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Essays on the Economics of Sustainable Agricultural Technologies in Ethiopia

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To

Efi, Mati and Shitu

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Abstracts

This thesis consists of five interrelated papers:

Paper 1: Adoption of multiple sustainable agricultural practices in rural Ethiopia

The adoption and diffusion of sustainable agricultural practices (SAPs) have 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 paper analyzes 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 modeling 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, labor availability, plot 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, to improve the adoption of SAPs.

JEL classification*: Q01, Q12, Q16, Q18.*
Key words and phrases: Multiple adoption; sustainable agriculture practices; multivariate probit; Ethiopia.

Paper 2: Cropping systems diversification, conservation tillage and modern seed adoption in Ethiopia: Impacts on household income, agrochemical use and demand for labor

The type and combination of sustainable agricultural practices (SAPs) adopted has a significant effect on agricultural productivity and food security. Previous studies on adoption and impact have focused on single practices. However, in reality several adoption decisions are made simultaneously. We developed a multinomial endogenous switching regression model of farmers' choice of combination of SAPs and impacts on maize income and use of agrochemicals and family labor use in rural Ethiopia and found four primary results. First, adoption of SAPs increases maize income and the highest payoff is achieved when SAPs are adopted in combination rather than in isolation. Second, nitrogen fertilizer use is lower in the package that contains systems diversification and conservation tillage. Third, conservation tillage increased pesticide application and labor demand, perhaps to compensate for reduced tillage. However, when it is used jointly with systems diversification practices such as legume rotations it does not have a significant impact on pesticide and labor use. Fourth, since women contribute much of the farm labor needed for staple crops, adoption of packages increases their workload, in most cases, suggesting that agricultural intensification technology interventions may not be gender neutral. This implies that policy makers and other stakeholders promoting a combination of technologies can enhance household food security through increasing income and reducing production costs, but need to be aware of the potential gender related outcomes.

JEL classification*: Q01, Q12, Q57*
Keywords and phrases*:* Agrochemical use, demand for labor, Ethiopia, income, multinomial switching regression, sustainable agricultural practices

Paper 3: The impact of shadow prices and farmers' impatience on the allocation of a multipurpose renewable resource in Ethiopia

In a mixed farming system in which farmyard manure (FYM) is considered an important multipurpose renewable resource that can be used to enhance soil organic matter, provide additional income, and supply household energy, soil fertility depletion could take place within the perspective of the allocation pattern of FYM. This paper estimates a system of FYM allocation regressions to examine the role of returns to FYM and farmers' impatience on the propensity to allocate FYM to different uses. We parameterize the model using data from a sample of 493 households in Ethiopia. Results indicate a heightened incentive for diverting FYM from farming to marketing for burning outside the household when returns to selling FYM and the farmer's discount rate are high. These reveal the need for policies that will help to reduce farmers' impatience and encourage the substitution of alternative energy sources to use FYM as a sustainable land management practice.

JEL Classification: **Q01, Q12**
***Key words and phrases*:** *Impatience, Shadow price, Allocation, Farmyard manure, Ethiopia*

Paper 4: Jointness in agricultural production and livestock technology adoption in Ethiopia

Even though farmyard manure is considered a promising soil fertilizer in many developing countries, its use in soil fertility restoration is constrained by a multitude of factors. Yet the adoption of a crop-livestock technology could relax these constraints. This paper examines the impact of a joint crop-livestock technology on farmyard manure production and the effect of farmers' risk preference on livestock technology adoption. An endogenous switching regression model is employed to account for self-selection in technology adoption. The model is implemented using survey data from 491 households collected in the central highlands of Ethiopia. The results show that farmers' risk preference, distance to the extension service center, and market access to complementary inputs significantly influence the adoption of improved livestock technology. Adoption of crossbreeding technology creates a positive and significant impact on organic fertilizer production. The positive indirect effect of crop technology is significantly higher for those who adopt livestock technology. This implies that a policy supporting crop-livestock synergies through joint provision of technologies is important in order to increase agricultural productivity through better soil fertility management.

***JEL Classification*:** **Q01, Q12, Q16**
***Key words and phrases*:** *mixed farming, organic fertilizer, technology, switching, Ethiopia*

Paper 5: Risk preferences as determinants of soil conservation decisions in Ethiopia

Soil degradation is one of the most serious environmental problems in the highlands of Ethiopia. The prevalence of traditional agricultural land use and the absence of appropriate resource management often result in the degradation of natural soil fertility. This has important implications for soil productivity, household food security, and poverty. Given the extreme vulnerability of farmers in this area, we hypothesized that farmers' risk preferences might affect the sustainability of resource use. This study presents experimental results on the willingness of farmers to take risks and relates the subjective risk preferences to actual soil conservation decisions. The study looks at a random sample of 143 households with 597 farming plots. We find that a high degree of risk aversion significantly decreases the probability of adopting soil conservation. This implies that reducing farmers' risk exposure could promote soil conservation practices and thus more sustainable natural resource management. This might be achieved by improving tenure security, promoting access to extension services and education, and developing income-generating off-farm activities.

JEL Classification: Q12, Q16, Q24, D81
Key words and phrases: Adoption, Ethiopia, risk preference, soil conservation

Overview

In countries where agriculture is the mainstay of the economy, soil fertility depletion in smallholder farming is one of the fundamental consequences of environmental problems causing low agricultural productivity. In the absence of appropriate resource management practices, the traditional farming method inevitably leads to degradation in the resource base with important implications for soil productivity, household food insecurity, and rural poverty. Concern over the consequences of land degradation for agricultural productivity and off-farm externalities has led many government and non-governmental organizations to encourage a wide range of sustainable agricultural practices. The design of policy to encourage the wider use of sustainable farming practices requires analysis of farmers' decisions and their potential implications (Wu and Babcock, 1998; Kassie et al., 2010). Accordingly, this thesis consists of five interrelated papers that study the adoption and economics of sustainable agricultural practices from a variety of angles with empirical evidence from rural Ethiopia.

Most previous adoption and impact studies have focused on analysis of a single technology while in reality farmers are typically faced with technology alternatives that may be adopted sequentially and/or simultaneously as complements, substitutes, or supplements to deal with their overlapping constraints (Dorfman, 1996; Khanna, 2001). Farmers adopt combinations of different agricultural technologies because of their synergies to improve soil fertility, suppress weeds, pests and diseases, and improve crop productivity. This suggests that the adoption of one technology may influence the adoption of other technologies.

The **first paper**, titled *Adoption of multiple sustainable agricultural practices in rural Ethiopia*, contributes to the growing economic literature on sustainable agriculture by applying an estimation method that considers the joint decision to adopt multiple types of SAPs such as crop rotation, modern crop varieties, inorganic fertilizer, manure, and conservation tillage. The study also extends the focus from the probability of adoption to the levels of adoption as measured by the number of SAPs adopted. The results show that there is strong complementarity and substitutability between SAPs, indicating the interdependence of SAP adoption. Studies that consider the adoption of multiple SAPs in isolation could lose important cross-technology correlation effects, and potentially yield biased estimates. The cross-technology correlation may have important policy implications in that a policy change that can affect one SAP may have spillover effects on other SAPs. 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, number of relatives and traders that the farmer knows in and outside his village, the farmer's trust in government support in case of crop failure, and confidence in the skills of extension agents.

Using a multinomial endogenous switching framework, the **second paper** "*Cropping systems diversification, conservation tillage and modern seed adoption in Ethiopia: Impacts on household income, agrochemical use and demand for labor*" analyzes adoption of alternative combinations of SAPs and examines the implications of adopting various combinations of these practices on outcome variables such as maize net income, agrochemical (nitrogen fertilizer and pesticide) use, and female and male labour demand for agricultural operations. The results show that adoption of SAP combinations significantly increases maize income, and that the package that contains all components of SAPs provides the highest income. This has promising policy implication: For example, the results can provide a framework for decision making for policy makers and other development practitioners to promote an alternative combination of SAPs so as to enhance household food security. Adoption of a full package has a positive effect on nitrogen and pesticide application as well as on the use of women's and men's labor on farm. However, it also appears that bio-diversification or conservation tillage or both with traditional varieties substituted for the insurance component of N use. This enables farmers to reduce N without significantly affecting income. On the other hand, comparing the change in pesticide use with the adoption of a package involving conservation tillage and bio-diversification with modern and traditional maize varieties reveals that pesticide application does not increase significantly when conservation tillage and bio-diversification are used with traditional maize varieties. In this regard, SAPs do have beneficial environmental effects in terms of reduced external off-farm inputs.

The **third and fourth papers** focus on soil nutrient cycling in the form of organic fertilizer such as farm yard manure in the mixed crop-livestock system. Crop-livestock systems can potentially play a key role in soil fertility management and in ecological balance. Livestock plays a crucial role in recycling of waste products and residues from cropping and agro-industries, and manure from livestock is used for crop production. Farmyard manure (FYM) use has often been suggested as a method of improving soil fertility in crop-livestock systems. The benefits of using FYM in crop production include improvements in the physical properties of soil, increases in soil organic matter content, and provision of N, P, K, and other mineral nutrients. Despite these benefits, the use of manure is constrained by limited supply due to low performance of indigenous livestock, lack of adoption of improved livestock technologies, and improved fodder.

Under the limited availability of FYM, the household allocation patterns of FYM are also interlinked with management of soil resources in such a way that the demand for FYM for energy within and outside farm households shifts the resources so that the application of FYM for improving soil fertility is limited. Therefore, building on the economic theory of the agricultural household model under credit and financial constraints, the thesis extends the existing economics literature on soil fertility depletion by examining the effect of the farmer's discount rate (farmer's impatience) and various returns to FYM on the propensity to allocate FYM as an input for agricultural production or for burning it as fuel within and outside farm households.

The empirical analysis is based on a system of equations concerning farmers' allocation of FYM for different purposes. The data indicates that farmers with a high degree of impatience tend to decrease the allocation of FYM to the farm, and the higher the selling price of FYM, the higher the incentive for farmers to sell FYM for burning outside the farm households. In order to encourage adoption of FYM farming as a sustainable land management practice, the results suggest that incentive policies may be developed in conjunction with the fuel pricing system such as promotion and dissemination of improved stoves not only to the rural areas but also to the surrounding towns. The high discount rates in this study, on the other hand, indicate that most farm households disregard the use of FYM farming, with effects on the sustainable management of soil resources. This implies that the poverty reduction scheme and ensuring the functioning of rural credit markets are also an important policy directions associated with sustainable land management practices.

Moreover, the jointness of crops and livestock production in the mixed farming system is often considered an opportunity for smallholder farmers to move toward sustainable agricultural production because of the associated intensified organic matter and nutrient recycling (Marenya and Barrett, 2007). Hence, joint crop-livestock technologies in the mixed farming system could be understood in that technologies for crop production are likely to improve livestock feed and productivity. These effects, jointly with livestock technologies, could improve income and crop-livestock nutrient transfers by increasing the availability of FYM. However, empirical research on the impact of joint crop-livestock technologies in a mixed farming system on the availability of FYM is limited. Additionally, although there is a wealth of empirical studies on agricultural technology adoption and its economic and environmental impacts, studies on the adoption of livestock technology in developing countries are very scarce. The study aims to examine the impact of joint crop-livestock technology on farmyard manure production and identify factors constraining livestock technology adoption using an endogenous switching regression model to account for self-selection in technology adoption.

The results indicate that the likelihood of adopting livestock technology (crossbreeding cattle) is positively correlated with complementary livestock production inputs such as an improved grazing system, access to extension services, veterinary services, and improved feeds. It is, however, negatively correlated with a farmer's risk aversion. The extent of the FYM production gap between adopter and non-adopter of livestock technology suggests that the non-adopters might face difficulties in increasing FYM production without using the improved livestock technologies. The most salient implication of the above results is provision of technologies consistent with joint intensification of the crop and livestock system.

The **last paper** *Risk preferences as determinants of soil conservation decisions in Ethiopia* starts out by reviewing how the sustainable use of land in the Ethiopian highlands faces problems due to continuous cropping and repeated cultivation of sloping lands without proper consideration of soil conservation and fertility amendments. Soil erosion – averaging 4.2 metric tons of soil loss per hectare per year – is a huge contributor to the low productivity of Ethiopian soils (Hurni, 1993). As a result, soil erosion is putting some 20,000-30,000 ha of croplands out of use annually (Bewket, 2007; FAO, 1986). The traditional explanations for soil degradation relate to resource depletion and land mismanagement associated with limited soil conservation practices. Some studies on the economics of soil conservation in developing countries have suggested incentives for farmers to adopt soil conservation by analyzing their household characteristics and the features and attributes of their farm operations (Thao, 2001; Gebremedhin and Scott, 2003). Generally, land tenure arrangements, soil characteristics, input and output prices, availability of off-farm employment, farm size, household size, discount rates, and government policies influence the use of (or refusal to use) soil conservation measures by farmers in developing countries. Rarely, however, has the influence of risk aversion for adoption of soil conservation practices been addressed. Strong empirical evidence to test the impact of risk aversion has been scarce and scattered. In practice, the major benefit that a farmer receives from soil conservation is the soil itself – a potential asset for future income.

In many cases, practical strategies to reduce soil erosion introduce economic risks that reduce their potential value. Considering the importance of risk, Yesuf and Bluffstone (2009) indicated that, in countries where poverty and environmental degradation are intertwined and credit and insurance markets are imperfect or completely absent, the critical factors affecting sustainability of resource use are the extent to which people discount the future and their willingness to undertake risky activities, such as investment decisions. This study, therefore, elicits smallholder farmers' attitudes toward risk using an experimental method and empirically examines the effects of farmers' risk preferences and other socioeconomic factors on soil conservation decisions at the farm level. Results from the experiment indicate that the estimated risk aversion is high and the majority of the farmers were found to have intermediate, severe, or extreme risk aversion. Empirical results from the multinomial logit analysis demonstrate that a high degree of risk aversion has a negative effect on adoption of labor-intensive soil conservation practices. Farmers' risk aversion increases the likelihood of non-adoption of stone terraces and soil bund practices. The results imply that, to promote soil conservation, policies that reduce farmers' risk behavior should have priority, especially those that address land tenure security and rights, access to better education and extension services, and development of income-generating off-farm activities.

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Paper I

Adoption of Multiple Sustainable Agricultural Practices in Rural Ethiopia

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Abstract

The adoption and diffusion of sustainable agricultural practices (SAPs) have 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 paper analyzes 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 modeling 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, labor availability, plot 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, to improve the adoption of SAPs.

JEL classification: Q01, Q12, Q16, Q18

Key words: Multiple adoption; sustainable agriculture practices; multivariate probit; Ethiopia

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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, 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 expansion of agricultural technologies is a key, if not the only, strategy option to increase production. The adoption and diffusion of sustainable agricultural practices (SAPs)[1] have become an important issue in the development-policy agenda for SSA (Scoones and Toulmin, 1993; Ajayi, 2007; Kassie et al., 2012), 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 organizations 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 behavior 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 emphasized for green revolution technologies (chemical fertilizer and improved seeds) and physical soil and water conservation technologies (e.g., Gebremedhin and Scott, 2003; 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

[1] The Food and Agriculture Organization (FAO, 1989) argues that sustainable agriculture consists of five major attributes: (1) it conserves resources, (2) it is environmentally non-degrading, (3) it is technically appropriate, (4) it is economically acceptable, and (5) 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 fertilizers, 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).

isolation, while 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 paper contributes to the growing adoption literature on SAPs, including, *inter alia,* Gebermedhin and Scott, 2001; Pender and Gebermedhin, 2007; Lee, 2005; Bluffstone and Köhlin, 2011; Kassie et al., 2009, 2010, 2012; Marenya and Barrett 2007, 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 recognize the interdependence between different practices and jointly analyze the decision to adopt multiple SAPs, including maize–legume rotation, conservation tillage, improved maize seed varieties (hereafter improved seed), inorganic fertilizer, and manure. Identifying the nature of interrelationships of the set of practices is relevant to the long standing debate of whether famers adopt technology in a piecemeal 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 summarizes 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 modeling would exclude useful economic information about interdependent and simultaneous adoption decisions (Dorfman, 1996). Our econometric specification is two parts: first, farmers' choice of inter-related SAPs is modeled using a multivariate probit model (MVP); second, we analyze the determinants of the extent of combinations of SAPs adopted, using pooled and random effects ordered probit models, since 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 parameterized by the mean values of plot varying covariates.[2] 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 (*ibid*). 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 modeled following a random utility formulation. Consider the i^{th} farm household $(i = 1,\ldots, N)$ facing a decision on whether or not to adopt the available SAP on plot p $(p = 1,...,P)$. Let U_0 represent the benefits to the farmer from traditional management practices, and let U_k represent the benefit of adopting the k^{th} SAP: where k denotes choice of crop rotation (R), conservation tillage (T), improved crop variety (V), inorganic fertilizer (F), and manure use (M). The farmer decides to adopt the k^{th} SAP on plot p if $Y^*_{ipk} = U^*_k - U_0 > 0$. The net benefit ($\mathrm{Y}^*_{\mathrm{ipk}}$) that the farmer derives from the adoption of k^{th} SAP is a latent variable determined by observed household, plot and location characteristics (X_{ip}) and the error term (ε_{ip}):

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

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

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

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

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 normalized to unity (for identification of the parameters) where: $(u_R, u_V, u_F, u_M, u_T) \sim MVN(0, \Omega)$ and the symmetric covariance matrix Ω is given by:

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

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 analyzing 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,[3] 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 analyze the factors that influence the adoption of a combination of practices (number of practices) as well as

[3] 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.

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 (Wollni et al., 2010). In our case, many farmers will not adopt the whole package; some apply only a mix of some SAPs 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 is usually analyzed 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 a 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 random 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)[4] 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, 3–6 PAs in each district, and 16–24 farm households in each PA were selected.

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 organizations, 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.

Dependent variables

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

The maize–legume rotation system (temporal bio-diversification) is one option for sustainable intensification that can help farmers to increase crop productivity through N 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.

Conservation tillage is part of a sustainable agricultural system, as soil disturbance is minimized 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

[4]These are the lowest administrative structure in Ethiopia.

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 fertilizer used for maize in the study areas was 43 kg N/ha and 13 kg P/ha. 67% of the maize plots received fertilizer and farmers who use fertilizer 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 fertilizer.

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.

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

Variables	Description	Mean	Std. Dev.
Household and farm characteristics			
FAMLYSZIE	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[5]	19543	50331
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			
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/labor 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	-
Stresses			
RAININDEX	Rainfall index (1= best)	0.52	0.30
PESTSTRES	1=pest and disease stress	0.12	-
WATRLOGG	1=water logging/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	

[5] 1 Birr = 0.059 USD at the time of survey.

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, particularly 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, e.g., 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 adoption decision, such as family size, age, gender, and education level of the household head and spouse. 92% of the sample households 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.

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 cart). The average walking distance to input markets is about 1 hour, and only 56%

[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".

of households use different transportation means (public transport, bicycle or donkey/horse cart) to visit the market.

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, since many non-borrowers do not borrow because they actually have sufficient liquidity from their own resources, and not because they cannot obtain credit, while 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%).

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 favorable or unfavorable 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 fertilizer and seed varieties, compared to other SAPs, such as manure, or crop rotation, that do not require cash outlays.

Government support

In Ethiopia it is common for government and international organizations to provide aid/or subsides (productive safety nets program) 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 on public support can positively influence the adoption of SAPs.

Social network/ capital

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 labor 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

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

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, labor 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., 2012). On the other hand, farmers with more relatives may have lower opportunity costs for family labour, so farmers may invest less, including in new technologies (Di Falco and Bulte, 2011).

Extension

Extension is a source of information for many farmers through contact with extension agents. Farmers' access to information through extension 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 though all five SAPs were applied in only 10 plots. Inorganic fertilizer 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 fertilizer on 3.5% of plots, and jointly with improved seed and inorganic fertilizer on 4.3% of plots. 1.6% of the plots received only the legume–maize rotation practice. Similarly, 4.3% of the plots benefited from adoption of crop rotation, improved seed, and inorganic fertilizer jointly, and 3.5% of plots jointly adopted legume–maize rotation, improved seed, inorganic fertilizer and conservation tillage.

Table 2. Joint and marginal probabilities of adoption of sustainable agricultural practices (SAPs)

	Joint	Marginal				
Percent adopting in:	probability	Rotation	Variety	Fertilizer	Manure	Tillage
Rotation only	1.58	1.58	-	-	-	-
Improved maize variety only	2.37	-	2.37	-	-	-
Inorganic fertilizer 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 fertilizer	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 fertilizer	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
Fertilizer and manure	3.52	-	-	3.52	3.52	-
Fertilizer and tillage	5.58	-	-	5.58	-	5.58
Manure and tillage	3.16	-	-	-	3.16	3.16
Rotation, improved seed, fertilizer	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, fertilizer, 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, fertilizer, manure	4.31	-	4.31	4.31	4.31	-
Improved seed, fertilizer, tillage	9.65	-	9.65	9.65	-	9.65
Fertilizer, 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, fertilizer, manure	1.40	1.40	1.40	1.40	1.40	-
Rotation, improved seed, fertilizer, tillage	3.52	3.52	3.52	3.52	-	3.52
Rotation, fertilizer, manure, tillage	0.67	0.67	-	0.67	0.67	0.67
Improved seed, fertilizer, 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

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 with inorganic fertilizer 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 fertilizer 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 fertilizer use is reduced by more than 19% when households applied manure to a plot, suggesting substitutability between manure and inorganic fertilizer.

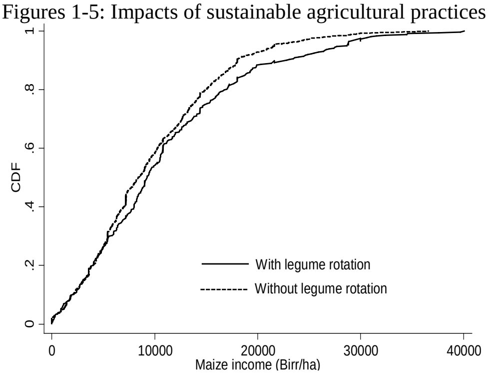
Table 3. Unconditional and conditional adoption probabilities

	Rotation	Seed	Fertilizer	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***	1	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

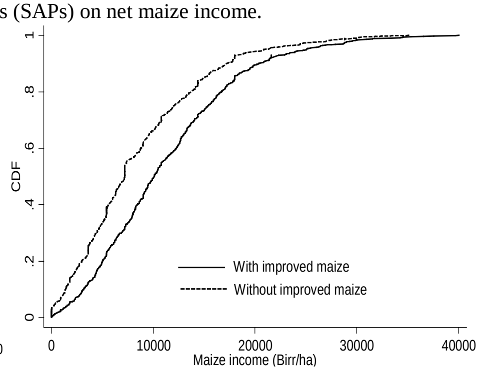
Note: Y_k is a binary variable representing the adoption status with respect to practice k (k = rotation (R), improved seed (V), fertilizer (F), manure (M), conservation tillage (T)); *, ** and *** indicate statistical significance at 10, 5 and 1%, respectively. The comparison is between unconditional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

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 production. The cumulative distribution of the net value of maize production on plots with legume rotation, chemical fertilizer, 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 1‒5) of maize net income of plots with SAPs being constantly 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.

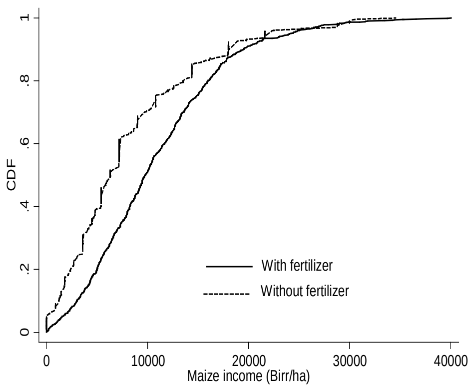
Figures 1-5: Impacts of sustainable agricultural practices (SAPs) on net maize income.



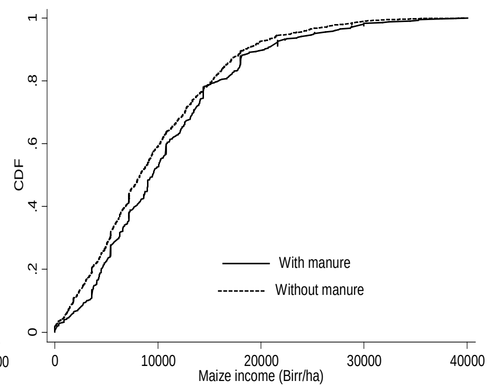
Cumulative distribution for the impact of maize‒legume rotation on maize net income. CDF = cumulative density function.



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

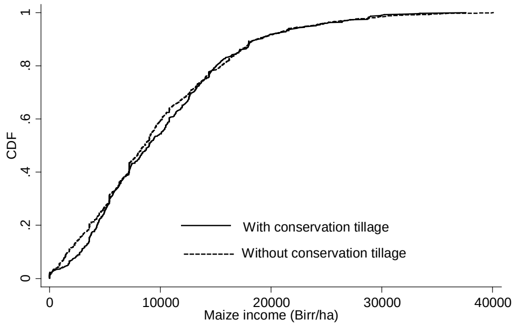


Cumulative distribution for the impact of inorganic fertilizer on maize net income. CDF = cumulative density function.



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

[10] Net of fertilizer, seed, and pesticides costs.
[11] Test result not shown in the interest of brevity.



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

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 [$\chi2(296) = 6937.74$, p = 0.000)] of the hypothesis that all regression coefficients in each equation are jointly equal to zero is rejected. As expected, the likelihood ratio test [$\chi2(10) = 111.096$, p = 0.000)] of the null hypothesis that the covariance of the error terms across equations are not correlated is also rejected (See Appendix Table 1b). This is supported by the correlation between error terms of the adoption equations reported in Table 1b. 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 fertilizer, and manure. The correlation between improved seed and inorganic fertilizer adoption is the highest (42%). On the other hand, manure is a substitute for inorganic fertilizer, crop rotation and conservation tillage. The substitution between manure and inorganic fertilizer contradicts the finding of Marenya and Barrett (2007) who found the two to be complementary for smallholder farmers in western Kenya in 2007.

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

[12] The results without Mundlak's approach are presented in the appendix Table 1a.

likelihood ratio test statistic of the null hypothesis of equal-slope coefficients is rejected (χ^2(224) = 4487.86, p = 0.000), reflecting the heterogeneity in adoption of SAPs and, consequently, supporting a separate analysis of each rather than aggregating them into a single SAP variable.

Table 4. Coefficient estimates of the multivariate probit model with Mundlak's approach

	Rotation		Improved seed		Fertilizer		Manure		Tillage	
Variables	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
MEDUMDEPT	-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 X DIST	0.01	0.02	-0.02**	0.01	0.01	0.02	-0.01	0.01	-0.01	0.01
MEDMSOL X DIST	0.01	0.02	-0.02**	0.01	0.01	0.02	-0.01	0.01	-0.01	0.01
RENTD X 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 X DIST	-0.01	0.01	0.04***	0.01	0.04***	0.01	-0.02	0.01	0.01*	0.01
MEDMSLP X 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
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
WATRLOGG	-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	
Sample size = 1616			Wald χ^2 (296) = 6937.74;			Prob. > χ^2 = 0.00				
Joint significance of mean of plot varying covariates: χ^2 (70) = 155.88;					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 EXTTILAGE.

The MVP model results reveal that the spouse's (woman's) education level has a positive impact on the adoption of inorganic fertilizers 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, modeled as a joint household decision.

The mode of transportation to output market influences the likelihood of adoption of improved seed and conservation tillage. Households which use a 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 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 costs. 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 fertilizer 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 (c.f. Marenya and Barrett, 2007). Credit constraints negatively influence investment in improved seed and inorganic fertilizers, 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 fertilizer 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 fertilizers 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

[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 the anonymous reviewer for pointing this out.

SAPs. Similarly, adoption of crop rotation and improved seed are negatively and significantly influenced by waterlogging and frost stress.

The hypothesis that social capital 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 increase 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 in order to enhance the adoption of maize technology, 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 fertilizer, probably 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 who 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 which 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 fertilizers is less likely on plots with good soil quality, while the use of manure is more likely. The propensity to adopt inorganic fertilizers 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 fertilizer adoption increases on distant flat and medium slope plots (see interaction term), suggesting a tradeoff for using inorganic fertilizers on nearby steep plots and distant flat plots. Although the use of fertilizers 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 are 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 305.9 and is statistically significant, 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 transportation to output market has a significant and negative impact on the number of SAPs adopted. Farmers who do not have their own means of transportation or access to public transport are 9% less likely to adopt more than two SAPs.

Social capital 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.

[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 (rho) 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 presented on the appendix Table 1c.

