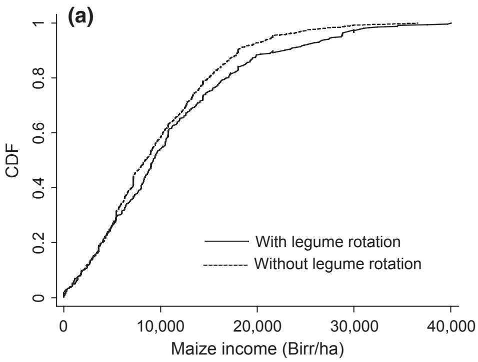
Table 3

Unconditional and conditional adoption probabilities

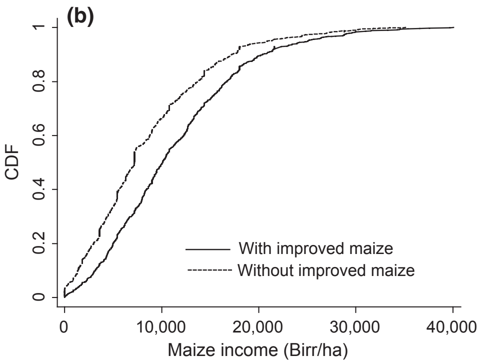
	Rotation	Seed	Fertiliser	Manure	Tillage
$P(Y_k = 1)$	0.23	0.53	0.67	0.27	0.36
$P(Y_k = 1 \mid Y_R = 1)$	1	0.58*	0.67	0.25	0.42**
$P(Y_k = 1 \mid Y_V = 1)$	0.25	1	0.78***	0.23**	0.38
$P(Y_k = 1 \mid Y_F = 1)$	0.23	0.61***	1	0.19***	0.36
$P(Y_k = 1 \mid Y_M = 1)$	0.21	0.44***	0.48***	1	0.33
$P(Y_k = 1 \mid Y_T = 1)$	0.27**	0.55	0.67	0.25	1
$P(Y_k = 1 \mid Y_R = 1, Y_V = 1)$	1	1	0.73*	0.24	0.41
$P(Y_k = 1 \mid Y_R = 1, Y_F = 1)$	1	0.63***		0.21**	0.45***
$P(Y_k = 1 \mid Y_R = 1, Y_M = 1)$	1	0.54	0.54***	1	0.39
$P(Y_k = 1 \mid Y_R = 1, Y_T = 1)$	1	0.55	0.71	0.24	1
$P(Y_k = 1 \mid Y_V = 1, Y_F = 1)$	0.24	1	1	0.19***	0.32
$P(Y_k = 1 \mid Y_V = 1, Y_M = 1)$	0.26	1	0.63	1	0.31
$P(Y_k = 1 \mid Y_V = 1, Y_T = 1)$	0.27	1	0.76***	0.19***	1
$P(Y_k = 1 \mid Y_F = 1, Y_M = 1)$	0.24	0.58	1	1	0.26***
$P(Y_k = 1 \mid Y_F = 1, Y_T = 1)$	0.29**	0.62***	1	0.14***	1
$P(Y_k = 1 \mid Y_M = 1, Y_T = 1)$	0.26	0.42***	0.38***	1	1
$P(Y_k = 1 \mid Y_R = 1, Y_V = 1, Y_F = 1)$	1	1	1	0.21**	0.42
$P(Y_k = 1 \mid Y_R = 1, Y_V = 1, Y_T = 1)$	1	1	0.76*	0.21	1
$P(Y_k = 1 \mid Y_R = 1, Y_V = 1, Y_M = 1)$	1	1	0.64	1	0.37
$P(Y_k = 1 \mid Y_R = 1, Y_F = 1, Y_M = 1)$	1	0.64	1	1	0.40
$P(Y_k = 1 \mid Y_R = 1, Y_F = 1, Y_T = 1)$	1	0.59	1	0.18**	1
$P(Y_k = 1 \mid Y_R = 1, Y_M = 1, Y_T = 1)$	1	0.50	0.55	1	1
$P(Y_k = 1 \mid Y_V = 1, Y_F = 1, Y_M = 1)$	0.26	1	1	1	0.25***
$P(Y_k = 1 \mid Y_V = 1, Y_F = 1, Y_T = 1)$	0.27	1	1	0.13***	1
$P(Y_k = 1 \mid Y_V = 1, Y_M = 1, Y_T = 1)$	0.30	1	0.49***	1	1
$P(Y_k = 1 \mid Y_F = 1, Y_M = 1, Y_T = 1)$	0.37**	0.54	1	1	1
$P(Y_k = 1 \mid Y_V = 1, Y_F = 1, Y_M = 1, Y_T = 1)$	0.32	1	1	1	1
$P(Y_k = 1 \mid Y_R = 1, Y_F = 1, Y_M = 1, Y_T = 1)$	1	0.48	1	1	1
$P(Y_k = 1 \mid Y_R = 1, Y_V = 1, Y_M = 1, Y_T = 1)$	1	1	0.53	1	1
$P(Y_k = 1 \mid Y_R = 1, Y_V = 1, Y_F = 1, Y_T = 1)$	1	1	1	0.15**	1
$P(Y_k = 1 \mid Y_R = 1, Y_V = 1, Y_F = 1, Y_M = 1)$	1	1	1	1	0.30

Note: Y_k is a binary variable representing the adoption status with respect to practice k (k = rotation (R), improved seed (V), fertiliser (F), manure (M), conservation tillage (T)); *, ** and *** indicate statistical significance at 10%, 5% and 1%, respectively. The comparison is between unconditional probability and conditional probability in each practice.

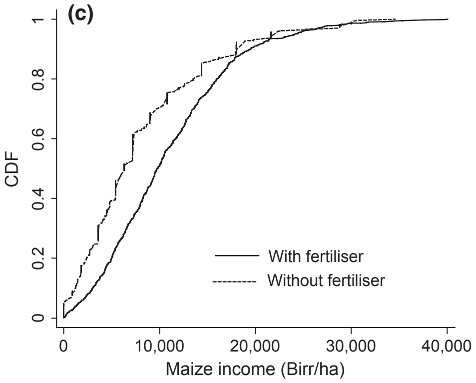
production. The cumulative distribution of the net value of maize production on plots with legume rotation, chemical fertiliser, improved seed, manure use and conservation tillage dominates the maize net-income cumulative distribution on plots without these SAPs. This is shown by the cumulative density function (CDF; Figures 1(a) to 1(e)) of maize net income of plots with SAPs being con-



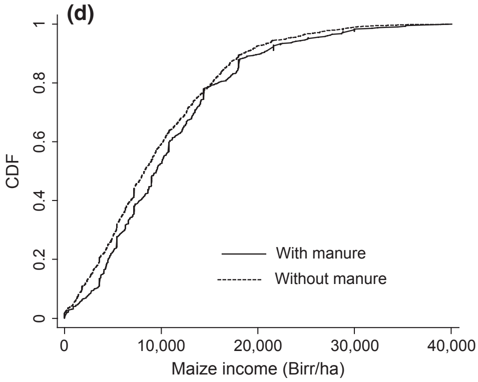
Note: Cumulative distribution for the impact of maize–legume rotation on maize net income.
CDF = cumulative density function.



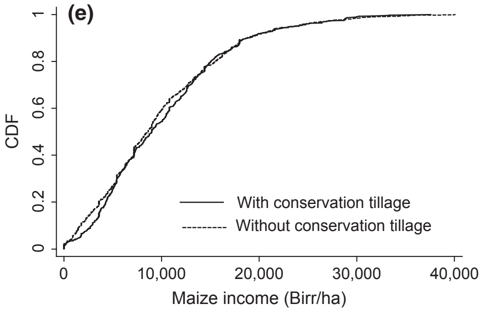
Note: Cumulative distribution for the impact of improved seed on maize net income.
CDF = cumulative density function.