Table 5. Coefficient estimates of the ordered probit model with Mundlak's approach

Variables	Pooled ordered probit model								Random effects ordered probit model	
			Marginal effects							
	Coefficients		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	
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: $\chi^2(7)$	38.01								45.61	
Prob. $>\chi^2(7)$	(0.00)								(0.000)	
Joint significance of mean of plot varying covariates:	$\chi^2(70)$ = 24.17; Prob. $>\chi^2$ = 0.002								$\chi^2(70)$ = 20.49; Prob. $>\chi^2$ = 0.01	
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	-2143								-2079	

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, WATRLOG, SHALDEPT, MEDMDEPT, GODSOIL, MEDMSOIL, FLATSLOP, MEDMSLOP.

Household assets positively influence the adoption of more than two SAPs, where (Table 2) improved seed and inorganic fertilizer predominate in the mixes of more than two SAPs. 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 fertilizers).

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 sustainable agricultural practices is important for the reduction of hunger and poverty in Ethiopia. In this study, we analyzed the probability and level of adoption of multiple SAPs by smallholder farmers using plot-level observations. We used multivariate probit and ordered probit models to jointly analyze the adoption of multiple SAPs and the number of SAPs adopted on the plot while recognizing the inter-relationship 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 since 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., labor, 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 fertilizer) 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 fertilizer 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 programs (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; Bloam 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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Appendix

Table 1a. Coefficient estimates of the multivariate probit model without Mundlak's approach

	Rotation		Improved seed		Fertilizer		Manure		Tillage	
Variables	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
Household and farm characteristics										
EDUCATSPOUS	0.02	0.02	0.02	0.01	0.07***	0.03	-0.001	0.01	0.04**	0.02
RENTD	0.07	0.37	0.36	0.36	0.44	0.32	-0.90*	0.52	-0.06	0.35
SHALWDEPT	0.10	0.11	0.01	0.11	0.29*	0.17	0.08	0.12	0.19	0.13
MEDUMDEPT	0.18*	0.09	0.13	0.09	0.17	0.14	0.07	0.09	0.14	0.12
GOODSOL	-0.03	0.18	-0.17	0.15	-0.51***	0.21	0.36**	0.17	-0.32*	0.17
FLATSLOP	0.23	0.20	-0.13	0.18	-0.79**	0.28	0.32	0.22	0.33*	0.19
MEDMSLOP	0.10	0.21	-0.24	0.18	-0.63**	0.28	0.17	0.23	0.46***	0.19
GODSOL X DIST	0.02*	0.01	-0.02**	0.01	-0.01	0.01	-0.01	0.01	-0.001	0.01
MEDMSOL X DIST	0.02	0.01	-0.01*	0.01	-0.01	0.01	-0.01	0.01	-0.001	0.01
RENTD X GODSOL	0.14	0.40	-0.15	0.39	0.07	0.38	0.18	0.56	0.06	0.39
RENTDX MEDSOL	-0.19	0.39	-0.23	0.37	-0.02	0.38	0.59	0.55	-0.17	0.39
FLATSLP X DIST	-0.01	0.01	0.02**	0.01	0.02**	0.01	-0.01	0.01	-0.004	0.01
MEDMSLP X DIST	0.002	0.01	0.03***	0.01	0.02	0.01	-0.03*	0.02	-0.002	0.01
Market access and resource constraints										
MEANSTRANS	-0.06	0.09	-0.16**	0.08	-0.12	0.10	0.03	0.08	-0.29***	0.10
WALKDIST (10^{-2})	-0.10	0.10	-0.10*	0.10	0.01	0.10	0.01	0.10	0.20*	0.10
ASSETVALUE	0.17	0.86	1.56**	0.81	7.93***	1.96	-1.25	0.91	3.49***	1.49
OTHERINCOM	0.19**	0.09	-0.07	0.08	-0.14	0.13	0.11	0.09	-0.07	0.11
TLU (10^{-2})	0.20	0.50	-0.40	0.30	0.20	0.80	1.20***	0.50	-0.20	0.60
CREDIT	-0.08	0.10	-0.17**	0.09	-0.32**	0.17	0.04	0.15	0.02	0.12
Social capital and extensions										
RELATIVE (10^{-2})	0.50*	0.30	0.10	0.30	0.30	0.40	-0.40	0.30	1.30***	0.40
KNOWTRUST	0.02*	0.01	0.02**	0.01	0.01	0.01	0.02**	0.01	0.01	0.01
INPUTMEMBER	0.28***	0.09	0.14	0.09	0.07	0.14	-0.16	0.10	0.36***	0.12
CONFDNT	0.04	0.12	0.06	0.10	0.09	0.13	-0.05	0.09	0.23*	0.13
Stresses										
RAININDEX	0.28*	0.17	-0.23	0.15	0.43**	0.23	0.19	0.15	-0.29	0.19
PESTSTRES	0.08	0.12	0.04	0.13	-0.09	0.18	-0.03	0.12	0.23*	0.14
WATRLOGG	-0.29***	0.12	-0.08	0.10	0.09	0.16	0.01	0.10	-0.02	0.12
FROSTSTRES	-0.12	0.19	-0.43***	0.16	-0.09	0.26	-0.09	0.15	0.02	0.18
RELYGOVT	-0.06	0.09	0.25***	0.08	6.97***	0.38	-0.46***	0.09	-0.01	0.09
CONSTANT	-0.43	0.37	0.34	0.33	-0.55***	0.50	-0.63*	0.36	-0.06	0.40
Joint significance of location variables: χ^2 (7)	37.06		63.90		96.74		19.13		46.05	
Prob. > χ^2 (7)	0.00		0.00		0.00		0.01		0.00	
Sample size = 1616			Wald χ^2 (221) = 2302.48;			Prob. > χ^2 = 0.00				

*,** and *** indicate statistical difference at 10, 5 and 1%, respectively; SE = standard errors adjusted for clustering on-farm households to allow for correlation within group; other non-significant control variables include: FAMLYSIZE, SEX, AGE, EDUCATHEAD, DIST, FARMSIZE, MEDMSOL, EXTMAZLEG, EXTPEST, EXTROTAT EXTTILAGE.

Table 1b. Estimated covariance matrix of the multivariate probit model (MVP) regression between sustainable agricultural practices (SAPs)

	ρ_R	ρ_V	ρ_F	ρ_M
ρ_V	0.12 (0.04)***			
ρ_F	0.09 (0.06)	0.42 (0.06)***		
ρ_M	-0.09 (0.05)**	-0.11 (0.05)***	-0.38 (0.05)***	
ρ_T	0.03 (0.05)	-0.02 (0.05)	0.06 (0.06)	-0.09 (0.05)*

Likelihood ratio test of: $\rho_{RV} = \rho_{RF} = \rho_{RM} = \rho_{RT} = \rho_{VF} = \rho_{VM} = \rho_{VT} = \rho_{FM} = \rho_{FT} = 0$

$\chi^2(10) = 111.09$

Prob> 0.00

*,** and *** indicate statistical significance at 10, 5 and 1%, respectively; numbers in parentheses are the standard errors.

Table 1c. Coefficient estimates of the ordered probit model without Mundlak's approach

Variables	Pooled ordered probit model								Random effects ordered probit model	
			Marginal effects							
	Coefficients		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	
FAMLYSIZE (10^{-2})	2.50*	(1.40)	-0.20*	-0.60*	-0.10	0.60*	0.30*	0.02	3.60**	(1.80)
AGE (10^{-2})	-0.50*	(0.30)	0.05*	0.10*	0.01	-0.10*	-0.10*	0.01	-0.70*	(0.40)
EDUCATSPOUS (10^{-2})	4.00***	(1.00)	-0.30***	-1.00***	-0.10*	1.00***	0.40***	0.03**	4.00***	(1.00)
MEANSTRANS	-0.5*	(0.07)	0.02***	0.06***	0.01	-0.06***	-0.03***	-0.002**	-0.32***	(0.09)
RELATIVE (10^{-2})	0.70***	(0.30)	-0.10***	-0.20***	-0.02*	0.20***	0.10***	0.01**	0.80**	(0.30)
KNOWTRUST (10^{-2})	2.10***	(0.70)	-0.20***	-0.50***	-0.10*	0.50***	0.20***	0.02**	2.50***	(0.80)
INPUTMEMBER	0.30***	(0.09)	-0.02***	-0.07***	-0.02**	0.07***	0.04***	0.003**	0.43***	(0.11)
EXTROTAT (10^{-2})	1.70***	(0.70)	-0.10**	-0.40***	-0.04	0.40***	0.20***	0.01**	1.80**	(0.90)
ASSETVALUE (10^{-6})	2.27***	(0.69)	-0.19***	-0.54***	-0.06*	0.53***	0.24***	0.02**	3.01***	(0.89)
FROSTSTRES	-0.23**	(0.11)	0.02*	0.06**	-0.003	-0.05**	-0.02**	-0.002**	-0.23*	(0.14)
RELYGOVT	0.55***	(0.07)	-0.05***	-0.13**	-0.02***	0.13***	0.06***	0.01***	0.86***	(0.09)
DIST (10^{-2})	-0.20*	(0.10)	0.01*	0.04*	0.004	-0.04*	-0.02*	-0.002	-0.30**	(0.10)
RENTD (10^{-2})	-1.70	(7.90)	0.20	0.40	0.04	-0.40	-0.20	0.02	-16.10*	(9.50)
SHALDEPT	0.20**	(0.09)	-0.02***	-0.05**	-0.01	0.05	0.02**	0.002*	0.25**	(0.12)
MEDMDEPT	0.21***	(0.08)	-0.02***	-0.05***	-0.01*	0.05***	0.02***	0.002**	0.24**	(0.09)
GODSOIL	-0.19*	(0.11)	0.02*	0.05*	0.004	-0.05*	-0.02**	-0.002	-0.19	(0.14)
MEDMSOIL	-0.22**	(0.11)	0.02**	0.05**	0.01	-0.05**	-0.02**	-0.002*	-0.22	(0.14)
FLATSLOP	0.18	(0.15)	-0.02	-0.04	-0.003**	0.04	0.02	0.001	0.18	(0.18)
MEDMSLOP	0.14	(0.15)	-0.01	-0.03	-0.01**	0.03	0.02	0.001	0.16	(0.17)
Joint significance of location variables: $\chi^2(7)$	40.86								49.23	
Prob. $> \chi^2(7)$	(0.00)								(0.00)	
μ_1	-1.76***	(0.29)							-2.33***	(0.37)
μ_2	-0.66**	(0.29)							-0.91**	(0.36)
μ_3	0.49*	(0.29)							0.56	(0.36)
μ_4	1.56***	(0.29)							1.92***	(0.36)
μ_5	2.74***	(0.32)							3.44***	(0.39)
Log-likelihood	-2154								-2089	

*, ** 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: SEX, EDUCATHEAD, WALKDIST, EXTMAZLEG, EXTPEST, EXTTILAGE, CONFDNT, FARMSIZE, OTHERINCOM, TLU, CREDIT, RAININDEX, PESTSTRES, WATRLOG.

Paper II

Cropping Systems Diversification, Conservation Tillage and Modern Seed Adoption in Ethiopia: Impacts on Household Income, Agrochemical Use and Demand for Labor

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Abstract

The type and combination of sustainable agricultural practices (SAPs) adopted has a significant effect on agricultural productivity and food security. Previous studies on adoption and impact have focused on single practices. However, in reality several adoption decisions are made simultaneously. We developed a multinomial endogenous switching regression model of farmers' choice of combination of SAPs and impacts on maize income and use of agrochemicals and family labor use in rural Ethiopia and found four primary results. First, adoption of SAPs increases maize income and the highest payoff is achieved when SAPs are adopted in combination rather than in isolation. Second, nitrogen fertilizer use is lower in the package that contains systems diversification and conservation tillage. Third, conservation tillage increased pesticide application and labor demand, perhaps to compensate for reduced tillage. However, when it is used jointly with systems diversification, it does not have a significant impact on pesticide and labor use. Fourth, since women contribute much of the farm labor needed for staple crops, adoption of packages increases their workload, in most cases, suggesting that agricultural intensification technology interventions may not be gender neutral. This implies that policy makers and other stakeholders promoting a combination of technologies can enhance household food security through increasing income and reducing production costs, but need to be aware of the potential gender related outcomes.

JEL classification: *Q01, Q12, Q57*

Keywords: Agrochemical use, demand for labor, Ethiopia, income, multinomial switching regression, sustainable agricultural practices

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1. Introduction

The major challenge facing sub-Saharan African (SSA) governments today is how to achieve food security and reduce poverty, while simultaneously mitigating degradation of essential ecosystem services. Most attention has been given to the low and stagnant returns from African agriculture (World Bank, 2007; Bluffstone and Köhlin, 2011). However, many ecosystem services, including nutrient cycling, nitrogen fixation, soil regeneration, and biological control of pests and weeds, are under threat in key African food production systems that are vital for sustainable food security. Declining fallow periods and a strong trajectory away from diversification in favor of mono-cropping, in otherwise traditionally complex farming systems, and inadequate investment in sustainable intensification are among the causes of environmental degradation in SSA (Pretty, 1999; Lee, 2005; Woodfine, 2009; Snapp et al. 2010; Jhamtani, 2011). These trends have contributed to the low agricultural productivity and food insecurity in SSA and will continue to do so at an accelerating rate under anticipated climate change.

Unfortunately, there is thus a risk of a trade-off between the attempts to increase the productivity in African agriculture through "modernization packages" that combine improved seed varieties with agrochemicals and the resulting stress that these have on ecosystem services. The loss of ecosystem services can in turn have implications on the use of agrochemicals (such as chemical fertilizers and pesticides) and on the demand for on-farm labor. Regulation of the occurrence of pests and diseases under increasingly simplified mono-cropping systems requires increased use of external inputs. For example, weed and pest populations previously controlled by natural ecosystem services now require the use of pesticides (Fuglie, 1999; Knowler and Bradshaw, 2007) and/or there is an increased labor demand for their control. If not properly used, agrochemicals can cause significant harm to the environment and human health.

It is in this context that Sustainable Agricultural Practices (SAPs)[1] are considered as strategies that can increase productivity but in a way that is sustainable by addressing the degradation of ecosystem services, and increasing resilience and adaptation of smallholder

[1] We define SAPs for agricultural intensification and productivity growth in farming systems more broadly to include conservation tillage (zero or reduced tillage), cropping bio-diversification (legume intercropping and crop rotations), improved crop varieties, use of animal manure, complementary use of organic fertilizers, and investment in soil and water conservation (Lee, 2005; Kassie et al. 2010; Wollni et al. 2010; Pretty et al. 2011; FAO, 1989).

farmers to climate variability and change (Antle and Diagana, 2003; Lee, 2005; Woodfine, 2009; Pretty et al. 2011).

This paper will analyze the application of various combinations of three SAPs. The first one is bio-diversification (maize–legume rotation) that performs and provides many ecosystem services including N fixation and C sequestration, breaking the life cycle of pests, smoothing out impacts of price fluctuations, and improving weed suppression (Liebman and Dyck, 1993; Altieri, 1999; Tilman et al. 2002; Woodfine, 2009; Snapp et al. 2010; Jhamtani, 2011). This can save farmers the cost of buying fertilizer and pesticides, which contributes to the mitigation of climate change. Bio-diversification enables farmers to grow products that can be harvested at different times and spaces and that have different weather or environmental stress-response characteristics. These varied outputs and degrees of resilience are a hedge against the risk of drought, extreme or unseasonal temperatures, rainfall variations and price fluctuations that affect the productivity and income of smallholder systems.

The second SAP is adoption of conservation tillage that can lead to substantial ecosystem services benefits by reducing soil erosion and nutrient depletion and conserving soil moisture (Fuglie, 1999; Tilman et al. 2002; Woodfine, 2009).

The third SAP considered is the introduction of modern crop varieties (Lee, 2005). In our case, the improved maize varieties used are primarily intended to increase yields, mostly augmented with fertilizer and pesticides, thus addressing food security and income needs (Bellon and Taylor, 1993; Fernandez, 1996). Important as it may be, in the future adoption of improved crop varieties is likely to be an important strategy to also adapt to climate change.

In this paper, we jointly analyze adoption of a combination of these SAPs and their impacts on income and agrochemical use. Specifically, the paper focuses on the following objectives: a) Analyze the factors motivating the adoption of a combination of SAPs (i.e., bio-diversification, conservation tillage and modern maize seed) in the maize–legume farming system of Ethiopia; and b) Examine the implications of adopting various combinations of these practices on selected outcome variables; more specifically maize net income[2], use of agrochemicals such as N fertilizer and pesticides (insecticides and herbicides) and demand for agricultural female and

[2] It is the net of fertilizer, seed, and pesticide costs. Labor is another important factor cost but since very little labor is traded in our sample households we chose to address the implications on male and female labor use as a separate evaluation criterion.

male labor by controlling for selection bias using multinomial endogenous switching treatment effects approach.

Despite the multiple benefits of SAPs and considerable efforts by national and international organizations to encourage farmers to invest in them, there is lack of evidence on farmers' incentives and conditioning factors that hinder or accelerate adoption of inter-related SAPs. An improved understanding of farmers' adoption behavior and the potential economic and agrochemical use implications associated with adoption of these practices is therefore important for sustainable intensification in the region.

The paper adds value to existing literature on adoption analysis and impacts of a technology in the following ways. First, we investigate –for the first time to our knowledge– whether adoption of SAPs in combination will provide more economic benefits and regulate agrochemical use than adopting them individually. This knowledge is relevant to the debate on whether farmers adopt technologies piecemeal or in a package and it is also valuable for designing effective extension policy by identifying a combination of technologies that deliver the highest pay off. Most previous adoption studies (e.g., Gebremedhin and Scott, 2003; Kassie et al. 2010; 2011) have focused on analysis of a single SAP using single equation models (e.g., probit, logit), although farmers are faced with technology alternatives that may be adopted simultaneously as complements, substitutes or supplements to deal with their overlapping constraints such as weeds, pest and disease infestations, and low soil fertility and crop productivity (Dorfman, 1996; Khanna, 2001, Moyo and Veeman, 2004). They also ignore the possibility of a path or state of dependence: the choice of technologies adopted more recently by farmers may be partly dependent on earlier technology choices (Wu and Babock, 1998; Khanna, 2001). Adoption and impact analysis of technologies while ignoring their inter-relationships may underestimate or overestimate the influence of various factors on adoption and impacts of adoption (Wu and Babcock, 1998). Modeling technology adoption and impact analysis in a multiple technology choice framework is therefore important to capture useful economic information contained in interdependent and simultaneous adoption decisions (Dorfman, 1996).

Second, our analysis uses comprehensive household and plot-level survey data covering major maize growing regions in Ethiopia. This has allowed us to include several policy relevant variables (e.g., governance indicators, kinship, rainfall and pest and disease shocks, and farmers' expectations on social safety nets or social insurance during crop failure) that determine SAP adoption and outcome variables that were not considered in previous studies. Third, we contribute to the scant empirical evidence on the impacts of SAP adoption on agrochemical and labor use.

2. Conceptual and Econometric framework

In a multiple adoption setting, farmers' adoption of bio-diversification, conservation tillage and an improved maize variety jointly leads to eight (2^3) possible SAP combinations that a farmer could choose. The actual choice is expected to be based on his expected utility of adoption, given his/her constraints. We model framers' choice of SAP packages (i.e., alternative combinations of bio-diversification, conservation tillage and modern maize seed) and outcome variables (maize net income per hectare, agrochemical use and female and male labor demand) in a setting of multinomial endogenous switching regression framework.

Farmers endogenously self-select themselves into adoption/non-adoption decisions, so decisions are likely influenced by unobservable characteristics (for example expectation of yield gain from adoption, managerial skills, motivation) that may be correlated with the outcomes of interest. This requires a selection correction estimation method. We apply a multinomial endogenous switching regression (ESR) treatment effects approach following Dubin and McFadden (1984) (hereafter, DM model) and Bourguignon et al. (2007) to correct selection bias. This framework has the advantage in that it evaluates alternative combinations of practices as well as individual practices. It also captures both self-selection bias and the interactions between choices of alternative practices (Mansur et al. 2008; Wu and Babcock, 1998).

In the first stage, farmers' choice of combinations/packages[3] of SAPs is modeled using a multinomial logit selection model[4], while recognizing the inter-relationship among them. In the second stage of the estimation, the impacts of each combination of SAPs on outcome variables are evaluated using ordinary least squares (OLS) with selectivity correction.

2.1. Multinomial adoption selection model

[3] Combination and package are used interchangeably.

[4] Bourguignon et al. (2007) using Monte-Carlo experiments show that selection bias correction based on the multinomial logit model can provide good correction for the outcome equation, even when the IIA (Independent and Irrelevant Alternative) hypothesis is violated.

We assume that farmers aim to maximize their utility U_i by comparing the utility provided by m alternative packages. The requirement for farmer i to choose any package j, over any alternative package m, is that $U_{ij} > U_{im}$ $m \neq j$, or equivalently $\Delta U_{im} = U_{ij} - U_{im} > 0$ $m \neq j$. The expected utility (U_{ij}^*) that the farmer derives from the adoption of package j is a latent variable determined by observed household, plot and location characteristics (X_i) and unobserved characteristics (ε_{ij}):

$$U_{ij}^* = X_i \beta_j + \varepsilon_{ij}, \tag{1}$$

where X_i is observed exogenous variables (household, plot and location characteristics) and ε_{ij} is unobserved characteristics. The farmer's utility from choosing an alternative package is not observable but the package adoption decision is. Let (I) be an index that denotes the farmer's choice of package, such that:

$$I = \begin{cases} 1 \text{ iff } U_{i1}^* > \max\limits_{m \neq j}(U_{im}^*) \text{ or } \eta_{i1} < 0 \\ \vdots \quad\quad \vdots \quad\quad\quad\quad \vdots \\ J \text{ iff } U_{iJ}^* > \max\limits_{m \neq J}(U_{im}^*) \text{ or } \eta_{iJ} < 0 \end{cases} \quad \text{for all } m \neq j \tag{2}$$

where $\eta_{ij} = \max\limits_{m \neq j}(U_{im}^* - U_{ij}^*) < 0$ (Bourguignon et al. 2007). Equation (2) implies that the i^{th} farmer will adopt package j to maximize his expected utility if package j provides greater expected utility than any other package $m \neq j$, that is if $\eta_{ij} = \max\limits_{m \neq j}(U_{im}^* - U_{ij}^*) < 0$.

Assuming that ε are identically and independently Gumbel distributed, the probability that farmer i with characteristics X will choose package j can be specified by a multinomial logit model (McFadden, 1973):

$$P_{ij} = \Pr(\eta_{ij} < 0 \mid X_i) = \frac{\exp(X_i \beta_j)}{\sum_{m=1}^{J} \exp(X_i \beta_m)}. \tag{3}$$

The parameters of the latent variable model can be estimated by maximum likelihood.

In the second stage of multinomial ESR, the relationship between the outcome variables and a set of exogenous variables Z (plot, household and location characteristics) is estimated for the chosen package. In our SAPs specification (Table 1), the base category, non-adoption of SAP (i.e., $R_0V_0T_0$) is denoted as *j*=1 and at least one SAP is used in the remaining packages (j=2, . . .,8). The outcome equation for each possible regime *j* is given as:

$$\begin{cases} \text{Regime } 1: Q_{i1} = Z_i\alpha_1 + u_{i1} \quad \text{if } I = 1 \\ \vdots \qquad\qquad \vdots \\ \text{Regime J}: Q_{iJ} = Z_i\alpha_J + u_{iJ} \quad \text{if } I = J \end{cases} \tag{4}$$

where $Q_{ij}'s$ are the outcome variables of the i^{th} farmer in regime *j*, and the error terms $(u's)$ are distributed with $E(u_{ij}|X,Z)=0$ and $\text{var}(u_{ij}|X,Z)=\sigma_j^2$. Q_{ij} is observed if, and only if, package *j* is used, which occurs when $U_{ij}^* > \max_{m\neq j}(U_{im}^*)$. If the ε's and u's are not independent, OLS estimates in (4) will be biased. A consistent estimation of α_j requires inclusion of the selection correction terms of the alternative choices in (4). The DM model assumes the following linearity assumption:

$$E(u_{ij} \mid \varepsilon_{i1}...\varepsilon_{iJ}) = \sigma_j \sum_{m\neq j}^{J} r_j(\varepsilon_{im} - E(\varepsilon_{im})),$$

With $\sum_{m=1}^{J} r_j = 0$ (by construction the correlation between $u's$ and $\varepsilon's$ sum to zero). Using this assumption the equation of the multinomial endogenous switching regression in (4) is specified as:

$$\begin{cases} \text{Regime } 1: Q_{i1} = Z_i\alpha_1 + \sigma_1\hat{\lambda}_1 + \omega_{i1} \quad \text{if } I = 1 \\ \vdots \qquad\qquad \vdots \\ \text{Regime J}: Q_{iJ} = Z_i\alpha_J + \sigma_J\hat{\lambda}_J + \omega_{iJ} \quad \text{if } I = J \end{cases} \tag{5}$$

Where σ_j is the covariance between ε's and u's, λ_j is the inverse Mills ratio computed from the estimated probabilities in (3) as follow:

$\lambda_j = \sum_{m\neq j}^{J} \rho_j \left[\frac{\hat{P}_{im}\ln(\hat{P}_{im})}{1-\hat{P}_{im}} + \ln(\hat{P}_{ij}) \right]$; ρ is the correlation coefficient of ε's and u's and ω's are error terms with an expected value of zero. In the multinomial choice setting, there are J-1 selection correction terms, one for each alternative package. The standard errors in (5) are bootstrapped to account for the heteroskedasticity arising from the generated regressor (λ_j).

2.2. Estimation of average treatment effects

The above framework can be used to examine the average treatment effect (ATT) by comparing the expected outcomes of adopters with and without adoption. The challenge in impact evaluation using observational data is to estimate the counterfactual outcome, the outcome the adopters could have earned had they not adopted the packages. The expected outcome for adopters had they not adopted the packages, is a counterfactual outcome. Following Carter and Milon (2005) and Di Falco and Veronesi (2011), we compute the ATT in the actual and counterfactual scenarios as follow; [5]

Adopters with adoption (actual adoption observed in the sample):

$$\begin{cases} E(Q_{ij} \mid I=2) = Z_i\alpha_j + \sigma_j\lambda_j & \text{(6a)} \\ \vdots \qquad\qquad\qquad \vdots & \\ E(Q_{iJ} \mid I=J) = Z_i\alpha_J + \sigma_J\lambda_J & \text{(6b)} \end{cases}$$

Adopters, had they decided not to adopt (counterfactual):

$$\begin{cases} E(Q_{i1} \mid I=2) = Z_i\alpha_1 + \sigma_1\lambda_j & \text{(7a)} \\ \vdots \qquad\qquad\qquad \vdots & \\ E(Q_{i1} \mid I=J) = Z_i\alpha_1 + \sigma_1\lambda_J & \text{(7b)} \end{cases}$$

These expected values are used to derive unbiased estimates of the ATT. The ATT is defined as the difference between (6a) and (7a) or (6b) and (7b). For instance, the difference between (6a) and (7a) is given as:

$$ATT = \mathrm{E}\,[Q_{ij} \mid I=2] - E[Q_{i1} \mid I=2] = Z(\alpha_j - \alpha_1) + \lambda_j(\sigma_j - \sigma_1) \qquad (8)$$

The first term on the right hand side of equation (8) represents the expected change in adopters' mean outcome, if adopters' characteristics had the same return as non-adopters, i.e., if adopters had the same characteristics as non-adopters. The second term (λ_j) is the selection term that captures all potential effects of difference in unobserved variables.

3. Data description and empirical specification

The data set used for this study is based on a farm household survey in Ethiopia conducted during October–December 2010 by the Ethiopian Institute of Agricultural Research (EIAR) in collaboration with the International Maize and Wheat Improvement Center (CIMMYT). The

[5] The effect of treatment on untreated (ATU) can also be computed using this framework; however, we did not report this to save space.

sample contains 900 farm households and about 1,644 farming plots. A multistage sampling procedure was employed to select peasant associations (PAs)[6] from each district and households from each of the PAs. First, based on their maize–legume production potential, nine districts from the three (Amhara, Oromia and SNNRP) regional states of Ethiopia were selected. Second, based on proportionate random sampling, 3–6 PAs in each district, and 16–24 farm households in each PA were selected.

The SAPs considered in this study include bio-diversification (maize-legume rotation), conservation tillage and improved maize seeds. Adoption of these practices provides eight possible combinations of SAPs. Table 1 presents the proportions of maize area cultivated under SAPs packages. Of the 1,644 maize plots, about 25% did not receive any of the SAPs ($R_0V_0T_0$); while all three practices were jointly adopted on 5.4% of the plots ($R_1V_1T_1$).