Note: Cumulative distribution for the impact of inorganic fertiliser on maize net income.
CDF = cumulative density function.



Note: Cumulative distribution for the impact of manure use on maize net income.
CDF = cumulative density function.



Note: Cumulative distribution for the impact of conservation tillage on maize net income.
CDF = cumulative density function.

Figure 1 (a)–(e). Impacts of sustainable agricultural practices (SAPs) on net maize income.

stantly below or equal to that of plots without these practices. The Kolmogorov–Smirnov statistics test for CDFs or the test for vertical distance between the two CDFs also confirms this result.[11] This is an important economic incentive for farmers to adopt SAPs.

4.2. Regression Results

4.2.1. Adoption decisions: MVP model results

The MVP model is estimated using the maximum likelihood method on plot-level observations.[12] The model fits the data reasonably well – the Wald test [$\chi^2(296) = 6937.74$, $P = 0.00$] of the hypothesis that all regression coefficients in each equation are jointly equal to zero is rejected. As expected, the likelihood ratio test [$\chi^2(10) = 111.10$, $P = 0.00$] of the null hypothesis that the covariance of the error terms across equations are not correlated is also rejected (See online appendix Table S1). This is supported by the correlation between error terms of the adoption equations reported in Table S1. The estimated correlation coefficients are statistically significant in six of the ten pair cases, where three coefficients have negative and the remaining three have positive signs.

In addition to supporting the use of the MVP, this also shows the interdependence of practices where the probability of adopting a practice is conditional on whether a practice in the subset has been adopted or not. These results agree with the conditional and unconditional adoption probabilities reported in Table 3. Improved seed is complementary with crop-rotation, inorganic fertiliser and manure. The correlation between improved seed and inorganic fertiliser adoption is the highest (42%). On the other hand, manure is a substitute for inorganic fertiliser, crop rotation and conservation tillage. The substitution between manure and inorganic fertiliser contradicts the finding of Marenya and Barrett (2007) who found the two to be complementary in smallholder farming system in western Kenya in 2002.

As is evident in Table 4, the MVP model estimates differ substantially across the equations, indicating the appropriateness of differentiating between practices. To formally test this, we estimated a constrained specification with all slope coefficients forced to be equal. The likelihood ratio test statistic of the null hypothesis of equal-slope coefficients is rejected ($\chi^2(224) = 4487.86$, $P = 0.00$), reflecting the heterogeneity in adoption of SAPs and, consequently, supporting a separate analysis of each rather than aggregating them into a single SAP variable.

The MVP model results reveal that the spouse's (woman's) education level has a positive impact on the adoption of inorganic fertilisers and conservation tillage. The result underscores the important role women play in agriculture and technology-adoption decisions in developing countries. One implication is that technology-adoption decisions should not be viewed as an isolated decision, but as part of an overall household strategy, modelled as a joint household decision.

The mode of transportation to output market influences the likelihood of adoption of improved seed and conservation tillage. Households using public transport, bicycle or donkey/horse cart are more likely to adopt improved seed and conservation tillage. This suggests that improving the road infrastructure and access to a

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[11] Test results not shown in the interests of brevity.

[12] The results without Mundlak's approach are reported in the online appendix Table S2.

Table 4

Coefficient estimates of the multivariate probit model with Mundlak's approach

Variables	Rotation		Improved seed		Fertiliser		Manure		Tillage	
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
Household and farm characteristics										
SEX	0.09	0.15	0.14	0.15	0.18	0.23	−0.26*	0.16	−0.13	0.18
AGE (10^{-2})	−0.70*	0.40	-0.01	0.40	0.20	0.60	0.10	0.40	0.20	0.50
EDUCATSPOUS	0.03	0.01	0.02	0.02	0.06**	0.03	-0.02	0.01	0.04*	0.02
DIST	−0.01	0.02	−0.01	0.01	−0.04***	0.01	0.02	0.01	−0.002	0.01
RENTD	−0.01	0.54	−0.07	0.53	0.64	0.48	−1.77***	0.58	0.41*	0.25
SHALWDEPT	−0.19	0.25	0.27	0.21	0.78**	0.33	−0.31	0.34	0.15	0.22
MEDMDEPT	−0.26	0.19	0.01	0.19	0.69***	0.24	0.02	0.28	−0.04	0.16
GOODSOL	0.31	0.34	−0.16	0.27	−1.06***	0.41	0.63*	0.33	0.17	0.20
FLATSLOP	0.02	0.27	−0.44**	0.21	−1.33***	0.34	0.74**	0.31	−0.01	0.21
MEDMSLOP	0.09	0.26	−0.58***	0.21	−0.77**	0.30	0.52*	0.29	0.10	0.201
GODSOL × DIST	0.01	0.02	−0.02**	0.01	0.01	0.02	−0.01	0.01	−0.01	0.01
MEDMSOL × DIST	0.01	0.02	−0.02**	0.01	0.01	0.02	−0.01	0.01	−0.01	0.01
RENTD × GODSOL	0.14	0.57	0.32	0.56	−0.15	0.52	0.73	0.63	−0.56*	0.29
RENTDX MEDSOL	−0.14	0.56	−0.06	0.54	−0.78	0.55	1.22**	0.61	−0.68**	0.29
FLATSLP × DIST	−0.01	0.01	0.04***	0.01	0.04***	0.01	−0.02	0.01	0.01*	0.01
MEDMSLP × DIST	0.01	0.01	0.04***	0.01	0.04***	0.01	−0.03	0.02	0.01**	0.01
Market access and resource constraints										
MEANSTRANS	−0.04	0.09	−0.15*	0.09	−0.23*	0.13	−0.02	0.09	−0.32***	0.11
WALKDIST (10^{-2})	−0.01	0.10	−0.10*	0.10	−0.01	0.10	−0.01	0.10	0.20*	0.10
ASSETVALUE	0.003	0.82	1.77**	0.83	8.47***	2.07	−1.31	0.84	4.12***	1.53
OTHERINCOM	0.21**	0.09	−0.07	0.08	−0.135	0.13	0.09	0.09	−0.09	0.11
TLU (10^{-1})	−0.01	0.06	−0.04	0.04	0.05	0.10	0.17***	0.06	0.01	0.07
CREDIT	−0.04	0.11	−0.17*	0.09	−0.36**	0.17	0.02	0.09	−0.01	0.12

Table 4
(*Continued*)

Variables	Rotation		Improved seed		Fertiliser		Manure		Tillage	
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
Social network/capital and extensions										
RELATIVE (10^{-2})	0.70*	0.40	0.01	0.40	−0.30	0.70	−0.60	0.40	1.10**	0.50
KNOWTRUST	0.02*	0.01	0.02*	0.01	−0.02	0.02	0.01	0.01	0.001	0.01
INPUTMEMBER	0.29***	0.09	0.13	0.10	0.06	0.16	−0.15	0.10	0.36***	0.12
CONFDNT	−0.01	0.54	−0.07	0.53	0.64	0.48	−1.77***	0.58	0.31	0.25
Stresses										
RAININDEX	0.29*	0.17	−0.22	0.16	0.42*	0.24	0.18	0.15	−0.30	0.19
WATRLOG	−0.27**	0.13	−0.08	0.11	0.03	0.18	−0.01	0.11	−0.07	0.13
FROSTSTRES	0.01	0.22	−0.46**	0.19	−0.21	0.30	−0.32*	0.18	−0.13	0.23
RELYGOVT	−0.06	0.09	0.27***	0.08	7.07***	0.18	−0.46***	0.09	−0.01	0.09
CONSTANT	−0.55	0.41	0.14	0.39	−0.82	0.59	−0.29	0.41	−0.06	0.48
Joint significance of location variables: χ^2 (7)	32.24		61.69		92.72		18.92		38.06	
Prob. > χ^2(7)	0.00		0.00		0.00		0.01		0.00	
Joint significance of mean of plot varying covariates	χ^2 (70) = 155.88; Prob. > χ^2 = 0.00									
Sample size = 1,616	Wald χ^2 (296) = 6,937.74; Prob. > χ^2 = 0.00									