Table 1. Sustainable agricultural practices (SAPs) packages used on maize plots

Choice (j)	Binary triplet (Package)	Bio- diversification (R)		Improved variety (V)		Conservation tillage (T)		Frequency (%)
		R_1	R_0	V_1	V_0	T_1	T_0	
1	$R_0V_0T_0$		√		√		√	25.40
2	$R_1V_0T_0$	√			√		√	5.43
3	$R_0V_1T_0$		√	√			√	24.79
4	$R_0V_0T_1$		√		√	√		12.03
5	$R_1V_1T_0$	√		√			√	8.00
6	$R_1V_0T_1$	√			√	√		4.46
7	$R_0V_1T_1$		√	√		√		14.47
8	$R_1V_1T_1$	√		√		√		5.43

Note: The binary triplet represents the possible SAPs combinations (package). Each element in the triplet is a binary variable for a SAP/rotation/bio-diversification (R), improved variety (V), conservation tillage (T)/, where the subscript refers 1 = adopted and 0 = otherwise.

Table 2 shows the interdependence of SAPs packages. Maize–legume rotation is practiced on about 23% of the plots. Maize is often rotated with legumes such as haricot bean and soybeans. Sampled farmers used conservation tillage on about 36.3% of plots. Conservation tillage in our study refers to either reduced tillage (only one pass) or zero tillage together with letting the residue remain on the plot. Improved maize variety is adopted on 53% of the maize plots. The sample unconditional and conditional probabilities presented in Table 2 highlight the existence of interdependence across the three SAPs. For instance, the conditional probability of household adopting conservation tillage and modern maize seeds is increased from 36% to 50%

[6] PA is the lowest administrative structure in Ethiopia.

and from 53% to 58%, respectively, when farmers adopt bio-diversification. The result indicates complementarity between the adoption of bio-diversification, conservation tillage, and modern maize varieties.

Table 2. The unconditional and conditional probabilities of sustainable agricultural practices (SAPs) adoption (%)

	Bio-diversification (R)	Conservation tillage (T)	Modern maize seeds (V)
$P(Y_k = 1)$	23.3	36.4	52.5
$P(Y_k = 1 \mid Y_R = 1)$	100.0	49.5**	57.6**
$P(Y_k = 1 \mid Y_T = 1)$	27.1**	100.0	54.8
$P(Y_k = 1 \mid Y_V = 1)$	25.5*	38.0	100.0
$P(Y_k = 1 \mid Y_R = 1, Y_T = 1)$	100.0	100.0	54.9
$P(Y_k = 1 \mid Y_R = 1, Y_V = 1)$	100.0	40.5	100.0
$P(Y_k = 1 \mid Y_T = 1, Y_V = 1)$	27.1**	100.0	100.0

Note: Y_k is a binary variable representing the adoption status with respect to choice k (k = bio-diversification (R), conservation tillage (T) and modern maize seeds (V)); *, ** and *** indicate a statistically significant difference at 10, 5 and 1%, respectively. The comparison is between unconditional probability and conditional probabilities in each SAP.

A description and summary statistics of explanatory variables for the eight sub-groups of observation are presented in Table 3. The specification of our empirical model is based on a review of theoretical work and previous similar empirical adoption and impact studies (D'Souza et al. 1993; Fuglie, 1999; Neill and Lee, 2001; Lee, 2005; Bandiera and Rasul, 2006; Knowler and Bradshaw, 2007; Kassie et al. 2010, 2011; Wollni et al. 2010; Kasem and Thapa, 2011). According to this literature, factors affecting adoption and our outcome variables include farm characteristics (soil depth, slope, fertility, plot distance to dwelling), social capital, governance and information (membership in farmers' association, number of traders farmers know in their vicinity, number of blood relatives in and outside the village, extension contact, household confidence in skill of extension workers), shocks and social insurance (self-reported rainfall shocks, plot level crop production disturbances and farmers' reliance on government support during crop failure), resource constraints and market access (farm size/livestock, farm equipment ownership, distance to main market and input dealers, and access to credit), household characteristics (family size, household head education, spouse education, gender, and age), and geographic location (district dummies).

Table 3. Definitions and summary statistics (average) of the variables used in the analysis

Variables	Variable description	Package of sustainable agricultural practices (SAPs)								All	
		$R_0V_0T_0$	$R_1V_0T_0$	$R_0V_1T_0$	$R_0V_0T_1$	$R_1V_1T_0$	$R_1V_0T_1$	$R_0V_1T_1$	$R_1V_1T_1$	Mean	SD
	Household characteristics										
FAMLYSZIE	Family size (number)	6.70	6.22*	7.02**	6.87	6.39	6.33	7.14**	7.43**	6.85	2.82
MALEHEAD	1= if the head is male	0.89	0.90	0.95***	0.91	0.94	0.86	0.92	0.90	0.92	-
AGE	Age of the head	42.58	41.28	40.67**	41.80	39.42***	42.15	43.49	39.24**	41.64	13.34
EDUCATHEAD	Years of education of the head	3.23	3.79*	3.52	2.99	3.79**	3.30	3.74**	3.24	3.43	3.43
EDUCATSPOUS	Years of education of the spouse	1.08	1.74***	1.22	1.19	1.80***	1.49**	2.17***	1.36	1.42	2.85
	Resource constraints and market access										
FARMSIZE	Farm size, ha	1.88	1.92	2.10	2.07	1.80	1.80	2.40**	1.82	2.00	2.48
ASSETVALUE	Total value of assets, '000 ETB	15.49	12.18*	16.19	19.90**	18.23	23.09**	29.79***	32.17***	19.64	50.48
OTHERINCOM	1= the household earns other income and transfers	0.66	0.82**	0.66	0.59*	0.66	0.67	0.59**	0.69	0.65	-
TLU	Livestock herd size (in tropical livestock unit)	5.17	4.23*	5.71***	5.51	5.39	5.21	5.59**	5.32	5.54	6.05
CREDIT	1=credit constrained (credit is needed but unable to obtain)	0.32	0.33	0.28	0.29	0.24*	0.21**	0.23**	0.30	0.28	-
MEANSTRANS	1=walking to market as means of transportation	0.49	0.49	0.52	0.43	0.41	0.40	0.28***	0.29***	0.44	-
WALKMKT	Walking distance to village markets, minutes	27.96	19.06**	29.01	28.37	22.44*	20.47**	30.11	24.49	27.13	37.31
WALKINPUT	Walking distance to input markets, minutes	61.80	54.58	59.95	63.14	55.51	62.96	57.39	57.67	59.30	55.75
	Social capital, governance and information										
TOTALMEMBER	Number of associations the household belongs to	2.13	1.91**	2.03*	2.16	2.06	2.18	1.91***	2.11	2.06	1.07
INPUTMEMBER	1= member of input/seed/marketing cooperatives	0.18	0.15	0.21	0.25**	0.32***	0.25	0.36***	0.35***	0.25	-
RELATIVE	Number of relatives living inside and outside the village	8.54	9.66	10.29***	11.48***	10.23**	11.86***	9.68*	13.39***	10.10	11.36
TRUSTTRADER	Number of grain traders that farmers know and trust	1.95	2.98***	2.78***	2.31*	3.02***	2.40	2.40**	2.44**	2.46	4.01
FREQEXTCONT	Frequency of extension contact, days/year	14.47	18.38	16.57	19.35	13.27	16.74	18.55	18.35	16.64	43.59
CONFDNT	1=confident with skills of extension workers	0.78	0.88**	0.83*	0.83	0.78	0.78	0.81	0.90***	0.82	-
	Shocks and social insurance										
RAININDEX	Rainfall index (1= best)	0.48	0.57**	0.50*	0.54***	0.59***	0.54**	0.55***	0.53*	0.52	0.30
PESTSTRES	1=pest and disease stress	0.07	0.12	0.09	0.14***	0.15***	0.18***	0.18***	0.12	0.12	-
WATRLOGG	1=water logging/drought stress	0.30	0.16***	0.25	0.19***	0.14***	0.18**	0.18***	0.20*	0.22	-
FROSTSTRES	1=frost/hailstorm stress	0.08	0.10	0.06	0.11	0.03*	0.05	0.04*	0.02*	0.06	
RELYGOVT	1=rely on government support in case of crop failures	0.38	0.34	0.55***	0.34	0.37	0.37	0.36	0.46	0.42	-
	Plot characteristics										
PLOTDIST	Plot distance from home, minutes	11.86	6.82**	12.91	8.37**	10.04	12.08	11.99	10.90	11.33	27.50
RENTD	1=rented plot	0.11	0.18*	0.19***	0.11	0.18**	0.11	0.15	0.11	0.15	-
SHALDEPT	1=shallow depth of soil[a]	0.17	0.26*	0.15	0.23*	0.15	0.32***	0.22	0.31***	0.20	-
MEDMDEPT	1=medium depth of soil	0.36	0.37	0.48***	0.50***	0.47**	0.44	0.47***	0.48**	0.44	-
GOODSOIL	1=good soil quality[b]	0.44	0.39	0.36**	0.41	0.47	0.44	0.32***	0.44	0.40	-
MEDMSOIL	1=medium soil quality	0.50	0.54	0.56	0.49	0.44	0.44	0.54	0.48	0.51	-
FLATSLOP	1=flat plot slope[e]	0.67	0.71	0.62	0.53***	0.69	0.63	0.55***	0.54**	0.62	-
MEDMSLOP	1=medium plot slope	0.28	0.27	0.31	0.42***	0.26	0.30	0.41***	0.42***	0.33	-
MANURE	1=manure was applied in the plot	0.33	0.28	0.26**	0.34	0.25*	0.26	0.18**	0.21**	0.27	-
N	Number of observations	422	89	404	197	131	73	239	89	1644	

Note: *, ** and *** denote failure to accept the null hypothesis of equal means or proportional between each package of SAPs and $R_0V_0T_0$ at 10%, 5% and 1%, respectively; SD – standard deviation; [a]1 ETB ≈ 0.058 USD at the time of the survey. [a]Farmer ranked each plot as "deep", "medium deep" or "shallow"; [b]the farmer ranked each plot as "poor", "medium" or "good"; [e]the farmer ranked each plot as "flat", "medium slope" or steep slope".

We focus on describing those variables that are not common in the adoption and impact literature. A detailed description and hypothesis of these variables is available in Kassie et al. (2012) and Teklewold et al. (forthcoming).

The rainfall disturbance variable is based on respondents' subjective rainfall[7] satisfaction in terms of timeliness, amount and distribution. The individual rainfall index was constructed to measure the farm-specific experience related 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 favorable or unfavorable rainfall outcomes, and averaged over the number of questions asked (five questions) so that the best outcome would be equal to one and the worst equal to zero. Plot-level disturbance is captured by the following most common stresses affecting crop production: attacks by pests and diseases, water logging and drought, and frost and hailstorm stress.

In this study, credit-constrained farmers are defined as those who need credit but are unable to get it (30%). Accordingly, credit-unconstrained farmers are those who do not need credit (40%) as well as those who need it and are able to get it (30%).

We also control for the possible role of farmers' perception of government assistance, by including a dummy variable taking the value of one if the farmer think that they can rely on government support during crop failure. We distinguish three social networks and capital: a household's relationship with rural institutions in the village; a household's relationship with trustworthy traders; and a household's kinship network. Such 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, labor sharing, the relaxing of liquidity constraints, and mitigation of risks.

4. Empirical results

4.1. Factors explaining adoption of package of SAPs

The results from the multinomial logit model are presented in Table 4. [8] The base category is non-adoption ($R_0V_0T_0$) where results are compared.

[7] Actual rainfall data are preferable but reliable in season village-specific data in most developing countries, including Ethiopia, are scarce.

[8] The model is estimated using the stata selmlog routine (Bourguignon et al. 2007).

Table 4. Parameter estimates of packages of sustainable agricultural practices (SAPs) adoption-multinomial logit selection model

Variables	$R_1V_0T_0$		$R_0V_1T_0$		$R_0V_0T_1$		$R_1V_1T_0$		$R_1V_0T_1$		$R_0V_1T_1$		$R_1V_1T_1$	
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE.	Coefficient	SE	Coefficient	SE	Coefficient	SE
Household characteristics														
log(FAMLYSIZE)	-0.196	0.386	0.261	0.293	0.209	0.329	-0.161	0.421	0.167	0.481	0.255	0.367	1.566***	0.514
log(AGE)	0.455	0.483	-0.264	0.312	-0.441	0.445	-0.427	0.472	-0.055	0.554	0.311	0.467	-1.367*	0.714
log(EDUCATSPOUS)	0.156	0.197	0.011	0.129	-0.001	0.174	0.088	0.186	0.186	0.208	0.452**	0.187	-0.029	0.206
Resource constraints and market access														
log(FARMSIZE)	-0.146	0.249	0.101	0.140	0.320**	0.152	-0.219	0.169	-0.049	0.198	0.192	0.163	-0.396**	0.190
log(OTHERINCOM)	0.751**	0.336	0.180	0.183	0.145	0.251	0.162	0.275	0.511	0.344	-0.063	0.238	0.435	0.394
CREDIT	-0.032	0.322	-0.336*	0.203	0.082	0.268	-0.476	0.323	-0.377	0.384	-0.175	0.293	-0.087	0.361
MEANSTRANS	0.694**	0.334	0.323*	0.192	-0.018	0.281	0.065	0.295	-0.003	0.330	-0.860***	0.278	-0.432	0.373
log(WALKMKT)	-0.296***	0.108	-0.041	0.065	0.070	0.087	-0.170*	0.099	-0.060	0.117	0.113	0.081	-0.061	0.112
Social capital and extensions														
INPUTMEMBER	-0.238	0.401	-0.081	0.227	0.177	0.311	0.584**	0.282	0.770**	0.380	0.610**	0.287	1.148***	0.341
RELATIVE	0.006	0.013	0.010	0.009	0.033***	0.010	0.012	0.014	0.038***	0.012	0.016	0.011	0.037***	0.012
TRUSTTRADER	0.103***	0.029	0.062***	0.023	0.042	0.031	0.084**	0.037	0.062*	0.036	0.075**	0.033	0.052	0.041
CONFDNT	0.752	0.484	0.400*	0.221	0.710**	0.315	0.100	0.316	0.359	0.345	0.514*	0.307	1.149**	0.495
Shocks														
RAININDEX	1.146*	0.592	-0.241	0.343	-0.120	0.444	0.268	0.533	-0.337	0.586	-0.623	0.464	-0.581	0.544
PESTSTRES	0.492	0.473	0.140	0.313	0.653*	0.344	0.654*	0.377	1.013**	0.411	0.781**	0.328	0.102	0.405
WATRLOGG	-0.922**	0.362	-0.158	0.227	-0.244	0.285	-0.882**	0.393	0.037	0.444	-0.216	0.321	-0.637*	0.372
RELYGOVT	-0.127	0.309	0.627***	0.188	0.012	0.239	-0.118	0.305	0.238	0.308	0.049	0.224	0.483	0.299
Plot characteristics														
log(PLOTDIST)	-0.151	0.114	0.063	0.073	-0.156*	0.088	0.002	0.109	-0.185	0.160	0.066	0.089	-0.081	0.134
SHALDEPT	0.594*	0.313	0.298	0.256	0.395	0.311	-0.206	0.357	0.532	0.396	0.205	0.302	1.127***	0.411
MEDMDEPT	0.417	0.295	0.435**	0.203	0.580**	0.273	0.721**	0.284	0.669*	0.368	0.375	0.286	0.761**	0.377
GOODSOIL	-0.157	0.540	0.664**	0.327	-0.771*	0.399	-0.307	0.488	-0.241	0.519	-1.353***	0.372	-0.201	0.537
MEDMSOIL	-0.083	0.562	-0.409	0.305	-0.832**	0.390	-0.693	0.490	-0.436	0.506	-1.044***	0.348	-0.127	0.513
FLATSLOP	0.910	0.871	-0.148	0.362	0.095	0.436	0.608	0.520	0.416	0.590	1.232***	0.465	0.037	0.669
MEDMSLOP	0.818	0.859	-0.248	0.353	0.428	0.417	0.107	0.549	0.192	0.564	1.138**	0.461	0.615	0.637
MANURE	-0.415	0.298	-0.263	0.176	-0.001	0.205	-0.533*	0.287	-0.650*	0.332	-0.744***	0.221	-0.669**	0.306
CONSTANT	-6.079***	2.345	-0.575	1.425	-0.224	1.952	0.204	2.108	-1.460	2.496	-1.311	2.108	0.310	2.841
Joint-significance of location variables: χ^2 (7)	16.39**		27.70***		19.61***		18.39***		30.56***		28.91***		30.04***	
Number of observations = 1614; Wald χ^2 = 970.72; p > χ^2 = 0.000														

Note: SE is robust standard errors; *, ** and *** indicate statistical significance at 10%, 5% and 1%; $R_0V_0T_0$ is the reference category. Other non-significant variables include: MALEHEAD, EDUCATHEAD; ASSETVALUE; TLU; WALKINPUT; FREQEXTCONT; FROSTSTRES; RENTD.

The model fits the data reasonably well and the Wald test that all regression coefficients are jointly equal to zero is rejected [$\chi^2(266) = 956.44$; $p = 0.000$]. The results show that the estimated coefficients differ substantially across the alternative packages.

The spouse's (women's) education level has a positive impact on the adoption of the improved variety–conservation tillage package ($R_0V_1T_1$). There is a strong correlation between the adoption of package $R_1V_1T_1$ and family size and age of the household head; increasing for family size but decreasing for household age.

Farm size has inconclusive results on the packages containing conservation tillage. It is positively related to SAPs packages containing only conservation tillage ($R_0V_0T_1$), perhaps because of demand for labor-saving technologies. A similar result was found by Fuglie (1999) in the US. However, adoption of package $R_1V_1T_1$ is more likely to be used by small farmers probably because smaller farmers tend to achieve food security by sustainably intensifying production.

All social network and capital variables have positive impacts on adoption of most packages of SAPs. With scarce or inadequate information sources and imperfect markets, including insurance market and transactions costs, social networks could facilitate the exchange of information, enable farmers to access inputs on schedule, and overcome credit constraints. This finding suggests that in order to enhance the adoption of SAPs, local rural institutions and service providers need to be supported because they can effectively assist farmers by providing credit, inputs, information, and stable market outlets.

Adoption of $R_0V_1T_0$ (only improved seeds combination) is more common by farmers who trust in government support when crops fail, probably because the benefit of new technologies (i.e., modern seeds) is uncertain and farmers may need insurance to adopt new technologies. The results also reveal that more highly-skilled extension agents enhance the likelihood of adopting packages $R_0V_1T_0$, $R_0V_0T_1$, $R_0V_1T_1$, and $R_1V_1T_1$, perhaps because a package containing modern seeds and the conservation tillage practice is relatively knowledge-intensive and require considerable management input. This underscores the importance of upgrading the skill of extension workers to speed up adoption of SAPs. The results further indicate the importance of rainfall and plot level shocks in determining the adoption of packages of SAPs. The probability of adoption of $R_1V_0T_0$ is high in areas/years where rainfall is reliable in terms of timing, amount and distribution. Similarly, adoption of $R_1V_1T_1$, $R_1V_1T_0$, and $R_1V_0T_0$ is negatively and significantly influenced by waterlogging stress. The incidence of pests and diseases positively influences the adoption of packages $R_0V_0T_1$, $R_1V_1T_0$, $R_1V_0T_1$, and $R_0V_1T_1$. Finally, plot characteristics also conditioned the adoption of different packages, suggesting the importance of considering these characteristics in promoting packages of SAPs.

4.2. **Average treatment effect on the treated**

The second stage regression estimates are shown in Appendices Table A1–A5. Because our major objective is to determine the average adoption effects of various combinations of SAPs under the actual and counterfactual scenarios, the regression results are not discussed here. However, it is worth noting that many of the coefficients on the selection correction terms are significant suggesting that adoption of packages of SAPs will not have the same effects on non-adopters should they choose to adopt, as it would on adopters.

Table 5 presents the unconditional and conditional average effects of adoption of a combination of SAPs. The unconditional average effects indicate that adopters of packages of any SAPs earn more maize income, on average, than non-adopters. The same is true for other outcome variables except that non-adopters use more N fertilizer under package $R_0V_0T_1$. However, this simple comparison is misleading because it does not account for both observed and unobserved factors that may have influence on outcome variables.

To estimate the true average adoption effects for households that did adopt, the outcome variables of farm households who adopted packages of SAPs are compared with what they would have been if the farm households had not adopted, by applying equation (8). We found that in almost all cases adoption of a combination of SAPs provides more maize income compared to adopting them in isolation. Farmers obtained higher income when bio-diversification and conservation tillage practices were combined with improved seeds, either together or individually. The largest income effect (5.58 thousand birr/hectare) is from adoption of package $R_1V_1T_1$.

Table 5. The average effect of adoption of package of sustainable agricultural practices (SAPs) using multinomial endogenous switching regression

Adoption effects	Package	Outcome: Maize income (Birr/ha)	N application (Kg/ha)	Pesticide application (l/ha)	Labor (labor days/ha) Women	Men
Unconditional average effects	$R_1V_0T_0$	5924.00***	101.66***	2.19***	0.411	4.01***
		(721.76)	(13.96)	(0.37)	(0.53)	(0.99)
	$R_0V_1T_0$	2751.24***	3.77***	0.89***	3.18***	2.62***
		(135.84)	(1.14)	(0.03)	(0.37)	(0.36)
	$R_0V_0T_1$	3929.43***	-12.18***	2.49***	9.26***	6.85***
		(207.32)	(1.06)	(0.10)	(0.42)	(0.55)
	$R_1V_1T_0$	5858.69***	31.80***	0.16***	2.52***	0.03
		(325.28)	(3.21)	(0.04)	(0.42)	(0.46)
	$R_1V_0T_1$	7324.07***	54.89***	21.60***	12.50***	24.87***
		(584.67)	(7.51)	(3.77)	(1.52)	(3.07)
	$R_0V_1T_1$	2795.68***	-1.19	1.25***	3.83***	1.81***
		(187.57)	(1.16)	(0.04)	(0.41)	(0.48)
	$R_1V_1T_1$	6822.82***	332.82***	2.83***	13.69***	2.23***
		(253.74)	(50.20)	(0.19)	(0.49)	(0.50)
Average treatment effects on treated (ATT)	$R_1V_0T_0$	1892.43***	9.45	0.59	-0.63	-3.32**
		(819.78)	(9.31)	(0.58)	(1.74)	(1.94)
	$R_0V_1T_0$	2823.06***	3.78**	1.04***	3.13***	1.71***
		(269.44)	(2.29)	(0.06)	(0.62)	(0.61)
	$R_0V_0T_1$	2349.90***	-13.92***	2.95***	2.97***	3.11***
		(376.70)	(2.89)	(0.49)	(1.06)	(1.26)
	$R_1V_1T_0$	4506.65***	7.81	0.01	6.08***	2.36**
		(752.39)	(6.72)	(0.13)	(1.33)	(1.33)
	$R_1V_0T_1$	497.54	-19.95***	3.42	1.57	3.61
		(903.52)	(5.69)	(3.21)	(2.54)	(3.44)
	$R_0V_1T_1$	2840.85***	-5.60**	0.84***	1.60**	0.59
		(405.59)	(3.57)	(0.09)	(1.05)	(0.99)
	$R_1V_1T_1$	5579.47***	15.27*	1.49***	10.12***	4.99***
		(745.39)	(10.65)	(0.30)	(1.73)	(1.99)

Note: Numbers in parentheses are standard errors; *, ** and *** indicate statistical significance at 10%, 5% and 1%.

With regards to input use, we found that for farmers who adopted package $R_1V_1T_0$, the average labor demand both for females and males is significantly higher than it would have been if the adopters had adopted $R_0V_0T_0$. However, the average N and pesticide use are not significantly affected, probably because bio-diversification saves farmers from using N and pesticides through N fixation by the legume crops and controlling for pest, disease and weed infestations. On the other hand, adoption of $R_0V_0T_1$ and $R_0V_1T_1$ significantly increased pesticide application and labor demands while significantly reducing the average N application. The decrease in N application is greater when farmers use traditional maize varieties ($R_0V_0T_1$) and even further under package $R_1V_0T_1$ (bio-diversification combined with conservation tillage) without significantly affecting the average maize income, pesticides use, and households' labor demand. Similarly, adoption of bio-diversification with traditional varieties ($R_1V_0T_0$) does not significantly affect the average N and pesticide use and female labor but reduces the male workload. On the other hand, the average N and pesticide use and labor demand significantly increases with adoption of $R_1V_1T_1$ and $R_0V_1T_0$. This is likely due to the complementarity between improved maize variety adoption and fertilizer and pesticides through the increase in agrochemical use because of adoption of package $R_0V_1T_0$. Without soil and water conserving technologies this may jeopardize agricultural sustainability in the long run. Furthermore, the use of more pesticides in the package that contains improved seed is probably because farmers would like to avoid risk as high yielding varieties may be susceptible to pest outbreaks (Jhamtani, 2011).

The above results have the following implications. First, adoption of SAPs increases maize income and the highest payoff is achieved when SAPs are adopted in combination rather than in isolation. Second, farmers appear to properly credit N fixed by legume crops and consider the soil fertility effects of conservation tillage because N fertilizer use is either lowered or turned out to be insignificant when bio-diversification was used in combination or isolation. Third, the notion that conservation tillage may increase pesticide application and labor demand to compensate for less tillage (Fuglie, 1999) is observed in this study. This is because pesticide use and labor demand increase in the package that includes conservation tillage. Fourth, in most cases pesticide use and the change in male and female labor demand was insignificant in the package that contains bio-diversification. This is perhaps because bio-diversification helps to maintain soil bio-diversity that can reduce pest and weed infestations that otherwise need pesticides and/or additional labor (Tilman et al. 2002; Hajjar et al. 2008). However, this effect of bio-diversification is outweighed when it is used in combination with improved variety and conservation tillage ($R_1V_1T_1$). Fifth, adoption of packages has different effects on male and female labor time allocation. In nearly all cases, the packages make females spend more time working on the farms than males do. This may negatively affect the larger households by diverting time from other activities such as food preparation and child care as women are often responsible for routine care of the household. Sixth, promoting bio-diversification and conservation tillage either in combination or isolation has an important positive long-term environmental implication without an economic trade-off.

5. **Concluding remarks**

Adoption and impact studies of SAPs have received considerable attention from development economists. Prior research focuses on specific practices; less information is available on joint adoption of multiple and interdependent SAPs and their impacts. In this paper, we evaluate the adoption of multiple SAPs and their impacts on maize income and agrochemicals and labor input intensity in maize–legume farming systems of Ethiopia. A multinomial ESR is used to account for self-selection in choosing combined and potentially interdependent packages of SAPs and the interactions between them.

The multinomial logit selection model results revealed that the likelihood of adoption of a package of SAPs is influenced by observable plot, household and village characteristics. These include rainfall and plot level disturbances, soil characteristics and distance of the plot, social capital in the form of access and participation in rural institutions, the number of relatives and traders known by the farmer, market access, wealth, age, spouse education and family size, the farmer's expectations of government support in case of crop failure, and confidence in the skill of public extension agents. These results can be used to inform and target policies aimed at increasing adoption rates of multiple and interdependent SAPs. For example, the correlation of spouse's education with increased adoption of conservation tillage and improved seeds suggests that female education can be an important driver of adoption of sustainable agricultural practices in Ethiopia. Similarly, the significant role of social capital suggests the need for establishing and strengthening local institutions and service providers to accelerate and support adoption of SAPs. The effects of weather related risks are also important for enhancing SAPs adoption and underscore the need to provide climatic information, not only in terms of rainfall amount but also of timing and its distribution. Furthermore, the use of SAPs is positively associated with the farmer's expectation of timely government support during crop failure and confidence in the skill of extension agents. These suggest a number of supplementary policy measures: investment in public safety-net programs (public insurance) and risk-protection mechanisms, and the need for technically capable extension service providers.

With regards to the results of adoption effects, adoption of multiple SAPs significantly increases maize income; and the package that contains all improved SAPs (bio-diversification, conservation tillage and improved varieties) provides the highest income. This has important policy implications. Efforts for improving productivity and food security should combine improved varieties with appropriate agronomic practices that increase the profitability of investments in seed-based technologies while enhancing ecosystem resilience and sustainability. Adoption of the combined SAP packages has a positive effect on N and pesticide application and women and men labor use on-farm. However, it also appears that bio-diversification or conservation tillage, or both, with traditional varieties enables farmers to reduce N without significantly affecting income. On the other hand, comparing the change in pesticide use with the adoption of SAPs involving conservation tillage and bio-diversification with modern and traditional maize varieties reveals that pesticide application would not significantly increase when conservation tillage and bio-diversification is jointly used with traditional maize varieties. Conservation tillage requires application of some herbicides (e.g. glyphosate) to kill weeds before planting under reduced or zero till systems. This may have some undesirable environmental effects, but will progressively be reduced as the weed pressure decreases with retention of residues on the field. This suggests that policy makers, researchers and extension agents should use alternative options to design win–win strategies to address household food security and minimize the use of non-renewable external off-farm inputs (pesticides and fertilizers) that harm the environment.