Note: *, ** and *** indicate statistical difference at 10%, 5% and 1%, respectively; SE is the standard error adjusted for clustering on-farm households to allow for correlation within group; Non-significant control variables include: FAMLYSIZE, EDUCATHEAD, MEDMSOL, FARMSIZE, PESTSTRES, EXTMAZLEG, EXTPEST, EXTROTAT and EXTTILAGE.

public transportation system is important in facilitating adoption, through facilitating product transport, reducing the cost of the farmer's time and enabling more timely market information. Transaction costs related to distance to input market from residence have a differentiated effect. Distance to the input market has a negative and significant effect on the adoption of improved seed, reflecting transaction and access cost. Distance to the input market, on the other hand, has a positive and significant effect on the adoption of conservation tillage practices, possibly because increased input costs increases the attraction of alternative input use, such as conservation tillage. Wealth, as measured by the value of major household and farm equipment, positively influences the adoption of improved seed, inorganic fertiliser and conservation tillage, reflecting the capacity to purchase external inputs and to cope with greater risk. Similarly, livestock ownership positively influences the adoption of manure farming because livestock waste is the single most important source of manure for small farms in most parts of Ethiopia (see Marenya and Barrett, 2007). Credit constraints negatively influence investment in improved seed and inorganic fertilisers, suggesting that liquidity-constrained households (those who need credit, but are unable to find it) are less likely to adopt SAPs that require cash outlays.[13]

Our results further underscore the importance of rainfall and plot-level stresses (waterlogging and frost) in explaining adoption of SAPs. The probability of adoption of inorganic fertiliser and crop rotation is high in areas/years where rainfall is reliable in terms of timing, amount and distribution. Kassie *et al.* (2010) and Pender and Gebremedhin (2007) found that inorganic fertilisers provide a higher crop return per hectare in wetter areas than in drier areas and suggest the need for careful agro-ecological targeting in the development, promotion and scaling up of SAPs. Similarly, adoption of crop rotation and improved seed are negatively and significantly influenced by waterlogging and frost stress.

The hypothesis that social capital and networks positively affects the probability of adoption of SAPs is confirmed. The probability of adopting crop rotation and conservation tillage practices is affected by a households' participation in a rural institution or group, and by the number of relatives inside and outside the village that farmers can rely on for support in times of need. Likewise, adoption of crop rotation and improved seed increases with the number of traders that farmers know inside and outside the village. With scarce or inadequate information sources and imperfect markets, social networks such as traders' and farmers' associations or groups facilitate the exchange of information, and enable farmers to access inputs on schedule and overcome credit constraints. This finding suggests that to enhance the adoption of technologies/practices, local rural institutions and service providers need to be supported because they can effectively assist farmers in providing credit, inputs, information and stable market outlets.

Households that believe that the government will provide support when crops fail are more likely to adopt improved seed and inorganic fertiliser, probably

[13] The variable credit access is potentially endogenous. Following Wooldridge (2002), we implemented a two-stage residual inclusion test for the endogeneity of the variable. We use walking distance to credit office as the instrumental variable. The instrument significantly explains the access to credit variable. The results suggest that endogeneity is not a problem. Results are available upon request. We thank an anonymous referee for pointing this out.

because the benefits of new technologies are uncertain, and farmers want to have insurance if they have to adopt new technologies. On the other hand, those who have less trust in government support are more likely to adopt practices that depend on local resources, such as manure. The results also reveal that households that have confidence in the skill of extension agents are more likely to adopt conservation tillage practices because this practice is relatively knowledge intensive and requires considerable management. However, the frequency of extension contact has no impact on adoption of this practice. This may indicate that it is not the frequency of extension contact *per se* that affects adoption, but the quality of the extension services.