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Appendix

Table A1. Parameter estimates of maize net income-multinomial logit endogenous switching regression dependent variable: *log*(maize net income)

Variables	$R_0V_0T_0$		$R_1V_0T_0$		$R_0V_1T_0$		$R_0V_0T_1$		$R_1V_1T_0$		$R_1V_0T_1$		$R_0V_1T_1$		$R_1V_1T_1$	
	Coefficient	SE	Coefficient	SE.	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
Household characteristics																
log(FAMLYSIZE)	0.645*	0.330	0.493	1.882	-0.453***	0.159	-0.218	0.509	0.634	1.197	1.204	12.707	-0.068	0.255	-1.581***	0.561
log(EDUCATHEAD)	-0.300**	0.139	0.469	1.543	0.292***	0.095	0.325	0.294	-0.355	0.548	-0.059	4.360	0.026	0.479	0.595	0.865
log(EDUCATHEAD)	0.297**	0.149	0.004	0.309	0.078	0.064	-0.207	0.274	0.284	0.501	-0.112	3.184	0.171	0.170	0.038	0.449
Resource constraints, market access and social capital																
log(FARMSIZE)	-0.497***	0.182	-0.265	0.693	-0.260	0.162	-0.119	0.335	-0.390	0.502	0.032	1.261	-0.532***	0.088	-0.556	0.447
log(TLU)	0.175***	0.051	0.525*	0.307	0.252***	0.072	0.148	0.305	-0.047	0.369	0.331	2.903	0.356**	0.181	0.391	0.463
CREDIT	-0.290***	0.091	0.346	1.348	-0.224	0.182	-0.132	0.220	-0.426	0.284	-0.058*	3.688	-0.196	0.227	-0.224	0.705
log(WALKMKT)	-0.194**	0.086	-0.201	0.361	0.012	0.020	0.075	0.129	-0.317***	0.107	0.240	1.557	-0.139*	0.073	-0.166	0.550
TRUSTTRADER	0.011	0.018	0.093	0.246	0.001	0.023	-0.048	0.050	0.083**	0.034	-0.009	0.464	0.054**	0.026	0.019	0.082
Shocks																
RAININDEX	0.652**	0.269	-0.330	1.590	0.737***	0.053	0.067	0.204	0.808	1.207	1.195	4.465	0.291	0.246	-0.432	1.573
WATRLOGG	-0.260	0.448	-0.654	1.901	-0.439*	0.246	-0.518*	0.309	0.547	0.645	0.487	4.721	-0.896***	0.136	-0.830	2.526
FROSTSTRESS	-0.102	0.259	-0.463	3.020	-0.385	0.301	0.120	0.376	-0.080	1.143	-0.526	5.237	-0.418*	0.215	-0.588	1.236
Plot characteristics																
log(PLOTDIST)	0.004	0.109	-0.257	0.497	-0.086*	0.050	0.091	0.166	-0.031	0.197	-0.173	1.739	-0.022	0.092	-0.204	0.311
RENTD	0.409	0.353	-0.104	2.317	-0.052	0.258	-0.681	0.482	0.746	1.086	0.624	1.542	-0.159**	0.063	-0.096	0.691
MEDMSLOP	-0.090	0.458	-1.159	1.955	0.116	0.313	0.532	0.636	-1.448	1.105	-1.082	4.365	-0.818***	0.294	-0.758	2.510
MANURE	0.458**	0.212	1.110	1.127	-0.070	0.259	0.358	0.275	0.892**	0.415	0.480	2.984	0.388*	0.230	-0.021	1.139
CONSTANT	5.057***	1.322	4.614*	2.523	9.076***	0.972	7.956***	2.779	6.783	7.282	2.754	59.926	8.657***	0.980	11.327***	3.190
Joint significance of location variables: F(7, 45)	2.18**		2.29**		2.69***		1.20		0.65		0.18		1.74*		1.30*	
Anciliary																
σ2	11.519***	3.132	65.126	259.2	4.387***	1.493	24.26***	6.292	42.450	38.102	89.021	752.001	10.590**	4.425	22.088	59.98
λ1			-0.504	0.658	-0.379	0.638	0.750**	0.338	-0.783**	0.392	0.138	0.671	-1.169***	0.378	-0.209	0.563
λ2	1.126***	0.184			0.523	0.591	0.229	0.673	0.480***	0.153	-1.174*	0.687	0.534*	0.290	0.161	0.720
λ3	-0.200	0.350	0.844	0.820			-0.662	0.476	0.928**	0.424	0.575	0.367	0.369	0.990	0.009	0.316
λ4	-1.071**	0.462	-0.179	0.924	-0.086	0.400			-0.625**	0.273	0.680	0.726	-0.438	0.392	0.251	0.641
λ5	0.512**	0.203	-0.151	0.591	1.181***	0.363	-0.244	0.273			0.650	0.686	0.203	0.271	1.202	0.930
λ6	-0.198	0.692	1.089*	0.568	-0.728	0.722	-1.088*	0.610	0.382	0.378			0.689	0.557	-0.855*	0.439
λ7	-0.318	0.684	-0.223	0.372	-0.640	0.629	0.302	0.684	-0.089	0.476	-0.520	0.771			-0.730*	0.408
λ8	0.218	0.601	-0.874*	0.479	0.285	0.384	0.633	0.388	-0.352	0.655	-0.395	0.432	-0.071	0.613		

Note: SE is bootstrapped standard error; *, ** and *** indicate statistical significance at 10%, 5% and 1%; non-significant variables included but not reported here are: MALEHEAD, AGE, EDUCATSPOUS; ASSETVALUE; OTHERINCOM; WALKMKT; PESTRES; RELYGOVT; GOODSOIL; SHALDEPT; MEDMDEPT; MEDUMSOIL; FLATSLOP.

Table A2. Parameter estimates of nitrogen (N) application- multinomial endogenous switching regression (MLESR), dependent variable: *log*(N)

Variables	$R_0V_0T_0$		$R_1V_0T_0$		$R_0V_1T_0$		$R_0V_0T_1$		$R_1V_1T_0$		$R_1V_0T_1$		$R_0V_1T_1$		$R_1V_1T_1$	
	Coefficient	SE	Coefficient	SE.	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
Household characteristics																
MALEHEAD	-0.950**	0.467	2.761	2.762	0.315	0.309	0.194	1.577	0.740	3.373	3.010	15.994	-0.583	1.001	2.222	2.556
log(FAMLYSIZE)	0.725**	0.354	-2.857	2.896	-0.134	0.122	0.270	1.249	-0.400	1.933	1.684	2.361	0.602	0.920	0.653	1.098
log(AGE)	-0.216	0.400	-0.246	3.590	0.426**	0.179	-0.019	0.371	-0.511*	0.302	0.558	6.779	-0.562	0.743	-1.706	4.059
log(EDUCATHEAD)	0.350***	0.034	1.192	1.965	-0.030	0.047	0.164	0.234	-0.051	0.241	0.225	1.307	0.097	0.208	0.838	2.179
Resource constraints, market access, social capital and extensions																
log(FARMSIZE)	-0.824***	0.225	-0.525	2.944	-0.326***	0.081	-0.524**	0.256	-0.957	1.218	0.240	5.342	-0.107	0.370	-0.346	3.696
log(ASSETVALUE)	-0.087**	0.041	-0.122	0.750	-0.055	0.057	-0.147	0.135	0.178	0.467	0.120	2.718	0.054	0.103	0.455*	0.256
log(OTHERINCOM)	-0.185	0.287	2.858*	1.708	-0.042	0.151	-0.366	0.521	0.564	2.428	-1.689	10.180	-0.114	0.324	-0.339	4.138
log(TLU)	0.408	0.267	1.039	3.892	0.192*	0.101	0.488**	0.229	0.547	2.381	-0.421	2.998	0.119	0.272	0.395	2.187
MEANSTRANS	0.209	0.271	4.008***	1.425	0.117	0.072	-0.309	0.778	-0.167	1.296	1.111	22.627	-0.200	1.112	2.506	6.087
log(WALKMKT)	-0.164***	0.040	-0.475	0.807	-0.096***	0.029	-0.114	0.294	-0.519	0.492	-0.126	10.856	-0.050	0.103	0.138	1.273
RELATIVE	-0.010**	0.005	-0.070	0.112	-0.018*	0.010	-0.013	0.053	0.021	0.097	-0.014	0.559	0.009	0.008	-0.040	0.037
TRUSTTRADER	-0.005	0.042	0.286***	0.089	-0.009	0.019	-0.062	0.053	0.051	0.195	0.087	3.752	-0.053	0.089	0.005	0.497
FREQEXTCONT	-0.004**	0.002	-0.004	0.034	0.002	0.003	-0.000	0.002	-0.006	0.019	-0.002	0.281	0.003	0.004	-0.001	0.008
CONFDNT	-0.528*	0.290	0.214	3.142	0.043	0.260	-0.656	0.750	-0.695	2.652	0.065	9.301	-0.393	0.594	-1.647	3.660
Shocks																
RAININDEX	0.220	0.157	2.256	5.474	0.313	0.226	-0.013	0.729	0.615	1.147	-0.050	11.081	0.720	1.024	2.080	5.779
PESTSTRES	-0.926***	0.134	-0.008	1.959	-0.319*	0.164	-0.463	0.921	1.330	2.447	0.263	20.215	0.015	1.159	-1.831	4.002
Plot characteristics																
MEDMDEPT	-0.408	0.385	2.529***	0.554	-0.160	0.199	-0.311	0.721	0.667	2.281	0.720	31.356	-0.079	0.292	0.314	3.765
GOODSOIL	0.792	0.728	-1.309	2.340	0.455*	0.243	0.155	0.512	1.513	5.486	-2.152	25.886	0.585	0.555	1.487	4.716
MEDMSOIL	0.576	0.608	-0.656	2.099	0.545*	0.315	-0.029	1.236	0.480	1.282	-3.317	29.928	0.405	0.681	1.189	6.943
MEDMSLOP	-0.317	0.371	-3.652*	1.874	-0.347	0.339	0.417	1.375	0.573	7.386	-0.017	1.398	0.554	0.841	-5.175	7.474
CONSTANT	-1.209	3.654	3.083	15.010	2.368	1.659	3.724**	1.476	-2.051	17.101	-3.841	61.368	2.164	6.227	1.342	30.770
Joint significance of location variables: F(7, 45)	7.53***		1.01		10.89***		2.25**		2.91**		1.59		4.94***		2.02*	
Anciliary																
σ^2	11.008*	5.911	660.075	693.188	4.645*	2.663	19.849*	11.289	67.124	299.766	94.959	81.370	27.652	22.981	360.167	238.04
λ_1			-0.687	0.000	0.736	0.644	0.723	0.669	-0.167	0.450	-0.201	1.210	0.683*	0.388	0.204	0.336
λ_2	0.834	0.532			0.224	0.190	-0.261	0.416	0.111	0.282	-1.171	0.000	0.089	0.403	-0.170	0.621
λ_3	-0.054	0.164	1.085**	0.495			-0.375	0.890	-0.868	1.113	0.343	0.742	-0.976*	0.557	0.889	0.702
λ_4	-1.228**	0.568	-0.350	1.199	-0.768**	0.321			-0.777**	0.383	0.372***	0.082	0.625	0.382	0.366	1.120
λ_5	0.042	0.897	0.493	0.000	-0.512	0.450	0.930*	0.514			1.114	1.003	-0.377	0.679	0.423	0.320
λ_6	0.579	0.604	-0.028	0.807	-0.154	0.200	-1.151	0.819	1.113	0.777			0.469	0.659	-0.831**	0.422
λ_7	-0.617	0.830	-0.364	0.784	-0.630	0.572	0.204	0.238	-0.149	0.582	0.113	0.226			-0.819	0.532
λ_8	0.089	0.488	-0.168	0.635	0.924	0.576	0.064	0.322	0.436	0.319	-0.556***	0.131	-0.448	0.949		

Note: SE is bootstrapped standard error; *, ** and *** indicate statistical significance at 10%, 5% and 1%; non-significant variables included but not reported here are: EDUCATSPOUS; CREDIT; WALKINPUT; INPUTMEMBER; WATRLOGG; FROSTSTRES; RELYGOVT; PLOTDIST; RENTD; SHALDEPT; FLATSLOP.

Table A3. Parameter estimates of pesticide application- multinomial endogenous switching regression (MLESR), dependent variable: *log*(pesticide)

Variables	$R_0V_0T_0$		$R_1V_0T_0$		$R_0V_1T_0$		$R_0V_0T_1$		$R_1V_1T_0$		$R_1V_0T_1$		$R_0V_1T_1$		$R_1V_1T_1$	
	Coefficient	SE	Coefficient	SE.	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
Household characteristics																
log(FAMLYSIZE)	0.274	0.529	-3.880**	1.977	0.013	0.642	-0.541	2.160	-0.693	2.419	-2.480***	0.011	-0.380*	0.225	3.545***	1.143
log(AGE)	-0.148	0.420	1.899	1.545	0.732	0.543	1.195	1.741	-0.459	1.609	3.611*	2.138	-0.176	0.374	-5.846***	1.331
log(EDUCATHEAD)	-0.047	0.105	-1.174	1.393	0.120	0.125	0.013	1.083	-0.109	1.922	-2.083***	0.383	-0.065	0.245	0.459	0.610
log(EDUCATSPOUS)	-0.106	0.128	-1.578	1.134	0.544*	0.322	-0.236	0.922	0.180	1.792	0.430	0.972	-0.169	0.331	-0.671	0.763
Resource constraints, market access, social capital and extensions																
log(FARMSIZE)	-0.263*	0.154	1.206	1.429	0.074	0.274	-0.232	1.105	-0.529	0.795	2.887***	0.767	0.549	0.455	2.129***	0.572
log(OTHERINCOM)	-0.278	0.197	-2.668**	1.226	-0.211	0.334	-0.170	2.184	0.879	2.839	-1.994***	0.634	-0.130	0.508	0.083	1.627
MEANSTRANS	-0.479	0.421	-0.871	2.017	-0.075	0.465	-0.358	4.691	0.225	5.388	-4.096	3.122	-0.696	1.614	3.169***	0.966
log(WALKINPUT)	-0.085	0.083	1.093***	0.295	-0.021	0.195	-0.217	0.571	0.234	1.325	0.673	0.912	0.183*	0.099	0.346	0.370
INPUTMEMBER	0.255	0.293	0.655	2.605	-0.028	0.131	0.691	3.041	1.115	4.511	0.826	2.126	-0.166	0.754	-5.929***	0.583
RELATIVE	-0.014	0.015	-0.058	0.093	-0.017	0.026	-0.034	0.171	0.005	0.090	0.205***	0.053	0.017	0.028	-0.040	0.026
TRUSTTRADER	-0.109***	0.034	-0.311	0.391	0.039	0.056	-0.017	0.180	0.128	0.332	-0.283	0.207	-0.091*	0.051	-0.113*	0.061
FREQEXTCONT	0.000	0.003	-0.013	0.011	-0.003	0.006	0.005	0.026	-0.006	0.037	-0.012	0.011	0.005***	0.002	0.015	0.014
CONFDNT	-0.701***	0.212	-2.131***	0.522	0.414	0.399	-0.097	1.569	0.941	1.584	0.506	1.725	-0.116	0.243	-0.691	1.417
Shocks																
RAININDEX	-0.029	0.384	-4.037	3.229	-0.390	0.293	-0.311	4.558	0.531	5.183	-4.240**	1.720	0.220	0.859	3.291***	0.914
PESTSTRES	-0.289	0.405	-1.062	0.992	-0.250	1.234	-1.617	3.615	1.824	2.027	1.531	1.134	-0.073	0.747	1.245*	0.725
WATRLOGG	0.397***	0.132	3.955**	1.796	-0.855	0.761	-0.131	1.521	-1.795	3.696	3.488***	1.231	-0.366*	0.200	2.332***	0.701
FROSTSTRES	-0.190	0.492	-5.011*	2.613	-1.074**	0.498	-1.545	1.272	-1.202	5.109	2.609*	1.500	0.805	0.810	0.000	0.000
RELYGOVT	-0.647	0.415	3.822***	1.000	0.527	0.760	-0.691	3.476	-0.430	2.719	0.353	2.812	-0.471	0.771	-1.331*	0.770
Plot characteristics																
log(PLOTDIST)	0.077	0.065	0.528	0.391	0.119**	0.061	0.235	0.259	-0.122	0.923	-0.420	0.830	-0.066	0.089	-0.642**	0.316
RENTD	-0.513**	0.250	-0.265	0.727	0.504***	0.187	-0.671	4.667	-0.041	0.969	-4.923	3.334	-0.683	0.673	0.487	0.359
SHALDEPT	-0.310	0.201	-2.782***	0.616	0.367	0.497	-0.587	1.741	0.135	2.353	2.841***	0.195	-0.243	0.628	-2.288***	0.718
MEDMDEPT	-0.605***	0.220	-0.656	1.931	0.502	0.471	-0.549	2.362	1.113	2.281	1.354	2.283	-0.043	0.212	-2.379***	0.807
GOODSOIL	1.040	0.766	-0.693	1.037	-1.249	1.561	0.654	7.750	-0.520	6.154	-6.338***	2.354	-0.243	0.922	1.042	0.933
MEDMSOIL	0.884	0.663	-0.708	1.005	-0.758	1.565	0.840	9.912	-1.021	6.356	-6.557***	2.366	-0.033	1.106	1.461	1.289
FLATSLOP	0.641	0.465	-0.049	0.968	0.473	0.631	-0.480	13.666	0.916	3.883	4.401***	1.549	0.653	1.400	-1.645**	0.710
MEDMSLOP	0.796**	0.345	0.000	0.192	0.254	0.704	0.262	14.821	0.609	5.425	6.974	0.000	0.747	1.639	-1.578*	0.886
MANURE	0.287	0.272	1.606	1.660	-0.481	0.529	0.161	0.690	-0.914	2.825	0.433	1.239	0.641	0.594	3.978***	0.751
CONSTANT	-4.940*	2.522	34.78***	10.738	-4.486**	2.096	4.933	8.776	-4.891	12.747	5.841	13.196	1.958	2.615	3.786	5.532
Joint significance of location variables: $F(7, 45)$	4.49***		2.19*		1.30		1.07		1.92*		0.71		1.43		4.81***	
Anciliary																
σ^2	8.490*	4.679	219.9***	23.613	32.764	60.383	58.800	1070.9	32.119	804.601	113.4***	1.260	39.605**	19.821	297.1***	11.756
λ_1			0.067	0.513	-0.628	0.727	0.807	0.854	-1.033	0.775	0.078	1.042	0.293	0.332	0.437	1.044
λ_2	0.128	0.547			0.183	0.540	-0.162	0.466	0.098	0.953	-0.668	0.000	-0.063	0.498	0.481	0.000
λ_3	-1.040	0.905	1.151	0.000			-0.263	0.871	-0.831	0.621	0.091	1.071	-0.822	0.893	-0.003	0.776
λ_4	-0.604	0.567	-0.038	0.758	-0.174	0.238			0.316	0.510	1.006	0.700	1.202**	0.598	1.056***	0.316
λ_5	-0.454	0.391	0.422	0.653	0.546	0.988	-0.234	0.588			-1.046	0.000	-0.149	0.437	-0.737	0.000
λ_6	-0.008	0.491	0.045	0.000	-1.280***	0.371	-1.132***	0.364	0.451	0.586			-0.125	0.486	-0.285	0.891
λ_7	0.655***	0.160	-0.909	1.226	0.859*	0.500	0.257	0.694	0.227	0.737	0.507	0.000			-0.697	0.000
λ_8	0.512	0.680	-0.195	0.000	0.271	0.573	0.880***	0.212	0.410	0.287	-0.009	0.000	-0.362	0.399		

Note: SE is bootstrapped standard error; *, ** and *** indicate statistical significance at 10%, 5% and 1%; non-significant variables include: MALEHEAD; ASSETVALUE; CREDIT; TLU; WALKMKT.

Table A4. Parameter estimates of female labor allocation- multinomial endogenous switching regression (MLESR), dependent variable: *log*(women labor)

Variables	$R_0V_0T_0$		$R_1V_0T_0$		$R_0V_1T_0$		$R_0V_0T_1$		$R_1V_1T_0$		$R_1V_0T_1$		$R_0V_1T_1$		$R_1V_1T_1$	
	Coefficient	SE	Coefficient	SE.	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
Household characteristics																
log(FAMLYSIZE)	0.467**	0.194	0.952	0.778	0.069	0.217	-0.035	0.083	0.350	0.742	0.376	0.989	0.165	0.425	0.433	0.783
log(EDUCATHEAD)	0.116	0.118	-0.269	0.318	-0.035	0.121	-0.208***	0.059	-0.228	0.192	0.111	2.889	-0.139	0.139	0.165	0.358
log(EDUCATSPOUS)	-0.168	0.110	0.019	0.465	-0.143**	0.069	0.340***	0.084	0.274	0.410	0.688	0.706	0.135	0.106	-0.368	0.264
Resource constraints, market access and social capital																
log(FARMSIZE)	-0.374	0.255	-0.330	0.207	-0.111	0.120	0.070	0.189	-0.099	0.445	-0.579	0.937	-0.379	0.304	-0.480**	0.192
log(ASSETVALUE)	-0.111***	0.030	0.030	0.268	0.048**	0.021	-0.184**	0.081	-0.063	0.156	-0.117	0.574	-0.049	0.093	-0.165***	0.050
log(OTHERINCOM)	0.078	0.179	-0.760	0.989	0.091**	0.041	-0.153	0.121	-0.127	0.142	0.217	2.009	-0.036	0.120	0.279	0.443
log(TLU)	0.123	0.103	-0.074	0.650	0.228***	0.044	-0.005	0.161	-0.070	0.488	0.080	0.712	0.213***	0.035	0.204	0.161
CREDIT	-0.068	0.179	0.523	0.460	0.062	0.152	-0.473***	0.115	0.399	0.643	-0.125	1.899	0.115	0.212	-0.135	0.410
log(WALKMKT)	-0.079*	0.040	-0.173	0.322	-0.010	0.047	0.016	0.072	0.252**	0.101	-0.175	1.034	-0.045	0.068	-0.012	0.105
TOTALMEMBER	-0.108	0.095	-0.014	0.206	0.062***	0.018	0.035	0.096	0.059	0.237	0.021	0.367	0.206***	0.050	0.048	0.147
RELATIVE	-0.018	0.011	-0.029	0.027	0.018**	0.009	-0.011	0.007	0.014	0.033	-0.014	0.138	-0.002	0.011	-0.014	0.016
Shocks																
RAININDEX	-0.134	0.213	0.104	1.221	-0.117	0.200	-0.721**	0.358	-1.078***	0.386	0.262	1.703	-0.863*	0.461	0.605	0.662
PESTSTRES	-0.180	0.213	0.049	0.507	0.544*	0.305	-0.151	0.225	0.093	0.406	0.730	0.548	-0.181	0.174	-0.425	0.520
Plot characteristics																
log(PLOTDIST)	0.010	0.039	0.026	0.316	-0.108	0.073	0.163**	0.080	-0.116	0.141	0.029	0.634	0.039	0.117	0.069	0.175
SHALDEPT	-0.087	0.309	-0.323	0.492	-0.138	0.191	-0.057	0.224	0.084	0.863	-0.206	2.493	0.094	0.128	0.457*	0.250
MEDMDEPT	-0.225	0.214	-0.333	1.222	0.055	0.183	-0.552**	0.275	-0.311	0.629	0.284	1.759	-0.336	0.224	-0.133	0.149
GOODSOIL	0.406	0.461	0.232	1.094	-0.053	0.280	0.130	0.344	-0.809	1.000	-1.349	1.486	0.173*	0.091	1.202*	0.698
MEDMSOIL	0.399	0.369	0.153	0.670	-0.286	0.275	0.540**	0.239	-0.573	0.576	-1.908*	1.012	0.305***	0.071	1.484**	0.656
CONSTANT	1.291	1.341	6.631	4.895	2.860**	1.243	3.473	2.675	6.513*	3.323	-3.934	28.020	3.165	2.704	3.017	5.629
Joint significance of location variables: F(7, 45)	6.15***		2.48**		3.74***		0.47		1.02		0.63		3.50***		1.79	
Anciliary																
σ^2	11.17***	1.751	13.765	25.192	6.976**	3.079	7.851**	3.501	13.772	24.308	31.276	417.325	3.675	3.883	11.747	9.602
λ_1			0.128	0.267	-0.670	0.426	0.199	0.443	-0.416	0.661	-0.358	0.397	0.082	0.172	0.935*	0.499
λ_2	0.365	0.429			-0.274	0.266	0.279	0.553	-0.293	0.469	-0.016	0.361	0.076	1.045	0.726	0.566
λ_3	0.410	0.407	-0.215	0.478			0.419	0.707	-0.688**	0.273	0.059	0.909	0.393	0.546	0.048	0.613
λ_4	-1.093*	0.621	-0.421	0.467	1.230***	0.420			0.896	0.698	-0.984	0.637	-0.587	0.727	-0.857***	0.264
λ_5	0.370	0.650	1.261	0.964	0.107	0.440	-1.287***	0.333			0.632	0.694	-0.294	0.522	-0.308	0.949
λ_6	-0.811	0.497	-1.083	1.161	-0.215	0.334	-0.396	0.738	1.060	0.989			-0.967	0.657	-0.623	0.800
λ_7	-0.064	0.697	-0.033	0.644	-0.458**	0.213	0.814***	0.174	0.102	0.674	0.957	0.842			-0.155	0.586
λ_8	0.783	0.832	0.436	0.669	0.214	0.393	0.026	0.394	-0.311	0.528	-0.317	0.524	1.288**	0.646		

Note: SE is bootstrapped standard error; *, ** and *** indicate statistical significance at 10%, 5% and 1%; non-significant variables included but not reported here are: MALEHEAD; AGE; WALKINPUT; WATRLOGG; FROSTSTRES; RENTD; FLATSLOP; MEDMSLOP.

Table A5. Parameter estimates of male labor allocation- multinomial endogenous switching regression (MLESR), dependent variable: *log*(men labor)

Variables	$R_0V_0T_0$		$R_1V_0T_0$		$R_0V_1T_0$		$R_0V_0T_1$		$R_1V_1T_0$		$R_1V_0T_1$		$R_0V_1T_1$		$R_1V_1T_1$	
	Coefficient	SE	Coefficient	SE.	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
Household characteristics																
MALEHEAD	0.182	0.200	-0.212	1.912	0.389**	0.185	0.404	0.354	-0.016	0.388	1.221	5.300	0.487	0.431	0.105	0.462
log(AGE)	0.075	0.200	0.661	0.877	-0.187*	0.103	-0.099	0.187	0.418	0.412	1.157	2.826	0.269	0.244	-0.574	1.666
log(FAMLYSIZE)	0.382	0.234	-0.010	0.733	-0.116	0.277	-0.330*	0.180	-0.176	0.513	0.086	2.412	-0.308	0.278	0.217	1.550
log(EDUCATHEAD)	0.075***	0.025	0.579	0.375	-0.038	0.101	-0.196	0.136	0.066	0.138	-0.051	1.060	-0.086	0.094	-0.004	0.454
Resource constraints, market access and social capital																
log(FARMSIZE)	-0.357**	0.170	-0.115	0.582	-0.096	0.072	0.172	0.154	0.021	0.191	-0.106	0.809	-0.403*	0.237	-0.387	0.256
log(ASSETVALUE)	-0.079*	0.046	-0.326	0.457	0.052*	0.029	0.044	0.047	0.016	0.153	-0.050	1.241	-0.018	0.061	-0.016	0.282
CREDIT	-0.164*	0.099	0.305	0.880	0.129	0.094	-0.086	0.124	-0.028	0.475	-0.066	1.855	0.044	0.204	0.151	0.523
log(WALKMKT)	-0.091**	0.042	-0.103	0.226	-0.039	0.024	0.135***	0.047	-0.008	0.120	-0.061	1.189	-0.058	0.065	0.024	0.210
log(WALKINPUT)	-0.051	0.057	-0.145	0.356	0.057	0.067	-0.125**	0.061	-0.007	0.134	-0.222	1.432	0.093	0.101	-0.053	0.534
TOTALMEMBER	0.062	0.048	0.003	0.195	-0.001	0.064	-0.066	0.049	0.051	0.137	0.100	0.798	0.121*	0.068	-0.019	0.204
RELATIVE	-0.013**	0.006	0.036	0.033	-0.000	0.006	-0.002	0.008	0.015	0.013	-0.029	0.159	-0.016	0.011	-0.013	0.028
Shocks																
PESTSTRES	-0.483*	0.252	-0.014	0.850	0.283	0.280	-0.157	0.239	-0.017	0.463	0.504	3.150	-0.237	0.208	-0.442	0.562
WATRLOGG	-0.181	0.138	-0.457	0.534	-0.190***	0.041	0.075	0.134	-0.159	0.354	-0.405	1.881	-0.062	0.149	-0.301	0.444
FROSTSTRES	-0.495*	0.282	-0.604	0.783	-0.306	0.237	-0.133	0.442	-0.088	0.693	-0.827	2.074	-0.120	0.543	0.055	2.615
Plot characteristics																
log(PLOTDIST)	0.053	0.052	-0.314***	0.120	0.005	0.052	0.011	0.108	0.029	0.147	0.300	1.295	0.093	0.130	0.010	0.320
RENTD	0.018	0.086	0.073	0.488	0.168	0.193	-0.232*	0.136	0.160	0.325	0.313	1.028	0.028	0.187	-0.044	0.647
SHALDEPT	-0.364**	0.159	0.780	0.533	-0.194	0.183	0.195	0.191	-0.014	0.508	-0.525	2.676	-0.037	0.214	0.223	0.432
MEDMDEPT	-0.396***	0.056	0.154	1.286	0.067	0.140	0.062	0.184	0.020	0.233	-0.110	4.412	-0.283	0.236	0.097	0.385
GOODSOIL	0.501**	0.218	0.135	1.161	0.060	0.286	-0.326**	0.130	-0.646	0.609	0.221	6.331	0.249***	0.077	0.929	0.862
MEDMSOIL	0.397**	0.186	-0.032	1.100	-0.103	0.279	-0.292**	0.140	-0.673	0.535	-0.601	6.607	0.273*	0.158	0.848	1.018
FLATSLOP	-0.118	0.203	1.964**	0.786	-0.049	0.273	0.071	0.468	0.340	0.535	1.454	1.499	-0.040	0.497	-0.987	2.486
MEDMSLOP	-0.235	0.276	2.219*	1.185	-0.074	0.194	0.399	0.388	0.079	0.098	1.255	3.382	-0.115	0.422	-0.762	2.398
CONSTANT	1.225	0.825	-2.895	2.960	3.358***	0.984	2.980***	0.692	3.635**	1.553	-1.287	12.442	1.437	1.763	3.442	8.516
Joint significance of location variables: $F(7, 45)$	5.47***		0.28		3.08***		5.82***		1.20		1.67		3.85***		1.26	
Anciliary																
σ^2	5.970***	1.793	19.265	17.506	2.260***	0.462	3.275	2.231	9.588*	5.709	18.912	291.129	5.222	4.475	13.634	20.951
λ_1			-0.187	0.794	-0.504	0.617	0.488	0.367	-0.804**	0.391	0.010	0.648	0.894***	0.146	0.366	0.237
λ_2	0.130	0.774			-0.745	0.580	-1.199***	0.341	0.209	0.438	-1.23***	0.426	-0.345	0.927	0.401	0.882
λ_3	0.150	0.557	-0.674**	0.320			0.560	0.390	-0.144	0.526	0.120	0.484	0.319	0.638	0.252	0.577
λ_4	-1.362**	0.584	-0.364	0.281	0.002	0.771			-0.576	0.919	-0.215	0.507	-1.085**	0.531	0.127	0.630
λ_5	0.168	0.292	-0.772	0.816	1.213**	0.588	-0.806***	0.258			1.179	0.834	0.293	1.083	0.572	0.746
λ_6	0.138	0.756	0.941	1.292	0.144	0.704	-0.157	1.071	1.373	1.027			-0.215	0.602	-1.522	1.239
λ_7	-0.220	0.405	-0.113	0.295	-0.420	0.395	0.359	0.525	0.253	0.302	0.513	0.988			-0.355	0.563
λ_8	0.884	0.822	1.060*	0.637	0.235	0.555	0.329	0.418	-0.123	0.617	-0.204	0.171	0.017	0.723		

Note: SE is bootstrapped standard error; *, ** and *** indicate statistical significance at 10%, 5% and 1%; non-significant variables included but not reported here are: EDUCATSPOUS; OTHERINCOM; TLU; RAININDEX.

Paper III

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The impact of shadow prices and farmers' impatience on the allocation of a multipurpose renewable resource in Ethiopia

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ABSTRACT. In a mixed farming system in which farmyard manure (FYM) is considered an important multipurpose renewable resource that can be used to enhance soil organic matter, provide additional income and supply household energy, soil fertility depletion could take place within the perspective of the household allocation pattern of FYM. This paper estimates a system of FYM allocation regressions to examine the role of returns to FYM and farmers' impatience on the propensity to allocate FYM to different uses. We parameterize the model using data from a sample of 493 households in Ethiopia. Results indicate a heightened incentive for diverting FYM from farming to marketing for burning outside the household when returns to selling FYM and the farmer's discount rate are high. These reveal the need for policies that will help to reduce farmers' impatience and encourage the substitution of alternative energy sources to increase the use of FYM as a sustainable land management practice.

1. Introduction

The challenge of achieving sustainable development in developing countries has been closely associated with reversing rates of resource

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degradation (Pender, 1996). In countries where agriculture is the mainstay of the economy, soil fertility depletion is an important cause of resource degradation and leads to low agricultural productivity and declining per capita income. Fundamentally, in the ideal agrarian economy, a productive and sustainable production system requires a combination of inorganic fertilizers and organic fertilizers such as farmyard manure (FYM) to replenish the soil and maintain soil organic matter level (Place *et al.*, 2003; Heerink, 2005). However, the limited use of inorganic and organic nutrient inputs among smallholder farmers exacerbates soil nutrient deficiencies (Place *et al.*, 2003).

One particular strand of literature indicates that the use of inorganic fertilizer is limited in developing countries due to low rural incomes, the high cost of fertilizer, inappropriate public policies and infrastructure constraints (Croppenstedt *et al.*, 2003). Another strand of literature points out that, while FYM has been considered an important renewable resource (Place *et al.*, 2003; Keplinger and Hauck, 2006; Erkossa and Teklewold, 2009), improving soil fertility is severely constrained due to the decline of FYM from the livestock system (Heerink, 2005). Given the limited availability of FYM, household FYM allocation patterns are interlinked with management of soil resources in such a way that the demand for FYM for energy within and outside of farm households shifts FYM allocation in ways that undermine its use in improving soil fertility.

The use of FYM either to provide energy for farm households or to improve soil fertility is well documented (Place *et al.*, 2003; Mekonnen and Köhlin, 2008; Erkossa and Teklewold, 2009). Mekonnen and Köhlin (2008) examine the determinants of the rural households' decisions to use dung as fuel and as soil fertilizer in Ethiopia. Yet previous studies have not considered the role of FYM as a source of additional income when sold to peri-urban and urban dwellers outside the farming community. Our data indicate that farmers on average allocate 34 per cent of their production of FYM for farming as organic fertilizer, 38 per cent for selling as an additional source of income and the remaining 28 per cent for burning as a household source of energy. This multipurpose role of FYM could be associated with two important disparities. First, there is growing evidence (see Mekonnen and Köhlin, 2008) that, despite the knowledge of alternative energy resources such as kerosene, electricity and liquefied petroleum gas, high prices and lack of access hinder the wider use of these as sources of domestic energy. As a consequence, due to the substitutability of FYM for these alternative sources of energy (Heltberg *et al.*, 2000), both the demand for and market price of FYM have risen. Under such conditions, the allocation of FYM among the various alternatives (farming, energy or income source) depends on the selling price of FYM and the return from farming.

Second, due to the long mineralization process whereby nutrients in the organic compounds become available to the crop (Place *et al.*, 2003) and the seasonality of agricultural production, the benefit earned from farming with FYM is not available in the short term compared to the return earned from selling FYM.[1] The discounted utility model states that later returns will be discounted by a fixed proportion of their utility for every time interval that they are delayed. In a perfect market setting, this devaluation should generally be closely related to the market interest rate. However, in the presence of credit market failures and constrained access to financial resources (typical for developing countries such as Ethiopia), farmers' subjective discount rates routinely deviate from and are usually higher than the prevailing market interest rates (Pender, 1996; Bezabih, 2009; Yesuf and Bluffstone, 2009). The underlying assumption of this relationship is that poor individuals with limited financial resources and binding credit constraints discount future consumption at a disproportionately high rate. Following the definition of Becker and Mulligan (1997), an impatient farm household has a low discount factor (high discount rate) and high rate of time preference. The implication here is that allocation of FYM is dependent on the extent of farmers' degree of impatience in waiting for the returns from FYM among the various alternatives. If individuals are impatient, due to an inability to access formal markets to tradeoff current and future consumption, through borrowing, then they may be disinclined to invest in long-term investments Adjustments of FYM may result, such as diverting the resources from the farm to the non-farm. Hence, soil fertility depletion may be explained by the impatience introduced by market failures.

Therefore, building on the economic theory of the agricultural household model under credit and financial constraints, this paper aims to examine the effect of the farmer's discount rate and various returns to FYM on the propensity to allocate FYM as an input for agricultural production or for burning as fuel within and outside of farm households. This study extends the existing economics literature of soil fertility depletion by providing a better understanding of how explicitly incorporating the sale of FYM for an additional source of income competes with using FYM for farming. The study also examines farmer's impatience as a determinant of allocation of FYM for alternative purposes. To the best of our knowledge this is the first study to do so in the economics of soil fertility management.

2. Conceptual framework

To explain the FYM allocation behavior of agricultural households, we construct a farm household model that assumes that farmers are engaged simultaneously in production and consumption decisions. This model is assumed to be non-separable due to the presence of financial and credit market constraints. Non-separability is a common feature of studies with applications to agriculture in developing countries (Jacoby, 1993; Skoufias, 1994). It means that each farm household determines FYM production and consumption by maximizing its utility subject to a shadow price of FYM for different activities, which is unobserved and unknown except to

[1] Agronomic studies have shown that, while the returns from FYM farming are not low, not all of the total nutrients are immediately available for crop uptake (Eghball *et al*., 2004).

the household itself, and which varies between households depending on household and village characteristics (Sadoulet and de Janvry, 1995). We build on Mekonnen and Köhlin (2008) and develop an approach in the spirit of Shively and Fisher (2004) and Fisher *et al*. (2005), who derived a model of a system of labor allocation and provided an assessment on the effect of the household shadow price in a given activity for forest decline. However, we add two main features to the model; first, we allow the various returns from FYM to be driven by profit or consumption motives; and, second, we add an experimentally measured time-preference component to capture farmers' impatience on the decision to divide FYM among household consumption, selling and farming. A detailed discussion of the conceptual model is presented in appendix A.

3. Empirical strategy

The empirical strategy involves a sequence of estimation stages. First, we estimate a production function to obtain the marginal product of FYM for those participating in FYM farming. Second, we use the marginal revenue product estimates from the above step along with the observed selling price and employ a sample selection model to compute shadow returns for the subsample of households that do not supply FYM for farming or the market. Third, we estimate a system of FYM allocation function.

3.1. Estimation of shadow prices

Following Jacoby (1993) and Skoufias (1994), the first step in the empirical analysis is to obtain the value of marginal productivity of FYM (p_f^*) estimated at the slope of the production surface around the input use vector for each farm household. The farm-level production function in logarithmic form is specified as:

$$lnQ_a = \beta_f lnM_f + \sum_k \beta_k \ln x_k + \varepsilon \tag{1}$$

where Q_a refers to the total value of agricultural outputs (**OUTVALU**) produced, M_f is the quantity of FYM used as organic fertilizer (**FYMFARM**), and β_f is the estimated parameter for it; x_k is the quantity of other inputs used, $\beta_k's$ are parameters estimated for other inputs, and ε is the error term. The specified production function includes the following inputs: quantity of inorganic fertilizer (**FERTILIZER**), seed used (**SEED**), hours of labor (**FARMLABR**), cropped area (**CROPAREA**), draft animal services (**BULOCK**), share of area covered with modern crop varieties (**MODERNVAR**) and fraction of area with good soil quality[2] (**GOODSOIL**). Locational dummies (**ZONE1** and **ZONE2**) are also included to control village-specific factors.

[2] Using farmers' soil quality classification method, soil quality in the study areas are grouped into three: ***lem, tef*** and ***lem-tef***, which refer to good, medium and poor soil quality, respectively. The characteristics used by farmers for classification are mainly physical properties (such as depth and thickness of the soil, moisture holding capacity, drainage, workability and erodability) that directly or indirectly affect the soil's capacity for sustainable productivity.

Inorganic fertilizer and modern crop varieties are externally purchased technological inputs. Thus, in the empirical model, they are considered to be potentially endogenous. In line with Jacoby (1993), who worked on cross-sectional data and relied on production and consumption-side instruments that are valid under non-separability, the endogeneity (reverse causation) of technological inputs such as fertilizer and improved varieties is controlled with instruments using the two-stage least square method (IV-2SLS). We identify these endogenous variables with village-specific and household characteristics and verify the statistical validity of the instruments by performing an over-identification test. Following the estimation of the production function, the estimated parameters for FYM are used to derive the value of marginal product (p_f^*) as follows:

$$p_f^* = \frac{\hat{Q}_a}{M_f}\hat{\beta}_f \tag{2}$$

where $\hat{Q}_a$ is the predicted value of output from the estimated coefficients.

The subsamples in this study are likely to be non-random due to the presence of non-participant farm households (about 20 per cent in each activity) for which the marginal product or selling price is not observed. Hence, direct estimation for participants only might lead to potential sample selection bias. A farmer's decision regarding participation in FYM farming or selling may, however, be endogenously determined with the respective return from FYM. Therefore, following the approach of Shively and Fisher (2004) and Fisher *et al*. (2005), we employ a Heckman specification with sample selection to jointly estimate participation in FYM farming and the value of marginal product using maximum likelihood (Heckman, 1974). The linkage between the discrete and continuous parts of the model implies that the participation equation, which essentially serves as an endogenous dummy variable to account for any gap between the observed price and the household shadow price in the given activity, provides a correction for the estimation of the shadow value (Shively and Fisher, 2004).

The empirical identification of the model requires that, in addition to the exogenous variables (both in the participation and outcome equations), one or more identifying variables must be included in the participation equation and at least one variable in the shadow value equation that does not enter into the FYM equations. In the case of FYM farming, to enable the identification of the shadow value we use eight potential variables.[3] These variables are hypothesized to affect the likelihood of participation in FYM farming by changing the household's shadow value. For instance, average plot distance affects FYM productivity and hence the decision to participate

[3] Instruments include: average distance from home to farm (**DSTFARM**); household's access to own means of transportation (**DONKEY**); off-farm income (**OFFINCOM**); herd size (**TLU**); distance to the most visited market center (**DSTMKT**); size of cultivated land (**CRPAREA**); whether household adopts stove (**STOVADOP**); and expenditure on alternative energy sources (**KEROSEN**).

in FYM farming. Identification of FYM allocation equations, on the other hand, is obtained with the use of location variables (an approach employed by Fisher *et al*. (2005)) and extension variables. We expect that the effect of these identifying variables works through their effect on participation and shadow value rather than directly. An estimation method similar to that above is motivated by an extension of Heckman's suggestion for imputing a farmer's asking price for FYM or the shadow price in FYM marketing (the value that the farmer places on FYM for selling). Again, the estimation relies on two behavioral schedules: the function determining participation of a farm household on the market and the function determining the selling price equation.

3.2. Econometric specification: farmyard manure allocation

Because a farmer's FYM allocations decisions across various alternatives are related to one another, it is expected that the disturbance terms across models of each outcome might also be correlated. Such interconnectedness thus implies that OLS models, which assume the absence of correlation among the disturbance terms, yield inefficient estimates of coefficients. A more efficient estimation technique in such a case is the seemingly unrelated regression, or SURE (Zellner, 1962), which simultaneously estimates the three equations as a set and allows for the potential correlation among the unobserved disturbances as well as the relationship between the decisions of FYM allocations. The systems of equations for FYM farming (M_f), burning (M_e) and selling (M_s), respectively, can be expressed more simply as:

$$M_f = \alpha_{ff} p_f^* + \alpha_{fs} p_s^* + \alpha_{f\delta}\delta + \alpha_{fz_q} z_q + \alpha_{fz_c} z_c + \upsilon_f \quad (3)$$

$$M_e = \alpha_{ef} p_f^* + \alpha_{es} p_s^* + \alpha_{e\delta}\delta + \alpha_{ez_q} z_q + \alpha_{ez_c} z_c + \upsilon_e \quad (4)$$

$$M_s = \alpha_{sf} p_f^* + \alpha_{ss} p_s^* + \alpha_{s\delta}\delta + \alpha_{sz_q} z_q + \alpha_{sz_c} z_c + \upsilon_s \quad (5)$$

where p_f^* is the marginal value product of FYM, p_s^* is the selling price of FYM, and δ is the farmer's discount rate; Z_c and Z_q are vectors of household and farm characteristics, respectively; υ is the error term. If the regression disturbances in the different equations are mutually correlated, then: $E[\upsilon_i, \upsilon_j] = \sigma_{ij}$ for $i, j = f, e, s$. The Lagrange multiplier test[4] will test the specification for the SURE model with the null hypothesis of $\sigma_{fs} = \sigma_{fe} = \sigma_{se} = 0$. If the test fails to reject the null hypothesis, estimation with SUR will be efficient.

4. Data and study areas

This study is based on data from household surveys conducted in the mixed crop-livestock farming system of three zones in the central highlands of Ethiopia – East Shewa, West Shewa, and North Shewa. These

[4] The test statistic is given by: $\lambda = N \sum_{i=2}^{3} \sum_{j=1}^{i-1} \frac{\sigma_{ij}^2}{\sigma_{ii}\sigma_{jj}}$. λ has a χ^2 distribution with three degrees of freedom.

surveys were conducted by the Ethiopian Institute of Agricultural Research (EIAR) in 2006. Mixed crop-livestock farming is the dominant farming system in the areas, where FYM is considered an important and integral part of the farming system. The three study areas are found within a radius of 100 km from the capital city of the country, Addis Ababa. The proximity to the capital and the peri-urban areas around the study areas provides important market opportunities for farmers for their agricultural products and byproducts. In particular, the three zones are characterized by differences in the availability and use of the FYM resources and their access to FYM markets. The shorter the distance to the FYM market, the lower the transaction cost, and hence the higher the selling price of FYM.

The initial sample contains 500 randomly selected farm households. However, after removing inconsistent and non-systematically missing information, data from 493 farmers remain for use in our empirical estimation. A two-stage cluster random sampling technique was employed for selecting districts and respondents from each area. The sample households were randomly selected from village rosters that exhaustively record all members of the villages. The data set features detailed information regarding household and farm characteristics, such as annual earnings from selling livestock and livestock products, including selling FYM. The selling price of FYM is defined as the quotient of annual earnings from FYM and the total quantity of sales. The FYM price is determined in local markets and, due to the high transaction costs associated with the bulkiness of the product, we exhibit inter-village price variations. Table 1 contains the descriptions and descriptive statistics of the variables used in the estimations.

Table 2 presents the farm household's total annual production of FYM[5] and its use for different activities. FYM selling in the study sites is also an important source of household income, covering 28–47 per cent of total livestock income. The empirical findings concerning the demand for FYM for farming may be more clearly understood if they are prefaced by the respondent's classification of soil quality – an indicator of soil fertility depletion due to lack of organic fertilizer. The survey participants were asked to evaluate the soil quality of their farms according to the local assessment criteria. Accordingly, on average 35 per cent, 31 per cent and 34 per cent of the respondents' farms, respectively, were classified as having good, medium and poor soil quality. Despite the positive correlation between good soil quality and FYM used for farming (figure 1), having farming plots with medium and poor soil quality might be an indication that such plots need more FYM to improve the soil.

[5] FYM refers to the amount of manure collected from the livestock system. In the study areas, FYM is stored in a pit covered with grasses and leaves or simply put into stacked piles outside the barn for some time prior to land application. At the time of cropland application the quality (nutrient content) of the stored FYM is generally heterogeneous across farmers depending on storage method, application procedure (time and method of application) and the livestock management system (the composition of feed ratio and its moisture content).

Table 1. *Definitions, means and standard deviations of variables used in the regressions*

Variables	*Description*	*Mean*	*Std. Dev.*
OUTVALU	Total output value, ETB	16,658.81	17,206.74
p_f^*	Predicted shadow price of FYM for farming, ETB/ton	1,018.30	568.82
p_s^*	Predicted shadow price of FYM for selling, ETB/ton	667.26	92.49
DISCOUNT	Farmer's discount rate	0.94	0.33
ZONE-1	Dummy: 1 if location is north Shewa	0.42	
ZONE-2	Dummy: 1 if location is west Shewa	0.15	
SEX	Dummy: 1 if male-headed household	0.88	
MARITAL	Dummy: 1 if married	0.86	
EDUCATON	Years of education	4.08	4.11
AGE	Age of the household head, years	46.14	12.90
FAMLYSIZ	Total family size (in adult equivalent[a])	4.69	1.80
MALFAMLSIZ	Male family size (in adult equivalent)	2.62	1.34
FEMFAMLSIZ	Female family size (in adult equivalent)	2.07	0.98
FERTILIZER	Inorganic fertilizer applied, kg	38.72	37.31
FERTEXPEN	Total expenditure on commercial fertilizer, ETB	241.53	233.21
TOTALFYM	Quantity of FYM produced, ton/year	9.17	10.57
BULOCK	Bullock services, hours	281.08	210.48
SEED	Seed used, kg	105.96	80.85
FARMLABR	Labor for farming, hours	664.45	223.54
CROPAREA	Cultivated area, ha	2.33	1.71
MODERNVAR	Fraction of area with modern crop varieties	0.89	0.57
PRIVATGRAZ	Private grazing area, ha	0.07	0.01
HIREINLABR	Dummy: 1 if hire in labor	0.22	
COMPOUND	Size of the compound/garden (m^2)	405.99	143.65
EXTNFREQ	Frequency of extension contact per month	3.79	3.52
DEMONVISIT	Dummy 1: if ever visited demonstration field	0.41	
DISTDA	Distance to extension agent office, hours	0.49	
DISTFARM	Average distance from home to farming plot, hours	0.27	0.17
DISTMKT	Distance to market, hours	0.16	0.16

(*continued*)

Table 1. *Continued*

Variables	*Description*	*Mean*	*Std. Dev.*
DISTWOOD	Distance to fetch fire wood, hours	3.49	1.75
ROTATION	Fraction of area rotated with legume crops	0.21	0.18
GOODSOIL	Fraction of area with good quality soil	0.35	0.05
EQUB	Dummy: 1 if participated on rotating saving and credit club	0.44	
DONKEY	Number of donkeys owned	1.66	1.65
OFFINCOM	Off-farm income, ETB	111.59	231.11
TLU	Herd size (in TLU[b])	6.73	4.09
KEROSEN	Annual kerosene consumption, lit	86.51	78.59
POPSIZE	Population size in the nearest town ('000)	23.46	31.55
TREE	Number of trees owned	98.40	124.11
STOVUSE	Dummy: 1 if use energy saving stove	0.49	

[a]Adapted from the Amsterdam scale (see Deaton and Muellbauer, 1980).
[b]Herd size measured in terms of Tropical Livestock Unit where 1 TLU (which equals 250 kg body mass) = 1 cattle = 6.67 sheep/goat = 1 horse = 1.15 mule = 1.54 donkey = 0.87 mule = 200 poultry.

Table 2. *Average shares of FYM by purposes, contribution of FYM to annual livestock income*

Purpose	*North Shewa*	*West Shewa*	*East Shewa*	*Total*
FYM produced (ton/annum)	9.33 (8.18)	12.67 (16.69)	6.98 (10.11)	9.17 (10.57)
Farming (M_f)	0.27 (0.26)	0.32 (0.20)	0.46 (0.23)	0.34 (0.25)
Selling (M_s)	0.42 (0.27)	0.36 (0.25)	0.31 (0.23)	0.38 (0.26)
Household energy (M_e)	0.31 (0.25)	0.31 (15)	0.23 (0.22)	0.28 (15)
Annual livestock income (Birr)	4,476.88 (5,180.29)	4,313. 42 (8,835.40)	2,966.05 (4,505.32)	4,022.97 (5,747.32)
Share of FYM income	0.30 (0.28)	0.47 (0.39)	0.28 (0.33)	0.32 (0.32)
Number of observations	278	75	140	493

Note: Numbers in parentheses are standard deviation.

In this study, to elicit the farmer's discount rate, a simple choice task was used. This is the most common method for eliciting time preferences (Pender, 1996; Holden *et al*., 1998; Frederick *et al*., 2002; Bezabih, 2009; Yesuf and Bluffstone, 2009). All sample respondents in the household survey were

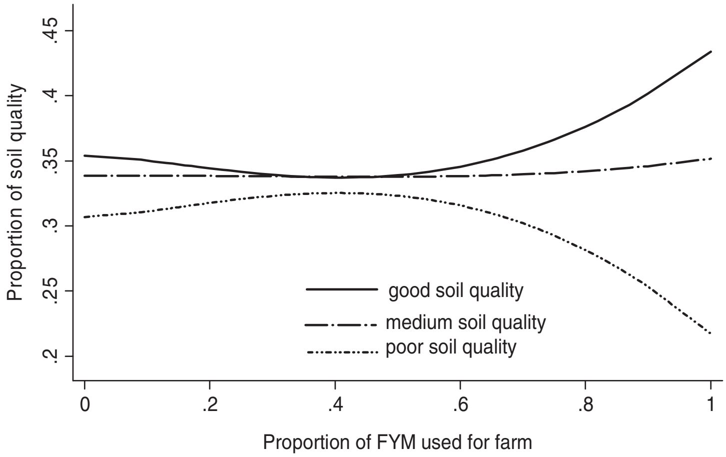

Figure 1. *Correlation between soil quality and FYM used for farming*

confronted with a hypothetical experiment designed to elicit their willingness to delay current consumption. Here, subjects were asked to choose between a smaller, more immediate reward and a larger, more delayed reward. This is the choice between the hypothetical future value payable after one year (almost one growing season) equivalent to a fixed present value. As discussed by Frederick *et al.* (2002), to precisely estimate the discount rate and to avoid a single choice between two inter-temporal options that only reveal an upper or lower boundary of the discount rate, this experiment presented a progression of choices that vary by the amount of delay rewards. Hence, a series of six binary choices between the specified amounts of wheat grain to be received now (50 kg) or the alternative amount of wheat grain to be given a year later (65, 80, 105, 130, 160 and 195 kg)[6] were presented in the order mentioned to show which option the farmer preferred within each choice pair (see appendix B for a description of the experiment).

A few words of caution about the hypothetical approach are in order. One limitation of the hypothetical choice experiment is the uncertainty regarding whether people are motivated to do as they would do if outcomes were real (Frederick *et al.*, 2002). Becker and Mulligan (1997) and the references therein also state that, in imagining future wants, the rate-of-discount factor grows larger as the future becomes more remote.

[6] The choice of the alternative amounts for future rewards is based on taking the midpoint of the alternatives from the credit terms of the local merchants who sometimes provide credit for cash-constrained farmers. The agreement stipulates repayment in kind with grain after harvest at about a 100 per cent interest rate. Formal credit usually linked to farm inputs (modern seeds, fertilizer and pesticide) is provided by farmers' cooperatives with some down-payments, usually 50 per cent. Friends, relatives and neighbors who constitute the other informal sources of financing often provide credit at a zero interest rate or certainly much lower than the rate offered by local merchants.

However, one can also note that the formulation of large-stakes rewards in a one-year timeframe, as in this experiment, might agree with the actual yearly agricultural production cycle, but in terms of cost it is also difficult to conduct with real rewards. Like all experimental elicitation procedures, the results from such types of choice tasks can also be affected by procedural nuances such as the anchoring effect that occurs when respondents are asked to make multiple choices between immediate and delayed rewards; the first choice they face often influences subsequent choices (Frederick *et al*., 2002).

5. Empirical results

5.1. Estimation of shadow values

The first step in the empirical analysis is estimation of the agricultural technology to obtain the marginal revenue product of FYM. Table 3 reports the instrumental variable (2SLS) estimates of the agricultural production function. This estimation is based on farm inputs and the total value of outputs recorded during the main growing season of the 2006 cropping period.[7] The results show that agricultural output significantly increases with the application of FYM. Output is also positively correlated with labor input, seed and cultivated land area. A concern in the estimation of agricultural production function is that agricultural outputs are in part determined by the agricultural activities chosen by the farm households, a worry for the possibility of simultaneity bias. Because of the expectation of reverse causality that inorganic fertilizer and modern seed varieties are determinants of agricultural output and are hence assumed to be potentially endogenous, the model is estimated using an instrumental variable. The choice of instruments for the endogenous regressors in this case is hypothesized to satisfy the relevance and validity conditions in which the instruments are engaged. The application of inorganic fertilizer and modern seed varieties are partly related to the farmer's access to information and household and farm characteristics.

The correlation of the included endogenous regressors with the instruments can be assessed by an examination of the explanatory power of the excluded instruments in the first-stage regressions. The F-statistics in the first-stage regressions for both endogenous variables are jointly significant at the 1 per cent level, which satisfies one condition that ensures instrument validity. However, for models with more than one endogenous variable, as specified here, these indicators may not be sufficiently informative. The Hanson J-test of over-identifying restriction is found not to be significant and therefore confirms the validity of our instruments to satisfy the orthogonality condition required for their employment.