Consistent with earlier work on technology adoption (e.g. Kassie *et al.*, 2010; Jansen *et al.*, 2006), land tenure influences the adoption of the use of animal manure and conservation tillage, which are more common on owned plots than on rented plots, possibly reflecting tenure insecurity and Marshallian inefficiency, suggesting that secure land tenure will encourage adoption decisions.

With respect to plot characteristics, the analysis shows that the use of inorganic fertilisers is less likely on plots with good soil quality, whereas the use of manure is more likely. The propensity to adopt inorganic fertilisers and improved seed is more likely on plots with a steep slope, while the practice of manure farming is less likely. However, the probability of inorganic fertiliser adoption increases on distant flat and medium-slope plots (see interaction term), suggesting a trade-off for using inorganic fertilisers on nearby steep plots and distant flat plots. Although the use of fertilisers on distant flat plots can prevent nutrient erosion, it can incur additional transaction and application costs. Similarly, adoption of improved seed and conservation tillage practices is more likely on distant flat and medium-slope plots.

4.2.2. Number of SAPs adopted: Ordered probit results

Table 5 shows the results from pooled- and random-effects ordered probit models.[14] The estimates of both models are numerically similar despite the significance of the random-effects. The discussion of results is based on the pooled ordered probit model using Mundlak's approach,[15] which distinguishes the marginal impact of each covariate on an individual outcome variable.

The Chi-squared statistic for the ordered probit model is statistically significant $[\chi^2(49) = 305.9,\ p = 0.00)]$ at less than 1% significance level, indicating that the joint test of all slope coefficients equal to zero is rejected. Results show that the number of SAPs adopted increases with family size and decreases with the age of the head of the household. As in the adoption decision, the spouse's education level has a significant and positive effect on the level of SAP use. Each additional year of education of the spouse increases the probability of adopting more than two SAPs by 12%. Means of transport to output market has a significant and negative impact

[14] The joint significance of the mean of plot varying explanatory variables is significantly different from zero, suggesting that there is a correlation between observed and unobserved heterogeneity and justifying the use of Mundlak's approach. Our analysis also shows that the likelihood ratio test of the null hypothesis that the correlation between two successive error terms of plots (ρ) belonging to the same household is significantly different from zero, justifying the application of the random-effects ordered probit model (Table 5).

[15] The results without Mundlak's approaches are reported in the online appendix Table S3.

Table 5

Coefficient estimates of the ordered probit model with Mundlak's approach

	Pooled Ordered Probit Model								*Random Effects Ordered Probit Model*	
			Marginal Effects							
Variables	*Coefficients*	*SE*	*Prob* $(Y=0\|X)$	*Prob* $(Y=1\|X)$	*Prob* $(Y=2\|X)$	*Prob* $(Y=3\|X)$	*Prob* $(Y=4\|X)$	*Prob* $(Y=5\|X)$	*Coefficients*	*SE*
EDUCATSPOUS (10^{-2})	2.90**	(1.00)	–0.20***	–0.70***	–0.10	0.70***	0.30***	0.02**	3.80**	(1.80)
MEANSTRANS	–0.26***	(0.07)	0.02***	0.06***	0.01	–0.06***	–0.03***	–0.002**	–0.33***	(0.09)
RELATIVE (10^{-2})	0.60*	(0.30)	–0.10**	–0.10***	–0.01	0.10**	0.10**	0.01*	0.80*	(0.40)
KNOWTRUST (10^{-2})	1.80**	(0.70)	–0.20***	–0.40***	–0.10*	0.40***	0.20***	0.01**	2.30**	(1.10)
INPUTMEMBER	0.29***	(0.09)	–0.02***	–0.07***	–0.02**	0.07***	0.03***	0.003**	0.39***	(0.11)
EXTROTAT (10^{-2})	1.70**	(0.70)	–0.10**	–0.40***	–0.04	0.40***	0.20***	0.01**	2.10*	(1.10)
ASSETVALUE (10^{-6})	2.33***	(0.74)	–0.19***	–0.55***	–0.06*	0.55***	0.24***	0.02**	2.98***	(0.89)
FROSTSTRES	–0.32**	(0.14)	0.02*	0.08**	–0.003	–0.07**	–0.03**	–0.002**	–0.29	(0.19)
RELYGOVT	0.56***	(0.07)	–0.05***	–0.13***	–0.02***	0.13***	0.06***	0.01***	0.87***	(0.09)
DIST (10^{-2})	–0.30**	(0.10)	0.02**	0.07**	0.01	–0.07**	–0.03**	–0.002	–0.40**	(0.20)
RENTD	–0.28***	(0.09)	0.03***	0.07***	–0.004	–0.07***	–0.03***	0.002	–0.36***	(0.11)
Joint Significance of Location Variables [X^2 (7)]	38.01 ($p=0.00$)								45.61 ($p=0.00$)	
Joint Significance of Mean of Plot Varying Covariates [X^2 (70)]	24.17 (p = 0.00)								20.49 (p = 0.01)	