[7] Similar to Skoufias (1994) and Jacoby (1993), the presence of zero values for some inputs is common in smallholder farming. Hence, to keep the empirical estimation manageable in such a case, the logarithmic transformation was carried out by adding one to the relevant inputs.

Table 3. *Instrumental variable (2SLS) estimation of agricultural production function (dependent variable: ln (OUTVALU))*

Variables	*Variable descriptions*	*Coefficients*	*Robust Std. Err.*
ZONE-1	Dummy: 1 if location is north Shewa	−0.809***	0.131
ZONE-2	Dummy: 1 if location is west Shewa	−0.344**	0.154
ln(FYMFARM)	FYM used for farming, tons	0.214**	0.089
ln(MODERNVAR)	Fraction of area with modern crop varieties	0.523	0.467
ln(FERTILIZER)	Inorganic fertilizer applied, kg	−0.151	0.282
ln(BULOCK)	Bullock services, hours	−0.015	0.036
ln(FARMLABR)	Labor for farming, hours	0.329***	0.087
ln(CROPAREA)	Cultivated area, ha	0.375***	0.131
ln(SEED)	Seed used, kg	0.365***	0.113
GOODSOIL	Fraction of area with good quality soil	0.979	0.939
CONSTANT		5.922***	1.357
Joint significance: F (10, 482)		71.10***	
Instrumented variables:		FERTILIZER, MODERNVAR	
Excluded instruments		DISTDA, DISTFARM, EQUB, AGE, FAMLYSIZE	
F test of excluded instruments:			
FERTILIZER: F(5, 479)		3.04***	
MODERNVAR: F(5, 479)		3.60***	
Over identification test of all instruments:			
Hansen J Statistic:		5.185	
$\chi^2(3)$ p-value:		0.159	

Notes: **, *** refer to significance level at 5% and 1%, respectively.

The marginal product of FYM estimated from the production function is observed only for FYM farming participant farmers. Not observing marginal productivity is likely to be indicative of non-participation in FYM farming. Hence, marginal products are imputed for each observation by estimating participation and marginal product equations jointly, matching with the household, farm and village characteristics. This is used to estimate the parameters and thus predict the shadow value of FYM in farming for each observation. Table 4 presents the maximum likelihood result of the determinants of participation in FYM farming and the return from it. Sample selection bias here may be due to self-selection by the farm households who found FYM farming to be more advantageous (due to pre-existing conditions or attributes) than non-FYM farming. Similarly,

Table 4. *Maximum likelihood estimate for participation and shadow values of FYM*

		Farming		*Selling*	
Variables	*Variable descriptions*	*Participation*	*Shadow price*	*Participation*	*Shadow price*
DISTMKT	Distance to market, hours		1824.14 (388.81)***		219.58 (76.41)***
ROTATION	Fraction of area rotated with legume crops		419.00 (193.36)**		−104.24 (53.98)**
EXTNFREQ	Frequency of extension contact per month		80.86 (14.51)***		−25.07 (4.40)***
DEMONVIST	Dummy 1: if ever visited demonstration field		−6.08 (64.44)		16.27 (19.03)
AGE	Age of the household head, years	0.07 (0.04)**	−19.72 (15.02)	−0.08 (0.04)**	13.12 (4.61)***
AGESQR (10^{-3})	Age squared	−0.57 (0.35)*	117.35 (146.25)	0.69 (0.38)*	−101.38 (47.45)**
SEX	Dummy: 1 if male-headed household	0.49 (0.27)*	−98.99 (135.38)	−0.01 (0.029)	60.79 (47.51)
MALFAMLSIZ	Male family size (in adult equivalent)	−0.03 (0.06)	57.12 (26.09)**	−0.01 (0.06)	−10.74 (6.91)
FEMFAMLSIZ	Female family size (in adult equivalent)	−0.04 (0.07)	35.79 (45.77)	0.01 (14)	3.40 (10.93)
EDUCATION	Years of education	−0.04 (0.02)*	5.69 (9.78)	0.02 (0.02)	−5.19 (2.78)*
MARITAL	Dummy: 1 if married	−0.31 (0.24)	19.36 (110.72)	0.09 (0.25)	−21.99 (38.35)
DISTFARM	Average distance from home to farming plot, hours	−0.96 (0.42)**		−1.52 (0.39)***	

(*continued*)

Table 4. *Continued*

		Farming		*Selling*	
Variables	*Variable descriptions*	*Participation*	*Shadow price*	*Participation*	*Shadow price*
DONKEY	Number of donkeys owned	0.18 (0.08)**		−0.03 (0.07)	
OFFINCOM (10^{-3})	Off-farm income, ETB	0.15 (0.32)		0.51 (0.44)	
CROPAREA	Cultivated area, ha	0.01 (0.05)		0.17 (11)***	
TREE (10^{-3})	Number of trees owned	0.12 (0.63)		−0.28 (0.56)	
KEROSEN (10^{-3})	Annual kerosene consumption, lit	3.15 (1.37)**		2.40 (1.12)**	
STOVADOP	Dummy: 1 if use energy saving stove	−0.39 (0.18)**		−0.30 (0.17)*	
TLU	Herd size (in TLU)	−0.08 (0.03)***		0.05 (0.04)	
CONSTANT		−0.13 (0.87)	998.29 (375.41)***	2.33 (0.94)**	463.13 (107.58)***
Number of observations		493	400	493	405
Wald statistic		157.61[a]		104.82[a]	
Joint significance of instruments		20.87[b]	96.47[c]	33.37[b]	61.64[c]
Wald test of independent equations: Prob. > $\chi^2(1)$		0.164		0.007	

Notes: *, **, *** refer to significance level at 10%, 5% and 1%, respectively; parenthetical terms are robust standard errors.
[a]Wald test for joint significance of the explanatory variables distributed as a chi-square with critical values of 27.69 for 13 degrees of freedom at 0.01 probability.
[b]Joint significance of the instruments (DISTFARM, DONKEY, OFFINCOM, CROPAREA, TREE, KEROSEN, STOVADOP and TLU) distributed as a chi-square with critical values of 20.09 for 8 degrees of freedom at 0.01 probability.
[c]Joint significance of the instruments (ZONE-1, ZONE-2, EXTNFREQ and DEMONVIST) distributed as a chi-square with critical values of 13.28 for 4 degrees of freedom at 0.01 probability.
Location controls are included but not shown here.

the shadow return of FYM selling is predicted for each observation by estimating market participation and selling price jointly.

There are different factors determining the selection process. As expected, with the additional eight variables that are included in the participation equation (for both FYM farming and selling), the outcome equations are jointly significantly different from zero ($\chi^2(8) = 33.37$ with a p-value of 0.001 for FYM selling; and $\chi^2(8) = 20.87$ with a p-value of 0.008 for FYM farming). The results suggest the identifying variables are successful at enabling identification. Hence, these variables are important for explaining participation of FYM farming and selling equations. The fitted shadow value of FYM in farming and selling from the above procedure is derived and kept for use in the FYM allocation model. Wald tests for the joint significance of the instruments used in each shadow value equation are presented in table 4.[8] At 0.01 probability, the instruments are jointly significant. This result confirms that our instruments are informative for the identification of FYM allocation equations. A note of caution is that, while the instruments are globally statistically significant, individually some instruments are weak.

5.2. Testing equality of prices

In theory, an individual allocates scarce resources among various alternatives until the point at which the marginal returns across alternatives are equal. By doing so, farmers could choose the most profitable alternative options. For instance, if the productivity of FYM in farming is higher than the return of FYM from selling, it pays for farmers to shift FYM resources into farming and away from selling in the market. It has been observed that the average selling price of FYM (ETB 667/ton) is significantly lower (t-value = 13.21) than the average marginal revenue product of FYM (ETB 1018/ton), but it is significantly higher (t-value = 7.36) than the discounted marginal revenue product (ETB 544.74).[9]

In order to formally test whether the FYM allocations are efficient, the equality between the estimated marginal returns of FYM and the observed FYM price from the markets is tested. This test could shed some light on the presence of farm household preferences that are relevant for determining the allocations. Following the approach of Jacoby (1993) and Skoufias (1994), who relate market wage with marginal productivity of labor in their agricultural labor supply analyses, we regress the discounted marginal product of FYM on the selling price as follows:

$$ln\, p_f^* = \gamma + \varphi\, ln\, p_s^* + v \tag{6}$$

where p_f^* is the discounted marginal revenue product of FYM in farming; p_s^* is the FYM price by selling on the market; and v is the random disturbance.

[8] Instruments include: location variables (ZONE-1 and ZONE-2) and extension variables such as frequency of extension contact (EXTNFREQ) and whether farmers ever visited demonstration fields (DEMONVISIT).

[9] 1 USD = 8.76 ETB at the time of survey.

The regression result from (6) is shown as:[10]

$$ln\ p_f^* = \underset{(1.338)}{13.094} - \underset{(0.206)}{1.077}\, ln\ p_s^*$$

The null hypothesis of efficient FYM allocations is contained in the conditions that $(\gamma, \varphi) = (0, 1)$. The value of F-statistics for $H_0 : \gamma = 0$ and $\varphi = 1$ is 139.26; and the 5 per cent critical value of F(2, 491) is 3.01. The value of the joint F-statistics rejects the hypothesis at standard significance levels. As explained by Skoufias (1994), these test results provide evidence contrary to the efficient operation of the market, and thus indirectly support the concern about non-separability between the production and consumption decisions of farm households. It is possible that there are other explanations for the rejection of the equality of the two values (p_f^* and p_s^*). Often the treatment of households' resource allocation behavior, which creates a wedge between the marginal revenue product and observed market price, could be related to household characteristics and constraints on factor availability and market imperfections (Jacoby, 1993). Another explanation from Jacoby (1993) for this rejection is based on the grounds that the estimated marginal products may in fact be systematically biased so that the instrumental variable method does not lead to consistent estimates. The next section explores the relationship between shadow prices, farmers' impatience and FYM allocations.

5.3. Shadow prices on farmyard manure allocation

The estimated shadow values predicted in the first stage of the analysis together with farmers' degree of impatience and other socioeconomic information were matched with the individual farm household FYM allocation data. The estimation results are presented in table 5. The estimated model performs well. The calculated χ^2-statistic of 4702.75 is statistically significant at the 1 per cent significance level, providing evidence for the hypothesis of joint significance of the explanatory variables across all equations. As expected, the test of independence confirmed the rejection of the null hypothesis, which states that the covariance of the error terms across equations is not correlated. The test supports the estimation with SUR [$\chi^2(3) = 152.477$ with the associated p-value of 0.000]. The estimates of FYM allocation functions with a full set of regressors provide empirical evidence on the effects of the shadow value of FYM-affecting allocations across different purposes. The coefficients for shadow prices $\ell n\ p_s^*$ and $\ell n\ p_f^*$ provide estimates of the uncompensated own-price elasticity for FYM farming and selling, respectively.

The results also provide the uncompensated cross-price elasticity for FYM farming, burning and selling. The estimated results are in agreement with the expectations. The point estimate of the return of FYM from selling ($\ell n\ p_s^*$) and farming ($\ell n\ p_f^*$) in the FYM farming equation is negative but individually statistically different from zero at the 1 per cent significance level for selling price only. The negative sign of FYM selling price in

[10] Figures in parentheses are robust standard errors.

Table 5. *Maximum likelihood estimates for FYM allocation*

		Farming		*Selling*		*Energy*	
Variables	*Variable descriptions*	*Coefficients*	*Std. Err.*	*Coefficients*	*Std. Err.*	*Coefficient*	*Std. Err.*
$\ell n\ p_f^*$	Predicted shadow price of FYM for farming, ETB/ton	0.011	0.026	−0.021	0.085	−0.462***	0.073
$\ell n\ p_s^*$	Predicted shadow price of FYM for selling, ETB/ton	−0.909***	0.211	1.471**	0.698	0.413	0.601
DISCOUNT	Farmer's discount rate	−2.866**	1.267	9.908**	4.184	−5.394	3.601
OFFINCOM (10^{-3})	Off-farm income, ETB	0.045	0.041	−0.148	0.134	0.184	0.115
AGE	Age of the household head, years	0.001	0.005	−0.003	0.017	−0.036**	0.014
AGESQR (10^{-3})	Age squared	0.016	0.048	0.007	0.159	0.244*	0.137
SEX	Dummy: 1 if male-headed household	−0.044	0.038	0.073	0.126	−0.164	0.108
MARITAL	Dummy: 1 if married	0.017	0.033	−0.113	0.109	0.214**	0.094
MALFAMLSIZ	Male family size (in adult equivalent)	−0.003	0.008	0.012	0.025	0.033	0.022
FEMFAMLSIZ	Female family size (in adult equivalent)	0.004	0.010	−0.020	0.032	0.006	0.028
HIREINLABR	Dummy: 1 if hire in labor	0.032	0.023	−0.013	0.075	0.018	0.065
EDUCATION	Years of education	0.000	0.003	−0.004	0.008	0.013*	0.007
FERTEXPEN (10^{-3})	Total expenditure on commercial fertilizer, ETB	−0.487***	0.051	0.712***	0.168	1.049***	0.145
ROTATION	Fraction of area rotated with legume crops	−0.006	0.057	0.167	0.190	0.670***	0.163
DISTMKT	Distance to market, hours	−0.025	0.365	0.989	1.203	−1.005	1.036
DISTFARM	Average distance from home to farming plot, hours	−0.032	0.055	−0.049	0.180	−0.068	0.155
DISTWOOD	Distance to fetch firewood, hours	−0.003	0.005	0.018	0.018	−0.011	0.015
DONKEY	Number of donkeys owned	−0.016*	0.008	−0.018	0.028	−0.021	0.024
CROPAREA	Cultivated area, ha	−0.018	0.033	−0.074	0.109	0.235**	0.094
PRIVATGRAZ	Private grazing area, ha	2.686***	0.926	−2.845	3.056	0.914	2.630

(*continued*)

Table 5. *Continued*

Variables	*Variable descriptions*	*Farming* Coefficients	*Farming* Std. Err.	*Selling* Coefficients	*Selling* Std. Err.	*Energy* Coefficient	*Energy* Std. Err.
COMPOUND	Size of the compound/garden (m^2)	0.011***	0.003	−0.024**	0.010	0.012	0.008
KEROSEN (10^{-3})	Annual kerosene consumption, lit	0.130	0.156	−0.797	0.515	0.944**	0.444
TREE (10^{-3})	Number of trees owned	0.097	0.079	−0.164	0.259	0.134	0.223
STOVUSE	Dummy: 1 if use energy saving stove	0.007	0.024	0.209***	0.080	−0.166**	0.069
TLU	Herd size (in TLU)	0.014***	0.004	0.010	0.012	0.024**	0.010
TOTALFYM	Quantity of FYM produced, ton/year	0.026***	0.001	0.023***	0.004	0.013***	0.003
POPSIZE (10^{-3})	Population size in the nearest town ('000)	−0.001*	0.000	−0.002	0.001	0.001	0.001
CONSTANT		4.716***	1.355	−8.055*	4.473	1.329	3.850
Correlation matrix of residuals							
Farming		1		−0.106		−0.103	
Selling		–		1		−0.536	
Test of independence: $\chi^2(3) = 152.477$; p-value = 0.000							

Note: *, **, *** refer to significance level at 10%, 5% and 1%, respectively.

the farming equation indicates the expected cross-price effect; as the selling price of FYM increases, the farmer responds by allocating less to farming. The estimate for uncompensated elasticity is that a 1 per cent increment of the selling price of FYM leads to an approximately 1 per cent decline of FYM for farming. This jeopardizes a smallholder's soil fertility maintenance with adverse implications on sustainable management of one of the most important natural resources.

The point estimates for the FYM selling price in the FYM selling equation are positive and statistically different from zero at the 5 per cent significance level. As expected, the findings reveal that farmers rationally respond to the change in price of FYM in the allocation of FYM for selling. As for allocating FYM for selling, it basically depends on the extent of the change in FYM for farming and the change in a household's consumption of energy from FYM burning. The increase in the selling price of FYM increases the price in terms of burning at home, thereby making burning FYM more expensive. This substitution effect, then, tends to cut the amount of FYM allocated for household energy. The uncompensated cross-price elasticity is positive but not significant.

5.4. Farmer's impatience on allocation of farmyard manure

Typically, individuals show a systematic preference for receiving a reward immediately rather than at some later moment in time. When a respondent shifts preference from the early amounts to the amount for a later reward, the implicit one-year rate of time preference was calculated as follows: $\delta = \ell n(f/p)$, where the respondent is indifferent between an amount of p at the current time and a reward of f received one year in the future (appendix B). The mean discount rate in this experiment is about 94 per cent. Pender (1996), however, reported a discount rate of 30–60 per cent for Indian villages, whereas Holden *et al*. (1998) found a mean discount rate of 93 per cent for Indonesia, 104 per cent for Zambia and 53 per cent for one village in Ethiopia. Similar to Holden *et al*. (1998) and Pender (1996), who found an upward bias from their experiment that asked farmers to adjust a present value equivalent to a fixed future value, about 64 per cent of farmers in this study were found to have a high discount rate (95–135 per cent) in an experiment that asks the future value equivalent for a fixed present value (figure 2).

From the foregoing discussions, the marginal return of FYM in farming is higher than the price of FYM from selling on the market, although the former presents a delayed outcome while the latter presents immediate benefits. The parameter estimates for the farmer's discount rate are in agreement with the expectation in the FYM allocation equations. The point estimate of farmers' degree of impatience in the FYM-selling equation is statistically different from zero at the 95 per cent confidence level. The positive sign indicates that farmers with a high degree of impatience increase allocation of FYM for selling. The theory that people with a positive time preference show a preference for receiving a commodity immediately is consistent with behaviors observed in the FYM-selling equation. Here, farmers usually receive the return immediately, so that, of the available options, it is the option of choice for impatient farm households.

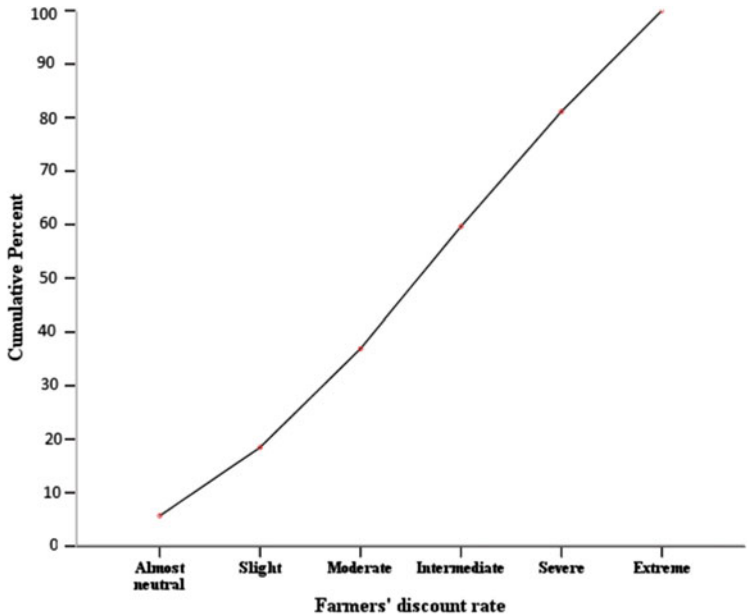

Figure 2. *Farmers' discount rate responses for future value equivalents*

In contrast, the farmer's degree of impatience negatively affects the allocation of FYM for farming and burning, but the effect is statistically significant in the former case only. The outcome of allocating FYM for farming is quite remote due to the seasonality in agriculture, forcing the impatient farmers to switch away from FYM farming. Smallholders operating under imperfect credit market settings may not invest their FYM today to increase the future agricultural productivity of their farms when the alternative of selling FYM is possible to meet immediate subsistence needs. The absence of credit for investing in on-farm improvements or consumption credit to meet immediate needs induces underinvestment and sacrifices the quality of the soil, resulting in lower future productivity and persistent poverty (Marenya and Barrett, 2007).

This result is in accord with the few other studies that combine time preference experiments with field observations for better understanding of field behavior. An empirical study of Ethiopia (Shiferaw and Holden, 1998) found a negative correlation between an individual's rate of time preference and adoption of soil conservation technologies. In Brazil, impatient fishermen in a time preference experiment exploited the fishing grounds more (Fehr and Leibbrandt, 2008), whereas people in Sri Lanka with a higher rate of time preference extracted more non-timber forest products, causing depletion of forest resources (Gunatilake *et al.*, 2007). Therefore, a high rate of time preference is an important constraint for investments in soil conservation and could be viewed as a cause of the continuous depletion of soil resources. In this context, the allocation of FYM in farming plots can be considered a present investment to improve soil fertility, thereby improving future agricultural productivity and returns. The policy implication of this is that fixing the broken credit market is important for investing FYM as soil fertility.

Table 5 also provides several factors that are obvious determinants of the allocation of FYM for the different activities. We find statistical evidence for the change in allocations of FYM for household energy over the life cycle. Our findings show a U-shaped relationship between age and consumption of FYM for household energy. Households spend less FYM for energy until they reach a certain age (around age 70), after which consumption is increased. Herd size (TLU) is a resource variable that provides a good indication of a household's wealth status. The result shows that wealthier households spent more FYM for farming and burning in the households. TLU could also approximate the household's capacity to produce more FYM. The result shows that, as the capacity to produce FYM increases, the amount of FYM spent for farming and burning in the household increases as well. This result corroborates the effect of the quantity of FYM produced at the household level. As production of FYM increases, the amount of FYM allocated for each purpose is increased significantly. The size of the effect is higher for selling and farming, however.

We observe a negative and statistically significant relationship between expenditure on inorganic fertilizer and FYM for farming, suggesting substitutability between FYM and inorganic fertilizer. Although the complementarity is likely due to the beneficial interactive effects of FYM on fertilizer efficiency (Marenya and Barrett, 2007), the substitutability is important for poor smallholders, as they use lower quantities of commercial fertilizers largely due to high price as well as liquidity constraints. The positive and statistically significant coefficients of fertilizer expenditure on FYM selling and burning in the household would seem to show an increase in quantity of FYM for selling and burning in the household when inorganic fertilizer substitutes for FYM for farming.

We find a positive and statistically significant coefficient of the 'KEROSEN' variable in the FYM-burning equation.[11] A possible explanation is the complementarity between consumption of kerosene and FYM used for household sources of energy, though the size of the effect is very small (the elasticity is about 0.08). In rural Ethiopia it is not uncommon to use kerosene as a source of lighting. The coefficient of use of improved stoves in the FYM-burning equation is negative and statistically significant, however. This coefficient is a measure of the technical substitution (Amacher *et al*., 1993) of stoves for FYM, suggesting that improved stoves reduce household FYM consumption by about 15 per cent. This result is consistent with Mekonnen and Köhlin (2008). The same study also indicated that encouraging households to use more efficient cooking stoves is a possible solution to the problem of the limited use of dung as manure. We also observe a positive and statistically significant correlation between use of stoves and FYM selling.

[11] Controlling the prices of alternative sources of fuel (e.g., kerosene) might better capture incentives to participate in alternative uses of FYM. In our case, however, we lack variation if we control these prices.

6. Conclusions

The causes of soil fertility depletion extend beyond the farm, receiving effects from market fundamentals and farmer preferences. The main contributions of this study are the analyses of the effects of various returns of FYM and farmers' impatience with the trade-offs of using FYM as inputs to agriculture or burning FYM within or outside of the household. The empirical analysis is based on a system of equations for the farmers' allocation of FYM for different purposes. The farm household survey data comes from the central highlands of Ethiopia, where a mixed crop-livestock farming system is practiced. The data support the predictions and show that the farmer's time preference and the returns to FYM are important predictors of the allocation of this multi-purpose resource in the real world. Farmers with a high degree of impatience decrease the allocation of FYM to the farm. The higher the selling price of FYM, the higher the incentive for farm households to sell FYM for burning outside the farm households.

In smallholder agriculture, where agricultural productivity remains low, the returns from selling FYM will increase as the demand for biomass fuel rises and supply declines. In Ethiopia, where fuel prices have been rising and electricity infrastructure is poor, there is growing interest in using FYM for energy production. In order to encourage adoption of FYM farming as sustainable land management practice, the results suggest that incentive policies may be developed in conjunction with the fuel-pricing system, including substitution and energy conversion technology such as promotion and dissemination of improved stoves not only to the rural areas but also the surrounding towns.

The high discount rate of the poor due to serious imperfections in the credit markets has received previous attention (Pender, 1996; Becker and Mulligan, 1997; Holden *et al*., 1998; Bezabih, 2009; Yesuf and Bluffstone, 2009; Tanaka *et al*., 2010). The high discount rates observed in this study, on the other hand, indicate the disregard of most farm households for the use of FYM farming with effects on sustainable management of the soil resources. This implies that the poverty reduction scheme and ensuring the functioning of rural credit markets are also important policy directions associated with sustainable land management practices.

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Appendix A: FYM-allocation model

The model presented below captures the case of a farm household involved in a mixed farming system, where FYM (Q_m) is one of the most important byproducts of the system, assumed to be a function of the vector of farm inputs and structural characteristics of the farm household. Utility is derived from consumption of agricultural and purchased goods (C), energy (E), and leisure (L_l). The demand for FYM burning at the farm household level is a derived demand from the demand for energy (E), where energy is sourced from FYM (M_e) and other sources such as kerosene and other biomass (O_e). Agricultural production (Q_a) takes place on individual plots using organic (FYM) and inorganic fertilizer. We assume inorganic fertilizer is the purchased variable input, while FYM is obtained from livestock production within the farm households.

Given a total amount of FYM at the farmer's disposal, the farmer's decision consists of allocating Q_m between farming (M_f), burning in the household (M_e), and selling on the market as an additional source of income (M_s) for burning outside the household. The implication is that farm households in the area are semi-commercial; even if markets for FYM exist, most retain some FYM for home consumption and farm production. Examination of the data for this study has also revealed that all farm households obtained FYM for burning (M_e) and farming (M_f) from their own production system without making any purchase. The net marketed amount of FYM is therefore non-negative: $Q_m - M_e - M_f \geq 0$. Households also choose the amount of labor for on-farm (L_f) and off-farm (L_o) activities. The household budget constraint binds the value of consumption of agricultural goods and purchased goods (C) by a household's total income (Y) that originates from agricultural income (π), off-farm work (L_o) at wage rate (w) and FYM sales (M_s) at a price (p_s). Agricultural production is specified as a function of M_f, L_f and other variable inputs (X), such as inorganic fertilizer, seeds, pesticide, etc. Agricultural income is the farm-restricted profit where the value of the cost of production is subtracted from the total amount of crop produced ($p_a Q_a$).

For each year, the agricultural season is divided into the wet or planting season and the dry or harvesting season. The nature of the agricultural production is such that for FYM applied to the field during the planting season, agricultural output is expected at the harvesting period. In Ethiopia, where agricultural production is mainly rain fed, this is nearly a year-round process. Investing FYM on the farm means postponing the current consumption originated from burning FYM in the household or income earned from selling FYM on the market. This loss, interpreted as the benefit obtained from selling or burning FYM now, is assumed to be compared and offset by the discounted returns of FYM in farming at a later time. When imperfect credit markets prevent perfect consumption smoothing, depending on the individual implicit discount rate, farmers often opt to sell or burn FYM, which limits their ability to use FYM for farming. Hence, with the subjective discount rate parameter (δ), the relationship between time preference and allocation behavior is more pronounced. A farmer's discount rate is expected to affect household resource allocation following the standard intuition: a higher δ should result in higher resources toward current consumption. Formally, given these specifications, farmers are assumed to choose M_f, M_e, M_s, L_l, L_f, L_o, and X so as to:

$$Max\, U = U\,(C, E, L_l; Z_c) \tag{A.1}$$

subject to farmers' resource and productivity restrictions:

$$Y = \frac{1}{\delta}\pi + wL_o + p_s M_s \quad \text{(income constraint)} \tag{A.2}$$

$$\pi = p_a Q_a(M_f, X, L_f; Z_q) - p_x X \quad \text{(farm restricted profit)} \tag{A.3}$$

$$E = E(M_e, O_e) \quad \text{(energy constraint)} \tag{A.4}$$

$$Q_m = M_e + M_s + M_f \quad \text{(FYM constraints)} \tag{A.5}$$

$$L = L_l + L_o + L_f \quad \text{(household time constraints)} \tag{A.6}$$

$$M_i \geq 0 \quad \text{for } i = e, s, f \quad \text{(non-negativity constraints)} \tag{A.7}$$

where Z_c and Z_q are vectors of household and farm characteristics influencing preferences and farm production, respectively.

Substituting the constraints into the utility function above and assuming the farm household's choice at the start of the dry season, we can specify the Lagrangean as:

$$\begin{aligned} \ell = U\big(&C,\ E(Q_m - M_s - M_f, O_e),\ L - L_o - L_f;\ Z_c\big) \\ &+ \lambda\left[1/\delta\left(p_a Q_a(M_f,\ X, L_f;\ Z_q) - p_x X\right) + wL_o + p_s M_s\right] \\ &+ \eta_f M_f + \eta_e M_e + \eta_s M_s \end{aligned} \tag{A.8}$$

where λ is the Lagrangean multiplier associated with income constraints and η_f, η_e and η_s are Lagrangean multipliers associated with inequality constraints on FYM farming, burning and selling, respectively.

Maximization of the Lagrangean with respect to M_s, M_f and M_e provides the following first-order conditions:

$$\frac{\partial U}{\partial E}\frac{\partial E}{\partial M_e} = \lambda\, p_s + \eta_s \tag{A.9}$$

$$\frac{\partial U}{\partial E}\frac{\partial E}{\partial M_e} = \lambda\, \frac{1}{\delta} p_a\, \frac{\partial Q_a}{\partial M_f} + \eta_f \tag{A.10}$$

The above first-order conditions indicate that, at the optimum, farm households allocate FYM across alternative options so as to equate the marginal value of household energy from FYM with that of FYM spent on selling (A.9) or farming (A.10) – that is, the discounted future marginal revenue product from agricultural production or net returns from marketing. In other words, the discounted gains from the extra increment of future agricultural production due to improved soil fertility and the net returns from FYM selling are equalized to the household-specific opportunity cost of FYM for burning. The complementary slackness condition for constrained maximum in equation (A.9) and (A.10) may infer the shadow price of FYM for selling and farming, respectively. When households optimally allocate FYM in the market and in farming, the shadow price of FYM selling ($p_s^* = p_s + \eta_s/\lambda$) and FYM farming ($p_f^* = (1/\delta)p_a(\partial Q_a/\partial M_f) + \eta_f/\lambda$) is equal to the respective observed FYM price ($p_s^* = p_s$) or the discounted marginal value product of FYM ($p_f^* = (1/\delta)p_a(\partial Q_a/\partial M_f)$). This is because, for an interior solution, the complementary slackness condition requires $\eta_i = 0$ given ($M_i > 0$; for $i = f, s$).

However, again following the complementary slackness condition that requires $\eta_i > 0$ for a farmer who exhibits corner solutions ($M_i = 0$; for $i = f, s$), the shadow prices, p_s^* and p_f^*, will be in general greater than the observed selling price and the marginal value product, respectively. The shadow prices of FYM are measured in real terms denoting the unobservable internal prices in the case of non-separability. They may be defined as the market price or returns plus the value that farmers assign to themselves for supplying or not supplying FYM to the market or to the farm. Thus the shadow prices of FYM are endogenously determined by parameters affecting the household's production and consumption decision variables. The first-order conditions above can be combined to derive a set of reduced form of Marshallian demand functions for FYM for farming, for household energy, and the supply of FYM for selling in the market. These are expressed as functions of shadow prices, farmer's time preference, and other individual and farm characteristics:

$$\left.\begin{matrix} M_f \\ M_s \\ M_e \end{matrix}\right\} = m\left(p_s^*,\ p_f^*,\ \delta;\ Z_q,\ Z_c\right) \tag{A.11}$$

Appendix B: Structure of the time preference experiment and farmer's discount rate

Instruction

We would like to know your preference for taking wheat grain now compared to taking wheat grain after a year. Please indicate for each of the following number of choices, whether you would prefer to receive the smaller amount of wheat now or the bigger amount of wheat one year from now. For instance, which would you choose: 50 kg wheat now or 65 kg wheat exactly after one year?

Choice	*Nominal size in kg of wheat*		*Rate of time preference*[a] *(δ), %*	*Discount rate class*
	Now (p)	*12 months (f)*		
1	50	65	26	Almost neutral
2	50	80	47	Slight
3	50	105	74	Moderate
4	50	130	96	Intermediate
5	50	160	116	Severe
6	50	195	136	Extreme

[a]The implicit one-year discount rate: $\delta = \ell n(f/p)$

Paper IV

Jointness in agricultural production and livestock technology adoption in Ethiopia

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Abstract

Even though farmyard manure is considered a promising soil fertilizer in many developing countries, its use in soil fertility restoration is constrained by a multitude of factors. Yet the adoption of a crop-livestock technology could relax these constraints. This paper examines the impact of a joint crop-livestock technology on farmyard manure production and factors determining livestock technology adoption. An endogenous switching regression model is employed to account for self-selection in technology adoption. The model is implemented using survey data from 491 households collected in the central highlands of Ethiopia. The results show that farmers' risk preference, distance to the extension service center, and market access to complementary inputs significantly influence the adoption of improved livestock technology. Adoption of crossbreeding technology creates a positive and significant impact on organic fertilizer production. The positive indirect effect of crop technology is significantly higher for those who adopt livestock technology. This implies that a policy supporting crop-livestock synergies through joint provision of technologies is important in order to increase agricultural productivity through better soil fertility management.

Key words*: *mixed farming, organic fertilizer, technology, switching, Ethiopia

JEL Classification: Q01, Q12, Q16

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1. Introduction

Soil fertility management and food production in the Ethiopian highlands take place in mixed crop-livestock farming systems. Studies carried out in the highland areas have shown that declining soil fertility, which is closely linked to productivity, has been identified as a root cause of declining per capita food production (Pender et al., 2007; Kassie et al., 2009; Kassie et al., 2010). Crop-livestock systems can potentially play a key role in soil fertility management and in ecological balance. Livestock plays a crucial role in providing draft power and recycling of waste products and residue from cropping or agro-industries, and manure from livestock is used for crop production.

Farmyard manure (FYM) use is a commonly suggested method of improving soil fertility in crop-livestock systems. The benefits of using FYM in crop production include improvements in the physical properties of soil and provision of nitrogen, phosphorous, potassium and other mineral nutrients. The application of FYM increases soil organic matter content, and this leads to improved water infiltration and water holding capacity as well as an increased soil carbon content (Kassie et al., 2009; Manyong et al., 2006; Marenya and Barrett, 2007; Girmay et al., 2008). In recognition of these benefits, government and non-governmental organizations have focused on promoting farming with FYM as part of the current agricultural extension system. However, despite the potential advantages, FYM production is constrained by limited supply due to the low performance of indigenous livestock, lack of veterinary services and non-adoption of improved feed and livestock technologies.

The crop sector also plays an important role in the livestock sector by serving as a major source of feed and increased productivity. This jointness of crop-livestock production provides opportunities to think beyond the confines of either crops or livestock enterprises alone and understand the crop-livestock production interdependence. Generally, jointness in agricultural production stems from (1) technical interdependences of multiple products where changes in the level of one output influence the supply of the other inputs, (2) non-allocable inputs where multiple outputs can be produced from the same input, and (3) allocable inputs where the available amount of inputs are used to the various outputs in the production process (Shumway et al., 1984).

Specifically, jointness caused by non-allocable technology (Shumay, 1984) in this study entails the production of outputs such as FYM from the livestock technology and crop by-product (e.g., straw) from the crop technology. The other form of jointness of interest in this study stems from the technical interdependence where changes in the level of one output (i.e., the effect of crop technology in straw production) indirectly influences the supply of input in other production (i.e., straw as livestock feed for FYM production). Hence, the effects of joint crop-livestock technologies in the mixed farming system are thus understood in that technologies for crop production are likely to improve livestock feed and productivity. These effects, jointly with livestock technologies, could improve income and crop-livestock nutrient transfers through increased availability of FYM.

However, empirical research on the impact of joint crop-livestock technologies in the mixed farming system for improving availability of FYM is limited. Additionally, although there is a wealth of empirical studies on agricultural technology adoption and its economic and environmental impacts, the literature on the determinants of livestock technology adoption in developing countries is very thin. [1] Hence, many questions concerning the determinants of adoption of technology in this sector in developing countries remain unanswered. The objectives of this study are threefold. First, assess the contribution of adoption of crossbreeding livestock technology on FYM production; Second, examine the indirect effect of modern crop varieties on FYM production; and third, explore the effect of

[1] An exception to this is Abdulai and Huffman (2005), who used a farm-level model of the adoption rate for crossbred cattle technology to establish the importance of learning effects, geographical proximity to markets, and credit constraints in Tanzania.

farmers' risk preference, market access to complementary inputs, spatial distance to extension services, and other socio-economic characteristics on the propensity of crossbreeding technology adoption.

The paper contributes to the literature in two ways. First, we aim to provide empirical evidence on adoption of livestock technology – a neglected area in the existing technology adoption literature. Second, the outcome of the study will help policy makers and development practitioners understand the impacts of joint crop-livestock technologies on production of yield-augmenting input, i.e., farmyard manure, as this is lacking in previous studies.

2. Econometrics framework

We develop a framework that will allow us to study the mechanics of the household adoption decision of livestock technology and the effect of technology in the production of FYM in a crop-livestock mixed farming system. While the propensity to adopt livestock technology depends on the gains from using the technology, adopters and non-adopters may be systematically different in their observed and unobserved characteristics that simultaneously affect the adoption decision and the outcome variable. This may lead to self-selection problems. A farmer's decision regarding the participation in livestock technology adoption may thus be based on individual self-selection and hence be endogenously determined.

Econometric approaches to deal with selection bias in cross-sectional data include propensity score matching (PSM) and instrumental variable (IV) approaches. PSM only controls for observed heterogeneity while IV can also control for unobserved heterogeneity. The traditional IV treatment effect models with one selection and outcome equation assumes that the impact can be represented as a simple parallel shift with respect to the outcome variable. This is not true in our case where the chow test rejected the assumption of parallel shift [F(18,455) = 6.22, p = 0.000], indicating interaction between observed covariates and adoption of crossbreeding cattle. The endogenous switching regression (ESR) framework can capture such interactions by estimating two separate equations (one for adopters and one for non-adopters) along with the selection equation. In this paper, ESR treatment effects approach adopted to correct for selection bias by controlling for both observed and unobserved heterogeneity. We check robustness of estimates from this model using PSM.

3. **Modeling the impacts of crossbred cattle on Farm Yard Manure production**

The observed outcome of adoption of crossbred cattle can be modeled following a random utility formulation. Consider the i^{th} farm household facing a decision on whether or not to adopt crossbred cattle. Let π^a represent the benefits to the farmer from adoption of crossbred cattle, and let π^n represent the benefit stream from traditional cattle. If other adoption constraints are not limiting, the farmer will adopt crossbred cattle if $T_i^* = (\pi^a - K) - \pi^n > 0$. The net benefit (T_i^*) that the farmer derives from the adoption of crossbred cattle is a latent variable determined by observed characteristics (w_i) and the error term (e_i):

$$T_i^* = w_i\alpha + e_i \text{ with } T_i = \begin{cases} 1 \text{ if } T_i^* > 0 \\ 0 \text{ otherwise} \end{cases} \quad (1)$$

where T_i is a binary indicator variable that equals 1 if a farmer adopts crossbred cattle and zero otherwise; α is a vector of parameters to be estimated, and K is the additional fixed cost associated with adoption of crossbreeding. The outcome functions, conditional on adoption, can be written as an endogenous switching regime model:

$$\text{Regime 1}: Q_{\text{im}}^{\text{a}} = x_{ia}\beta_a + u_{ia,}\ if\ T = 1 \quad (2)$$

$$\text{Regime 2}: Q_{\text{im}}^{n} = x_{in}\beta_n + u_{in,}\ if\ T = 0 \quad (3)$$

where Q_{m}^{a} and Q_{m}^{n} are representing FYM production, with and without adoption, respectively; x represents a vector of covariates, and β is a vector of parameters to be estimated and u_a, u_n, and e are error terms assumed to be trivariate normally distributed with mean zero and a variance-covariance matrix specified as follows:

$$\text{cov}(e, u_a, u_n) = \begin{bmatrix} \sigma_e^2 & \sigma_{ea} & \sigma_{en} \\ \sigma_{ae} & \sigma_a^2 & . \\ \sigma_{\text{ne}} & . & \sigma_{\text{n}}^2 \end{bmatrix}, \quad (4)$$

where $\sigma_e^2 = \text{var}(e), \sigma_a^2 = \text{var}(u_a), \sigma_{\text{n}}^2 = \text{var}(\text{u}_n), \sigma_{ea} = \text{cov}(e, u_{\text{a}}), \text{and } \sigma_{en} = \text{cov}(e, u_n)$. The variance of σ_ε^2 can be assumed to be equal to 1 since the β coefficients in the selection model are estimable up to a scale factor. The covariance between u_{a} and u_n is not defined since Q_{im}^{a} and Q_{im}^{n} are not observed simultaneously (Maddala, 1983). The expected values of u_{a} and u_n conditional on the sample selection is non-zero because the error term in the selection equation (1) is correlated with the error terms of the FYM functions (u_{a} and u_n):

$$E\left(u_{ia} \middle| T_i = 1\right) = \sigma_{\text{ae}} \lambda_{ia}$$
$$= \sigma_{ae} \frac{\phi(w_i \alpha)}{\Phi(w_i \alpha)} \text{ and}$$
$$E\left(u_{in} \middle| T_i = 0\right) = \sigma_{\text{ne}} \lambda_{in}$$
$$= -\sigma_{ne} \frac{\phi(w_i \alpha)}{1 - \Phi(w_i \alpha)},$$

where λ_{ia} and λ_{in} are the inverse Mills ratios computed from the selection equation and will be included in 2 and 3 to correct for selection bias; $\phi(.)$ is the standard normal probability density function, $\Phi(.)$ is the standard normal cumulative density function.

Following Carter and Milon (2005) and Di Falco et al (2011), the conditional expectations of Eq. (2) and (3) are used to derive unbiased estimate of the average adoption effects on the treated and untreated by comparing the excepted outcomes of adopters and non-adopters with and without adoption. These are given as:

$$E\,(Q_m^a / T_i = 1; x_a, w) = x_a \beta_a + \sigma_{ae} \lambda_{ia} \quad (5a)$$

$$E\,(Q_m^n / T_i = 1; x_n, w) = x_a \beta_n + \sigma_{ne} \lambda_{ia} \quad (5b)$$

$$E\left(Q_m^n / T_i = 0; x_n, w\right) = x_n \beta_n - \sigma_{ne} \lambda_{in} \quad (5c)$$

$$E\,(Q_m^a / T_i = 0; x_a, w) = x_n \beta_a - \sigma_{ae} \lambda_{in} \quad (5d)$$

Note that $E(Q_{im}^{a}/T_i=1)$ and $E(Q_{im}^{n}/T_i=0)$ represent observed expected FYM production quantities, while $E(Q_{im}^{n}/T_i=1)$ and $E(Q_{im}^{a}/T_i=0)$ represent counterfactual expected production quantities. Using these four expected values, the average treatment effect on the treated (ATT) and untreated (ATU) computed as follow. The ATT computed as the difference between (5a) and (5b):

$$ATT = E(Q_{im}^{a} | T=1, x, w) - E(Q_{im}^{n} | T=1, x, w) = x_{ia}(\beta_a - \beta_n) + \lambda_{ia}(\sigma_{ae} - \sigma_{ne}) \qquad (6)$$

Similarly, the expected change in non-adopter's FYM production, the effect of the treatment on the untreated (ATU) is given as the difference between (5d) and (5c):

$$ATU = E(Q_{im}^{a} | T=0, x) - E(Q_{im}^{n} | T=0, x, w) = x_{in}(\beta_a - \beta_n) + \lambda_{in}(\sigma_{a\varepsilon} - \sigma_{n\varepsilon}) \qquad (7)$$

The first term on the right hand side of equation (6) represents the expected change in adopter's mean outcome, if adopters' characteristics had same return as non-adopters, or if adopters had similar characteristics as non-adopters. The second term (λ) is the selection term that captures all potential effects of difference in unobserved variables. For the effect of treatment on the untreated, Equation (7) can be interpreted in the same way.

The difference between equations (6) and (7) gives the transitional heterogeneity effect. This provides information on whether the adoption effect is larger or smaller for the adopters or non-adopters groups. This difference between the two groups could happen because those who adopt may exhibit a different outcome regardless of adoption due to other endogenous determinants of the outcome.

Identification is fundamental in the endogenous switching regression model. The w vector therefore should contain additional explanatory variables that affect the adoption equation directly but not the outcome equations. The variables considered as instrument include farmers' risk preference, distance to development workers office and credit (participation in rotating saving and credit clubs). We follow the simple falsification test of Di

Falco et al. (2011) to establish the admissibility of these instruments. The results reveal that the instruments are jointly statistically significant in the adoption equation ($\chi^2(3) = 21.18$, p = 0.000) but not in the outcome equations ($F(3, 199) = 1.46$, p = 0.223).

The ESR estimated using full information maximum likelihood method (FIML) following Lokshin and Sajaia (2004).

In addition to the ESR, we also employed a semi-parametric matching procedure to further check results robustness. The parametric method used in this paper might have some limitations. The resulting parameter estimates from endogenous switching regression model are subject to the underlying assumption of trivariate normal distribution of the errors in the adoption and outcome equations. Moreover, the production equations also tend to impose a linear functional form assumption. We therefore implement a propensity score matching (PSM) method because of the free distributional and flexible functional form assumption. The matching process involves pairing a group of adopters and non-adopters of crossbreeding that are similar in terms of all their relevant observable characteristics.

The PSM model used to construct counterfactual and reduce problems of sample selection bias due to observables. It is defined as the conditional probability that a farmer adopts crossbreeding cattle given covariates (Rosenbaum and Rubin, 1983). This is given as:

$$p(w) = \Pr(T_i = 1 / w) = E(T_i / w) \tag{8}$$

The conditional distribution of w, given the propensity score $p(w)$, is similar for adopters and non-adopters. After estimating the $p(w)$, the average adoption effect for adopter households (ATT) can be estimated as:

$$ATT = E\left\{Q_{im}^{a} - Q_{im}^{n} / T_i = 1, p(w)\right\} \tag{9}$$

Various matching techniques have been proposed in the literature to match adopters and non-adopters with similar propensity scores. The nearest neighbor matching (NNM) and kernel-based matching (KBM) methods are widely used in matching studies (Kassie et al., 2010). We employed both approaches in this study. The basic idea of the methods is to numerically search for neighbors of non-adopter farm households that have a propensity score that is very close to that of the adopter farm households (Rosenbaum and Rubin, 1983).

4. Study areas and data descriptions

The data used in this study comes from a survey of farm households conducted in 2006 by the Ethiopian Institute of Agricultural Research (EIAR). The survey consists of 491 farm households from seven different districts of Ethiopia's central highlands. In Ethiopia, the highlands represent areas higher than 1,500 m above sea level. They cover about 44% of the total area and are inhabited by 90% of the country's human population and 75% of the livestock population. In Ethiopia, the livestock sector contributes about 16% of the national and 27%-30% of the agricultural GDP, and generates 13% of the country's export earnings (Ministry of Agriculture and Rural Development, 2007). Farmers in the study areas are familiar with the traditional crop-livestock mixed farming systems. The mixed farming system in these areas is considered as integrating different type crop and livestock. The major crops grown in the study areas include wheat, tef [2], chickpeas, lentils, grasspeas, and fababeans. Cattle (oxen and cow), small ruminants (sheep and goat), and poultry are also part of the area's farming system.

We employed a two-stage cluster random sampling technique for selecting districts and households from each area. A structured questionnaire was prepared and administered using trained enumerators for the purpose of interviewing each sampled household's head.

The adoption model incorporates household-specific constraints that are due to the associated market and institutional failures, including poor access to information and complementary inputs, and risk and uncertainty associated with farm households' engagement in the adoption process. As pointed out by Abdulai and Huffman (2005), livestock

[2] An indigenous small seeded cereal crop mainly used for making a popular traditional pancake – like the local bread called *injera*.

technologies have been the source of puzzling outcomes stemming from the fact that livestock production is usually very sensitive to changing environments and market conditions. Dairy production, for example, which has received major attention in almost all countries and has shown varying degrees of success, is hampered by yield-reducing environmental stresses, inadequate feed production, poor nutritional management, high capital costs, limited market size, low costs of competing imports, and product perishability (Steinfeld et al., 2006). Under such uncertain conditions, risk-averse farmers are less likely to adopt livestock technologies such as crossbreeding to improve productivity.

Thus, the survey was designed to include instruments [3] to elicit farmers' risk preferences as well. The approach was set up following the experimental method of Binswanger (1980). This approach, which could be conducted as a hypothetical or a real-payoffs situation, measures attitudes by observing farmers' reactions to a set of gambles. In the survey, respondents were presented with certain real lotteries of the form (q_{max}, q_{min}, p), promising a real monetary prize for q_{max} with probability p, or q_{min} with probability $1 - p$. The lotteries represent different farming conditions with six different payoff levels for a given probability of bad or good outcome (such as harvesting). The sample farm households were allowed to choose from the different payoff alternatives. Once the households had selected one of the alternatives, they had a 50/50 probability of getting the bad and getting the good payoff.

The experimental method consisted of offering farmers a set of alternatives representing different risk-aversion classes (extreme, severe, intermediate, moderate, slight, and neutral risk aversion), within which a higher expected gain could only be obtained at the cost of higher variance, and thus a decline in risk aversion. It is generally acknowledged that experiments conducted without real payment options may suffer from hypothetical bias. In

[3] See Teklewold and Köhlin 2011 for the basic structure of the instrument used for measuring farmers' risk preference.

order to avoid such a problem and provide enough incentive for the farmers to reveal their true preferences, our experiment included a real payoff.

As is common in many developing countries, the public research and higher education institutions as well as some non-governmental organizations are the major suppliers of crossbreeding in Ethiopia. The diffusion of the technology from these sources is often channeled to farmers through extension agents, with limited private-sector participation. This indicates that with a weak institutional setup, the role of access to information in the crossbreeding adoption decision is measured based on farmers' travel distance to the extension service center.

Furthermore, as with most innovations that involve a package of inputs (Carlson et al., 1993), lack of access to complementary inputs such as veterinary services, supplementary feeds, and human capital may also influence the productivity of the livestock production system and therefore hinder adoption of crossbred cattle. The constraints in accessing complementary input markets to obtain, e.g., veterinary services and supplementary feeds are directly associated with the transaction cost that farmers may face in these markets. This access to inputs is measured by the distance to the nearest input markets and distance to main road in hours of walking.

Increases in human capital increases the returns to adopting new technologies and make the potential user more efficient in gathering and interpreting information (Woznaik, 1993). Technical training is usually considered as a component of human capital. Carlson et al. (1993) define it as disembodied technological change taking the form of knowledge about improved methods of production. Because of technical training, farmers could realize the advantages of new technologies and adjust their production decisions by incorporating the innovations in to the production process. We thus control for the possible role of subject-oriented technical skill by including a dummy variable taking the value one if the household attends training on livestock production and management practices before adoption takes place.

The quantity of FYM produced (metric tons per annum) is the dependent variable in the outcome equation. Modern livestock technologies (such as crossbred cattle) are important in order to increase the production of livestock products and by-products (Steinfield et al., 2006). Thus it is reasonable here to consider FYM production differential among adopters and non-adopter households. Following the definition of Abdulai and Huffman (2005), and to identify the regimes in the switching regressions, we considered livestock technology-adopting households defined as households reporting to own at least one crossbred[4] cattle, while non-adopting households are defined as those that use only indigenous or local breeds. Based on this classification, at the time of the survey, 227 farm households (46%) in the sample were adopters. We control crop technology via cultivated area covered with improved crop varieties. Modern seed varieties are the major agricultural technologies used for crop production in the study areas. Improved cereal and legume crop seeds covered about 50% of the total cultivated land in the 2006 cropping season. Table 1 presents definitions and descriptive statistics of the variables used in the regression.

[4] Crossbreeding of indigenous cattle breeds (Borana, Barca, and Horro) with exotic sire breeds (Fersian, Jersey, and Simmental).

Table 1. Definitions and descriptive statistics

Variables	Definition	Non-adopter	adopter
Technologies			
LIVETECHNO	1 if own crossbred cattle	0.54	0.46
CROPTECHNO	Area covered with modern crop variety, ha	0.79 (0.75)	1.01 (0.69)
Extension service			
DISTANCEDA	Spatial distance to extension agent office, hrs	0.50 (0.40)	0.40 (0.40)
RISK	Farmer's risk preference (Rank)		
	1=Neutral to preferring	0.12	0.21
	2=Slight to neutral	0.09	0.15
	3=Moderate	0.20	0.19
	4=Intermediate	0.18	0.19
	5=Severe	0.14	0.08
	6=Extreme aversion	0.27	0.18
Market access			
DISTROAD	Distance to the main road, hrs	0.08 (0.14)	0.12 (0.19)
DISTMKT	Distance to market, hrs	0.15 (0.13)	0.17 (0.18)
Other socio-economic variables			
COMUNALGRAZ	1 if farmer has access to communal grazing land	0.34	0.37
PRIVATGRAL	Private grazing land area, ha	0.06 (0.06)	0.08 (0.10)
TLU	Livestock size (in Tropical Livestock Unit)	5.82 (3.01)	7.82 (4.86)
COOPMEMB	1 if member of the cooperative	0.08	0.21
ZEROGRAZ	1 if uses cut and feeding system	0.03	0.09
OFFARM	1 if involved in off-farm work	0.36	0.47
CULTIVATED	Cultivated land area, ha	2.15 (1.53)	2.54 (1.88)
AGE	Age in years	46.00 (13.00)	47.00 (13.00)
MALEHEAD	1 if household head is male	0.87	0.91
FAMLYSIZE	Family size (in adult equivalent)	5.00 (2.00)	5.00 (2.00)
EDUCATION	Years of education	3.29 (3.72)	4.99 (4.35)
TRAININGLIVE	1 if participated in training on livestock management before adoption	0.05	0.30
EQUIB	1 if involved in rotating credit and saving club	0.42	0.47
Locations			
ALELTU	1 if located in Aleltu district	0.15	0.14
BEREH	1 if located in Bereh district	0.12	0.17
SULULTA	1 if located in Sululta district	0.13	0.15
ALEMGENA	1 if located in Alemgena district	0.18	0.12
ADA	1 if located in Ada district	0.14	0.14
AKAKI	1 if located in Akaki district	0.17	0.11
KUYU	1 if located in Kuyu district	0.11	0.18
N	Number of observations	265	226

* Figures in parentheses are standard deviation.

5. Estimation results

5.1 The switching equation: determinants of adoption

Table 2 reports the maximum likelihood estimates of the parameters of the switching regression for the crossbreeding adoption and the outcome equations.

Table 2. Endogenous switching regression results: livestock technology adoption and FYM equations

Variables	Switcher		FYM equation			
			Adopter		Non-adopter	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
CONSTANT	-0.922	0.838	0.828	0.529	1.634***	0.386
CROPTECHNO	0.744	0.797	0.549***	0.100	0.275**	0.136
Residual for CROPTECHNO	0.006	0.817	-	-	-	-
FAMLYSIZE	0.049	0.043	0.027	0.024	0.022	0.025
CULTIVATED	-0.037	0.070	-0.067**	0.029	-0.007	0.035
PRIVATGRAZ	-0.236	1.031	0.365	0.423	0.826	0.656
COMUNALGRAZ	0.009	0.178	-0.013	0.093	-0.234**	0.106
TLU	0.020	0.068	0.126***	0.028	0.016	0.044
TLU-squared	0.003	0.004	-0.003***	0.001	-0.001	0.003
ZEROGRAZ	1.205***	0.288	0.712***	0.221	-0.008	0.212
TRAININGLIVE	0.971***	0.232	0.245**	0.108	-0.289*	0.163
COOPMEMB	1.236***	0.333	0.571***	0.202	0.292	0.238
OFFARM	0.251*	0.143	0.030	0.082	-0.284***	0.082
DISTROAD	-2.327***	0.604	-1.084***	0.332	-0.661	0.467
DISTMKT	-1.926	1.923	-1.801***	0.388	-1.752***	0.479
AGE	0.014	0.030	-0.001	0.022	-0.013	0.014
$AGE^2/1000$	-0.071	0.289	0.061	0.216	0.095	0.130
MALEHEAD	-0.103	0.201	-0.277**	0.119	-0.055	0.095
EDUCATION	0.071***	0.019	0.031***	0.010	-0.032***	0.011
EQUIB	0.010	0.117	-	-	-	-
RISK	-0.082**	0.034	-	-	-	-
DISTANCEDA	-0.316**	0.138	-	-	-	-
Sigma (σ_i)			0.606***	0.073	0.568***	0.091
rho (ρ_i)			0.859***	0.099	-0.929**	0.100
Joint significance of instruments			$F(3, 199)^a = 1.46$ $\chi^2(3)^b = 21.18$***			
Number of observation				491		
Wald χ^2				167.90		
Log pseudolikelihood				-544.09		

*significant at 10%; ** significant at 5%; *** significant at 1%; [a] and [b] refer to joint significance test in the outcome and selection equation, respectively. District dummies are included to control for agro-ecological differences across locations, but the results are not shown here.