Table 5
(*Continued*)

	Pooled Ordered Probit Model									Random Effects Ordered Probit Model	
			Marginal Effects								
Variables	*Coefficients*	*SE*	*Prob* $(Y=0\|X)$	*Prob* $(Y=1\|X)$	*Prob* $(Y=2\|X)$	*Prob* $(Y=3\|X)$	*Prob* $(Y=4\|X)$	*Prob* $(Y=5\|X)$		*Coefficients*	*SE*
μ_1	–1.71***	(0.36)								–2.13***	(0.42)
μ_2	–0.60*	(0.35)								–0.70*	(0.41)
μ_3	0.56*	(0.32)								0.78**	(0.41)
μ_4	1.63***	(0.36)								2.15***	(0.42)
μ_5	2.83***	(0.39)								3.69***	(0.45)
Log-likelihood	–2,143									–2,079	

Note: *, ** and *** indicate that the null hypothesis is rejected at a level of significance of p = 0.10, 0.05 and 0.01, respectively. Figures in parentheses are standard errors adjusted for clustering on-farm households to allow for correlation within group; other non-significant control variables include: *AGE*, *FAMLYSIZE*, *SEX*, *EDUCATHEAD*, *WALKDIST*, *EXTMAZLEG*, *EXTPEST*, *EXTTILAGE*, *CONFDNT*, *FARMSIZE*, *OTHERINCOM*, *TLU*, *CREDIT*, *RAININDEX*, *PESTSTRES*, *WATRLOGG*, *SHALDEPT*, *MEDMDEPT*, *GODSOIL*, *MEDMSOIL*, *FLATSLOP* and *MEDMSLOP*.

on the number of SAPs adopted. Farmers who do not have their own means of transport or access to public transport are 9% less likely to adopt more than two SAPs.

Social capital and network variables (household's membership of a rural institution, a kinship network and trust in traders) have significant and positive effects on the number of SAPs used, with varying marginal probabilities. If a household is a member of a rural institution or group, the probability of adopting more than two SAPs increases by 10%. Households with more relatives and who know more traders are 0.2% and 0.5% more likely to adopt two or more SAPs, respectively. Extension contact on the practice of crop rotation has a statistically significant, but small positive marginal probability effect (0.6%) for adopting more than two SAPs. Household assets positively influence the adoption of more than two SAPs, where improved seed and inorganic fertiliser predominate in the mixes of more than two SAPs (Table 2). This result is consistent with the positive effect of wealth on the likelihood of adoption of SAPs. Households that experience plot-level stresses such as incidence of frost and hailstorms are 10% less likely to apply more than one SAP on their farming plot than households who have not experienced these. Consistent with the probability of adoption of SAPs, a farmer's perception of government support in case of crop failure plays an important role in the number of SAPs adopted. In the study area, farmers who rely on government support during adverse conditions are 20% more likely to adopt more than two SAPs. The effect of this variable seems to be more important on the adoption of externally purchased SAPs (such as improved seed and inorganic fertilisers).

Plot-related variables, such as plot access as measured by plot distance to residence, have a negative impact on the number of SAPs adopted. An increase of 10 minutes in the walking time to the plot decreases adoption of more than two SAPs by 1%. Farmers are more likely to apply a greater number of SAPs on plots they own, as above.

5. Conclusions and Implications

Increasing and sustaining agricultural productivity through investment in SAPs is important for the reduction of hunger and poverty in Ethiopia. In this study, we analysed the probability and level of adoption of multiple SAPs by smallholder farmers using plot-level observations. We used MVP and ordered probit models to jointly analyse the adoption of multiple SAPs and the number of SAPs adopted on the plot while recognising the interrelationship among them. Our approach extends the existing empirical studies by allowing for correlations across SAPs and including a number of policy-relevant variables that affect adoption decisions.

The results reveal that there are strong complementarities and substitutabilities between SAPs, reflecting the interdependence of SAP adoption. Studies that consider the adoption of SAPs in isolation ignore important cross-technology correlation effects, and potentially generate biased estimates. The cross-technology correlation information can have important policy implications as policy changes which affect one SAP can have spillover effects to other SAPs. In addition, such information helps policy-makers and development practitioners to define their strategies of promoting agricultural technologies.

Most importantly, the results show that the probability and extent of adoption of SAPs are influenced by several factors: social capital in the form of membership of rural institutions, credit constraint, spouse education, asset ownership, distance to markets, mode of transportation, rainfall and plot-level disturbances, the number of relatives and traders known by the farmer inside and outside his village, farmer's belief in government support during crop failure and confidence in the skill of extension agents. In particular, social safety nets (government support during crop failure), social capital, market access and tenure security are important policy variables that have a high impact on adoption of multiple SAPs.

The significant role of social capital on adoption suggests the need for establishing and strengthening local institutions and service providers to accelerate and sustain technology adoption. In a country where there is information asymmetry and where both input and output markets are missing or incomplete, local institutions can play a critical role in providing farmers with timely information, inputs (e.g. labour, credit, insurance) and technical assistance.

The importance of the value of assets and the availability of credit in influencing the purchase of inputs (improved seed and fertiliser) calls for improving credit delivery systems. Livestock ownership clearly influences the use of manure. Although increasing the number of livestock might not be a feasible option, introducing high-yield breeds and improved forage legumes can increase livestock products, including manure.

The effects of rainfall disturbance on inorganic fertiliser and maize–legume rotation adoption are also important for targeting technologies, and for better rainfall forecasts, not only in terms of amount but also of timing and distribution. Furthermore, the use of SAPs is associated positively with the farmer's reliance on government support during crop failure. This suggests that investment in public safety-net programmes (public insurance) and risk-protection mechanisms can be expected to have a positive impact on the adoption of SAPs. Investment in rural public education with a special focus on women will also facilitate the adoption of technologies and practices according to our results.

Finally, while there is ample evidence from on-station and on-farm experiments on the impact of SAPs on productivity (Nzabi *et al*., 2000; Bloem *et al*., 2009; Rockstrom *et al*., 2009; Ghosh *et al*., 2010), little is known about the associated effects under smallholder farmers' conditions. Although the results of this study help, further research that examines the productivity, risk, environmental and welfare implications of the adoption of individual SAPs and combinations of SAPs is important to bridge the knowledge gap and influence farm policies.

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Supporting Information

Additional Supporting information may be found in the online version of this article:

Table S1. Estimated Covariance matrix of the multivariate probit (MVP) model regression between sustainable agricultural practices

Table S2. Coefficient estimates of the MVP without Mundlak's approach

Table S3. Coefficient estimates of the ordered probit model without Mundlak's approach