Most of the results in the switching equation are in line with the expectation. There is a negative association between distance to extension services from residences and adoption of crossbreeding – as the distance increases, adoption of the technology decreases. The result is consistent with the prediction of the innovation adoption model that the shorter the distance, the better the opportunity to obtain information, the better the communication in the innovation diffusion process, and the lower the transaction cost of accessing the information and technologies (Rogers, 1962; Wozniak, 1993; Abdulai et al., 2008).

Farmers' market access to improved livestock feeds (concentrate feeds) and to veterinary services are found to be important determinants of crossbreeding adoption. The coefficients of variables for input market access (distance to road and distance to market) are both negative and jointly statistically significant. The result is in agreement with Abdulai and Huffman (2005), who argue that increased productivity of the livestock system based on crossbreeding is not intrinsic to the modified germplasm but is rather a function of the availability of complimentary inputs; without coupling these supporting technological inputs, adoption of crossbred cattle by farmers might not be likely. The positive and significant effect of technical training on adoption of crossbreeding is a clear indication of the importance of subject-specific skills for the critical evaluation of innovations. With subject-oriented skills – here training on livestock production and management practices before adoption takes place – farmers' entrepreneurial abilities, resource allocation skills in particular, become increasingly advanced (Schultz 1975; Carlson et al., 1993; Wozniak, 1993). Evidence on the importance of human capital in the adoption of new technologies provides support for policy initiatives such as educational support facilities for the technologies.

About 44% of the sample households (about 58% of crossbreeding non-adopters and 45% of crossbreeding adopters) preferred the alternatives representing the intermediate to extreme risk-aversion categories (Table 1). This figure agrees with that of Yesuf and

Bluffstone (2009) and is slightly lower than that of Teklewold and Köhlin (2011), who found that about 50% and 63% of farm households in the Ethiopian highlands fell in the mentioned risk-aversion categories, respectively. The estimation results show that farmers' attitudes to risk have a negative effect on the propensity to adopt crossbreeding livestock technology. Understandably, keeping crossbred cattle is likely affected by several random variables that bring uncertainty to the yield and even risk of technology failure, e.g., death of cattle due to the need for intensive and costly management practices (Abdulai and Huffman, 2005). Consistent with Baerenklau (2005) and Carlson et al. (1993), the risk-averse farmers who do not invest in livestock technology may accept the uncertain consequences, hence a disincentive effect on the likelihood of using the technologies. Risk-averse farmers endeavor to stay away from strategies of having crossbred cattle that are expected to yield relatively high variance in farm income, and instead tend toward the status quo with relatively low variance, possibly at the cost of some reduction in expected farm income.

The estimated coefficient for the crop technology is positive on livestock technology adoption, but not statistically significant at conventional levels. We expect crop technology to be endogenous to the adoption of livestock technology. For instance, farmers may allocate more land to improved crop technology if they own crossbred cattle. Hence, we need to instrument crop technology. We do so by using as instruments the average distance of farming plots and whether farmers visited crop demonstration farms. There is no reason to suspect that the distance to plots and visiting demonstration farms will affect the decision to adopt livestock technology except through their effect on adoption of crop technology. The instruments are jointly highly significant with an F-statistic of 4.95. Since the livestock technology adoption variable is dichotomous and our endogenous variable is continuous, we use the Rivers and Vuong (1988) approach to instrumentation and include the reduced form residuals from the instrumenting regression[5] in the regression. The t-statistic of the predicted residual is only 0.01, which suggests that endogeneity is not a problem.

The additional insight from the switching equation is that the coefficient of education is positive and statistically significant, which supports the human capital theory of innovation diffusion (Wozniak, 1993; Abdulai and Huffman, 2005). The use of a zero grazing system, membership in farmers' cooperatives, and participation in off-farm activities are all positively correlated with adoption of crossbreeding. This points to the important role of product market and asset market imperfections in the technology adoption process.

5.2 The farmyard manure production equation

Table 2 presents estimates of the endogenous switching FYM production regression model. We also estimated the exogenous switching[6] FYM production model to reveal important differences between the two models. This approach assumes that technology adoption is exogenously determined although it is potentially a choice variable. However, allowing for correlation between the error terms of the FYM equations and the selection equation leads to an upward correction for the adopters and downward correction for the non-adopters for most of the coefficients of the covariates.

For farm households that did not adopt crossbreeding, the correlation coefficients are negative ($\rho = -0.929$) and statistically significant; for the adopters they are positive ($\rho = 0.859$) and significantly different from zero. Therefore, the hypothesis of absence of sample selectivity bias may be rejected, and the estimated selection effect is negative for the non-adopters and positive for the adopters. The result allows estimation with endogenous switching to control for the predicted probability of adoption in order to correct for a possible selection effect associated with unobserved factors that might simultaneously affect the participation and outcome decision.

[5] To save space, the results for the instrumenting regression are omitted.
[6] To save space, the empirical estimates of the exogenous switching model are not presented here.

The signs of the correlation coefficients imply that farm households that adopted crossbreeding have unobserved characteristics that allow them to produce more than a random farm household from the sample. However, non-adopters do not do better than random households.

The result of the switching regression model could logically link joint application of crop-livestock technologies to organic fertilizer production. As expected, the result reveals the difference between adopters and non-adopters of crossbreeding on the effect of crop technology on FYM production. In both cases, this effect is positive and significant. However, the effect of crop technology is higher for farm households that adopt crossbreed cattle (0.55 percentage points) than those that use traditional livestock production practices (0.28 percentage points). The explanations for the significant indirect effect of modern crop varieties adopted in the cropping system on FYM production in the livestock system may hold in two ways. Firstly, in crop-livestock systems, farmers usually choose to grow modern crop varieties that could increase both grain and straw yields (Traxler and Byerlee, 1993; Magnan et al., 2012). Straw is a valuable source of animal fodder to increase the production of livestock products and by-products such as FYM for small farmers in regions characterized by an intensive crop-livestock system, low or high seasonal biomass production, and local fodder markets that are isolated due to high transportation costs (Traxler and Byerlee, 1993; Marenya and Barrett, 2007; Magnan et al., 2012). Secondly, the increase in grain productivity and income may relax financial constraints to buy inputs for livestock production.

The switching regression results also provide insight on the contribution of other socio-economic variables to FYM production. The use of zero grazing systems (stall-feeding), herd size (in terms of tropical livestock unit (TLU)), and membership in farmers' cooperatives are the three most important variables positively affecting FYM production of farm households that adopted crossbreeding. The role of the zero grazing system is important for increasing FYM production, compared to the open grazing system. With stall feeding systems, farmers basically keep their livestock at a certain place that allows them to provide better management and close follow-ups, and that naturally also offers the opportunity for farmers to collect the by-products (such as dung) with minimum effort.

Even though TLU has a positive effect on FYM production, its implication for policy recommendations must be considered with great care, as it might be constrained, e.g., by shortage of grazing land as well as overgrazing (because of overstocking) – problems that might cause land degradation. Here we may also observe a parabolic-shaped relationship between FYM production and herd size. This non-linear relationship indicates that livestock output increases with the size of livestock until a certain herd size and then declines due to overstocking. The result also implies that controlling the number of animals and shifting to improved breeds are other possible important sources of efficiency gains, especially in a developing country where large numbers of low-producing animals are available (Herrero et al., 2009).

The regression result also reveals the negative and significant effect of market access on FYM production. Education has significant impacts, with a positive effect for adopters and a negative effect for non-adopters. Female-led households produce significantly more FYM than do male-led households. Perhaps in rural areas women could be responsible for the collection, management, marketing, and utilization of FYM. However, a non-significant gender effect on FYM production is found in the absence of the crossbreeding technology.

5.3 Estimation of average crossbreeding adoption effect

We predict unconditional and conditional expected FYM production in each regime (Table 3). The unconditional FYM production could be interpreted as the expected or suggested FYM quantity before the farm household decides on a particular regime, while conditional FYM is the quantity for farm households that actually made a decision on whether or not to adopt the technology. As for the unconditional FYM production, we find an average production of 6.49 and 3.97 tons for adopters and non-adopters, respectively. This represents a 64% (2.52 tons) advantage of adopting the livestock technology for a randomly selected farm household. This expected effect is lower than the difference between the sample means of FYM production under actual conditions, which is ~5 tons (calculated as 10.67 – 5.53). This illustrates the fact that adopters and non-adopters have systematically different characteristics; simply contrasting sample averages is likely to provide misleading estimates.

Table 3. Expected quantity (ton/year) of FYM produced under actual and counterfactual conditions and average adoption effects

Decision	Unconditional	Conditional on farm households that	
		Adopted	Did not adopt
Adopting	$E\left(Q_{mi}^{a}\right)$ = 6.49 (0.19)	$E\left(Q_{mi}^{a} \mid T_{li}=1\right)$ = 10.67 (0.33)	$E\left(Q_{mi}^{a} \mid T_{li}=0\right)$ = 3.68 (0.08)
Not-adopting	$E\left(Q_{mi}^{n}\right)$ = 3.97 (0.08)	$E\left(Q_{mi}^{n} \mid T_{li}=1\right)$ = 2.72 (0.09)	$E\left(Q_{mi}^{n} \mid T_{li}=0\right)$ = 5.53 (0.14)
Effects	**2.52 (0.20)**	**7.94 (0.34)**	**-1.84 (0.16)**

* Figures in parentheses are standard errors. All differences are statistically significant at the 1% level

The average adoption effect for farm households that did adopt in the actual and counterfactual case is 7.94 tons (10.67 tons versus 2.72 tons), an increase of 292%. This is the effect of crossbreeding on the treated households (i.e., households that adopted the technology). The result points to a higher-than-expected crossbreeding effect for randomly drawn farm households. The difference between the two measures (i.e., 7.94 – 2.52 = 5.42 tons) indicates the extent of positive self-selection. The expected adoption effect for untreated households (farm households that did not adopt crossbreeding) is -1.84 tons FYM (3.68 tons versus 5.53 tons). This is, however, lower than the unconditional adoption effect (i.e., 2.52 – -1.84 = 4.36 tons), which indicates negative self-selection. The difference between the average adoption effect for farm households that did adopt (7.94) and those that did not adopt (-1.84) is the transitional heterogeneity (Di Falco et al., 2011). This indicates that farm households that did adopt the technology have systematically different characteristics than those that did not adopt, making adopters better producers than non-adopters even without adopting the technology. This finding highlights that improvement in FYM production requires not only encouragement of adoption of high breed livestock technology but also consideration of the associated socio-economic characteristics such as complementary market, cropping, and livestock management options.

To analyze FYM production heterogeneity further, we predict unconditional and conditional production with different market, livestock, and crop production characteristics (Table 4).

Table 4. Estimation of average crossbreeding adoption effect on FYM production (tons/year) under different crop-livestock production scenarios using switching regression

Scenarios			Average adoption effect		
Zero grazing*	Cooperative member*	Proportion of area covered with improved crop varieties	Unconditional	Conditional on farm households that	
				Adopted	Didn't adopt
0	0	< 0.25	1.33	6.49	-2.72
0	0	0.25 - 0.85	1.97	6.22	-2.96
0	0	0.85 - 1.0	2.56	7.47	-2.62
0	1	< 0.25	5.17	6.05	-2.90
0	1	0.25 - 0.85	4.84	9.29	-2.33
0	1	0.85 - 1.0	3.62	5.43	-4.16
1	0	< 0.25	3.79	6.44	-2.52
1	0	0.25 - 0.85	7.85	11.81	-2.11
1	0	0.85 - 1.0	7.46	10.56	-5.87
1	1	< 0.25	8.65	10.37	-3.14
1	1	0.25 - 0.85	2.25	6.66	-0.91
1	1	0.85 - 1.0	6.21	11.35	-0.47

*: 1= if practiced; 0=otherwise

The unconditional and conditional average crossbreeding adoption effects tend to increase when the livestock management practice is further integrated with increased intensity of crop technology. For instance, farm households that practiced the stubble-feeding system and grew modern crop varieties on more than 85% of the cultivated land produced 14.7 tons of FYM if using crossbred livestock, while they produced only 3.4 tons under the traditional livestock production system. Under such a scenario, the average adoption effect for farm households that did adopt is 11.3 tons and -0.47 tons for farm households that did not adopt crossbreeding. This pattern probably reflects the complementarity between crop and livestock production.

Table 5 also presents the average crossbreeding adoption effects estimated by the KBM and NNM methods, as well as indicators of the matching quality from the matching models.

Table 5 Estimation of average crossbreeding adoption effects (ATT) according to extent of modern crop variety adoption using Propensity Score Matching Methods

Matching algorithm	Proportion of area covered with improved crop varieties	ATT	Absolute standardized bias			p-value of LR		Number of observations with in common support	
			Before matching	After matching	% bias reduction	Unmatched	Matched	Number of treated	Number of control
Nearest neighbor matching	<0.25	5.64* (3.09)	22.56	21.41	5.1	0.000	0.093	46	73
	0.25 - 0.85	3.49** (1.55)	22.56	15.78	30.1	0.000	0.099	82	134
	0.85 - 1.00	5.09 (5.89)	22.56	20.64	8.5	0.000	0.429	33	57
	Total	3.91** (2.14)	22.56	10.79	52.2	0.000	0.146	191	265
Kernel-based matching	<0.25	4.45* (2.70)	22.56	15.30	32.2	0.000	0.954	43	73
	0.25 - 0.85	3.49*** (1.38)	22.56	11.36	49.6	0.000	0.959	82	134
	0.85 - 1.00	4.89 (7.36)	22.56	15.57	30.9	0.000	0.987	33	57
	Total	2.66* (1.64)	22.56	7.16	68.2	0.000	0.782	191	265

Notes: Numbers in parentheses are bootstrap standard errors; *significant at 10%; ** significant at 5%; *** significant at 1%.

The results are consistent with the parametric results. The matching results from the KBM and NNM approaches indicate that adoption of crossbreeding leads to a positive and significant effect on FYM production. Specifically, the KBM and NNM causal effects of crossbreeding adoption on FYM production suggest that the quantity of FYM produced is 2.66–3.91 tons higher for adopters than for non-adopters. Table 5 also presents results of the causal impacts of crossbreeding adoption on FYM production for different intensities of modern crop technologies. As in parametric regression, the results generally reveal that even within the different intensities of modern crop varieties, crossbreeding tends to affect positively the quantity of FYM produced. This finding is robust[7] in suggesting integration of crop-livestock technology adoption in the mixed farming system.

The major objective of propensity score estimation is to balance the distribution of relevant variables across the groups of adopters and non-adopters, rather than obtaining a precise prediction of selection of treatment (Kassie et al., 2010). The covariate balancing test before and after matching, using the NNM and KBM methods, is used to examine whether the differences in covariates in the two groups in the matched sample have been eliminated. As shown in Table 5, the results revealed that a substantial reduction (up to 68%) in absolute standardized bias was obtained through matching. This is higher than what Rosenbaum and Rubin (1983) suggested is reasonable, as according to them a standardized difference of greater than 20% should be considered as large. The *p* values of the likelihood ratio tests before and after matching indicate that the joint significance of the regressor is always rejected after matching, whereas it was never rejected before matching. The results suggest that there is no systematic difference in the distribution of covariates between adopters and non-adopters after matching.

7. Conclusions

A negative soil-nutrient balance is the main constraint in most crop-livestock mixed systems on smallholder farms in many developing countries. Jointness of crops and livestock

[7] The results of the logit specification of the propensity score to predict the probability of adopting the crossbreeding is similar to the results of the probit specification in the switching regression. For the sake of space, this result is not reported here.

production in the mixed farming system is often considered to be an opportunity for smallholder farmers to move toward sustainable agricultural production because of the associated intensified organic matter and nutrient recycling (Marenya and Barrett, 2007). In the mixed farming system, adoption of crop-livestock technologies that contribute to better nutrient cycling would be an important part of the attraction for greater crop-livestock integration. However, agriculture development policies in developing countries are sometimes at odds with realities of agriculture jointness. The lack of due consideration of livestock production and improvement, due to policy makers and planners underestimating the importance of farming system approaches that consider livestock an integral and significant component of a mixed farming system, affects the sustainable management of resources. In further support of the idea, using farm household data from Ethiopia this study employed an endogenous switching model to examine the effect of crop and livestock technology on FYM production and identify factors limiting the adoption of livestock technology.

The results indicate that the likelihood of adopting livestock technology is positively correlated with complementary livestock production inputs such as improved grazing systems, veterinary services, improved feeds, and access to extension services. It is, however, negatively correlated with an individual’s risk aversion. The extent of the FYM production gap between adopters and non-adopters of livestock technology – particularly with respect to improved crop, livestock, and market conditions – suggests that non-adopters might face difficulties increasing FYM production without using the improved livestock technologies. The most salient feature of the above result is that it is a clear indication for the importance of the most subtle and often ignored issues of the farming systems as far as agricultural technologies development and dissemination are concerned. As is the case for the mixed farming system, provision of technologies consistent with the system for joint intensification of the crop and livestock systems is perhaps required to maximize the positive external effect that one produces over the other.

Motivated by the limitations of this study, we also highlight a few points for possible further investigation that would conceivably complement the results found here. Critical analysis of the diversification of FYM utilization with options for analyzing the allocation patterns must be sought to couple the implications of the production-side problems.

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Paper V

RESEARCH SECTION

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Risk preferences as determinants of soil conservation decisions in Ethiopia

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Abstract: Soil degradation is one of the most serious environmental problems in the highlands of Ethiopia. The prevalence of traditional agricultural land use and the absence of appropriate resource management often result in the degradation of natural soil fertility. This has important implications for soil productivity, household food security, and poverty. Given the extreme vulnerability of farmers in this area, we hypothesized that farmers' risk preferences might affect the sustainability of resource use. This study presents experimental results on the willingness of farmers to take risks and relates the subjective risk preferences to actual soil conservation decisions. The study looked at a random sample of 143 households with 597 farming plots. We found that a high degree of risk aversion significantly decreases the probability of adopting soil conservation. This implies that reducing farmers' risk exposure could promote soil conservation practices and thus more sustainable natural resource management. This might be achieved by improving tenure security, promoting access to extension services and education, and developing income-generating off-farm activities.

Key words: adoption—Ethiopia—risk preference—soil conservation

The Ethiopian highlands cover 40% of Ethiopia's land mass but account for about 95% of all cultivated land. Almost 88% of its human population lives there, with 70% of the total livestock population of the country (Ayele 1999). It is estimated that over 90% of the economic activities in Ethiopia are concentrated in the highlands. The sustainable use of land in these areas faces problems due to continuous cropping and repeated cultivation of sloping lands without proper consideration for soil conservation and fertility amendments. The soil resources are eroding at an alarming rate, but at this time, there is insufficient awareness, both within and outside the farming community, of the sources of this problem. Now, even the more productive areas in Ethiopia are facing high rates of soil erosion.

Soil erosion—averaging 4.2 t ha^{-1} y^{-1} (1.68 tn ac^{-1} yr^{-1}) of soil loss—is a huge contributor to the low productivity of Ethiopian soils (Hurni 1993). As a result, soil erosion is putting out of use some 20,000 to 30,000 ha (49,600 to 74,400 ac) of croplands annually (Bewket 2007; FAO 1986). The Soil Conservation Research Project (Hurni 1993) estimated the effect of soil erosion on crop productivity for the major crops using a production function based on time-series data. In this study, a loss of 1 cm of soil depth (about 100 t ha^{-1} [40 tn ac^{-1}] of soil) was estimated to reduce about 2% and 4.5% of the production of wheat in vertisols (black, fissured soil) and red upland soil, respectively. Like in other subSaharan African countries (Sanchez et al. 1996), depletion of the soil fertility of small Ethiopian farm plots is the fundamental biophysical limiting factor responsible for the declining per capita food production (Elias and Scoones 1999). In view of this, soil erosion and soil depletion constitute a national hazard, whose containment is a prerequisite for national development, particularly in a society that is agriculture based.

The traditional explanations for soil degradation relate to resource depletion and land mismanagement associated with limited soil conservation practices. Generally, the objectives of soil conservation are prevention of soil loss and management of soil fertility. Sheng (1989) defined soil conservation as a conscious process for the use and protection of land, including wise land use, necessary soil management, and erosion control. Some studies on the economics of soil conservation in developing countries have suggested incentives for farmers to adopt soil conservation by analyzing their household characteristics and the features and attributes of their farm operations (Thao 2001; Ervin and Ervin 1982; Saliba and Bromley 1986; Soule et al. 2000; Gebremedhin and Scott 2003). Generally, land tenure arrangements, soil characteristics, input and output prices, availability of off-farm employment, farm size, household size, discount rates, and government policies influence the use of (or refusal to use) soil conservation measures by farmers in developing countries.

Rarely, however, has the influence of risk aversion for adoption of soil conservation practices been addressed, and strong empirical evidence to test its importance and impact has been scarce and scattered. Feder et al. (1985), in their review of the conservation adoption literature, attributed this scarcity to difficulties in observing and measuring risk and uncertainty. Farmers are unlikely to invest in soil conservation unless they can see the benefits of soil erosion control. In practice, the major benefit that a farmer receives from soil conservation is the soil itself—a potential asset for future income. The stock of soil available to a farmer is essentially an economic asset that can be exploited through cultivation to yield a stream of present and future income (Barbier 1990). Often, the return for practicing soil conservation can be long in coming, a feature that helps explain low adoption rates (Shively 1997). However, delays in payback do not completely explain low rates of investment, even if subjective discount rates are high. In many cases, practical strategies to reduce soil erosion introduce economic risks that reduce their potential value. Although several empirical studies have shown that the assumptions of risk neutrality can overestimate the value of soil conservation (e.g., Ndiaye and Sofranko 1994), such assumptions remains pervasive in studies of soil conservation adoption and performance.

Considering the importance of risk, Binswanger et al. (1980) validated that a portion of the observed variation among

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individual farmers' agricultural decisions can be related to variations in the same farmers' degrees of risk aversion (as measured in experiments), where the more risk averse choose more conservative options. Yesuf and Bluffstone (2009) also indicated that, in countries where poverty and environmental degradation are intertwined and credit and insurance markets are imperfect or completely absent, the critical factors affecting sustainability of resource use are the extent to which people discount the future and their willingness to undertake risky activities, such as investment decisions. Dillon and Scandizzo (1978) and Binswanger (1980) mentioned that poor people are risk averse and their production and investment decisions are characterized by a high degree of uncertainty and inefficiency, which in turn affects sustainable use of their resources.

Our study, therefore, was intended to measure the degree of risk preference of smallholder farmers and empirically examine the effects of farmers' risk preferences (plus other socioeconomic factors) on soil conservation decisions at the farm level. The importance of this study lies in identifying ways to enhance soil conservation practices and to assist policymakers in promoting appropriate soil conservation strategies. We test two main researchable hypotheses: that farmers with high-risk aversion behavior exist in the study area, and that the probability of farm households' soil conservation decision is negatively affected by a high degree of risk aversion. In addition, we expect that the choice of conservation system would be influenced by a number of factors, namely, farmers' attributes (level of education, farming experience, labor availability, wealth status, and social capital), farm characteristics (soil types, soil fertility, slope, plot size, and distance of plot from house), and policy-related variables (extension services, use of radio, market access, off-farm work, and land tenure security).

Economic Model for Soil Conservation. There are a range of approaches applied in the analysis of soil conservation, ranging from quantification of the national impacts of soil loss to the identification of factors that influence farmers' soil management decisions. The model used in this paper is an adaptation of Barbier's (1990) economic model of the soil-conservation investment decision of farmers in developing countries. The model posits price-taking producers who choose to install and maintain conservation practices in order to maximize the net present value of output. In our study, we extend the Barbier (1990) model to include farmers' risk preferences and other socioeconomic characteristics as factors influencing the adoption decision.

Let $f(x_t, s_t)$ be a vector of outputs produced at time t, with x_t as a vector of production inputs used at time t, and s_t as soil stock at time t. Consider a farm household that produces farm output in each period using a depletable input, s_t, and production inputs, x_t. Soil dynamics, ds/dt, is represented by the soil quality retained by the investment in soil conservation, $I(k_t, \theta_t, h_t)$, and loss of soil from inputs used in agricultural production, x_t. Investment in soil conservation, in turn, is a function of the stock of soil conservation structures (k_t) and other factors, such as farmers' risk preferences (θ_t) and socioeconomic characteristics (h_t). Let p_t, w_t, and c_t be the respective price vectors corresponding to output, input, and soil conservation, respectively, at time t. The net present value of a stream of output is defined as the accumulated crop revenue minus the cost of production inputs and the cost of soil conservation investment discounted by the discount rate (δ). Thus, the farmer's objective function is to maximize the net present value of profit from agricultural production using the production inputs (x_t) and soil conservation (k_t) (Max $[x,k]$ II) (subscripts are suppressed), given by

$$\underset{\{x,k\}}{Max} \prod - \int_{t=0}^{T} e^{-\delta t}[pf(x,s) - wx - ck]dt + e^{-\delta t} V(s_t) \text{ , } \quad (1)$$

and subject to

$$ds/dt = I(k_t, \theta_t, h_t) - x \text{ , } \quad (2)$$

where T is the last period, dt is a mathematical expression indicating the change in time, and $V(s_T)$ is the scrap value of soil stock at the last period.

The first step in the optimization is the construction of the Hamiltonian (H) in equation 3. The right-hand side of the equation of motion (equation 2) is multiplied by the costate variables λ_t and is appended to the objective function from equation 1:

$$H = e^{-\delta t}[pf(x,s) - wx - ck] + \lambda \, [I\,(k,\theta,h) - x] \text{ . } \quad (3)$$

The costate variable λ represents the shadow or implicit price of the equation of motion or the shadow price of the soil stock in time t. The amount of soil stock used (the right hand side of the motion equation [equation 2]) multiplied by the implicit price of the soil stock gives the shadow value of soil capital (or the dynamic cost to future generations using the soil). The optimal level of soil conservation investment can be determined by differentiating equation 3 with respect to k:

$$\frac{\partial H}{\partial k} = -e^{-\delta t}c + \lambda \, [I_k(k,\theta,h)] = 0 \text{ . } \quad (4)$$

By rearranging equation 4, the condition $e^{-\delta t} c = \lambda[I_k(k, \theta, h)]$ implies that optimal soil conservation investment takes place at the level where the present value of the additional income derived from soil conservation equals the discounted additional cost of soil conservation. Alternatively, the optimal level of soil conservation can be determined as the level at which the additional user cost of soil erosion avoided just equals the discounted additional cost of soil conservation.

Soil is necessary for agricultural production, and yield increases with soil stock ($\partial f[s, x]/\partial s > 0$), but yield also depends on other production factors. One of the features of this type of model is that stock of soil can be enhanced by investment in soil conservation ($\partial s/\partial I > 0$). In turn, risk aversion is related to soil stock through investment in soil conservation structures, implying that soil conservation investment decreases with the farmer's risk preferences ($\partial I/\partial\theta < 0$). The more risk-averse farmers may be reluctant to sacrifice short-term returns for less certain long-term benefits of conservation practices.

Materials and Methods

Econometric Approach: Analysis of Soil Conservation Decision. Most adoption studies treat the use of soil conservation measures as a discrete all-or-nothing adoption decision of a single practice. From a policy perspective, such studies do not supply information on how multiple practices can fit together into an overall conservation package. Adopting multiple soil conservation practices is common in Ethiopia because topography and soils frequently vary substantially within farms and because farmers usually diversify crop and livestock production. For a given plot of land, a farmer is assumed to have preferences over a discrete set of alternative soil conservation systems—a choice problem that requires application of multinomial discrete choice models.

A multinomial logit model of a qualitative response variable characterizes a choice from discrete (nominal) alternatives by a decisionmaker as a function of attributes associated with each alternative, as well as the characteristics of the individual. Because of its analytical and computational tractability, this model has been applied extensively to discrete choice processes in economics with great success (Manski and McFadden 1981; Train 2003). A certain soil conservation system is chosen for a given plot, if and only if the expected utility from the selected option is greater than the utility obtainable from other available alternatives.

Consider the utility of farmer *n* adopting soil conservation practice choice *j* on the plot U_{nj}. The systematic component of the utility of alternative *j* is specified as a function of an array of household (*H*), farm (*F*), and regional (*R*) characteristics. Hence,

$$U_{nj} = \alpha_j H_n + \Phi_j F_n + \varphi_j R_n + \varepsilon_{nj} \qquad (5)$$

where α_j is the parameters for household variables in the jth soil conservation alternatives, Φ_j is parameters for farm variables in the jth soil conservation alternatives, and φ_j is parameters for regional variables in the *j*th soil conservation alternatives.

Assuming the errors ε_{nj} are independently and identically distributed with an extreme value distribution, the probability that alternative *j* is chosen from *J* alternative sets can be represented by the multinomial logit model function (McFadden 1974; Train 2003). The general form of the multinomial logit model is

$$Prob\ (choice = j|J) = \frac{e^{\beta_j, Z_{nj}}}{\sum_j e^{\beta_j, Z_{nj}}} = \frac{exp(\alpha_j H_n + \Phi_j F_n + \varphi_j R_n)}{\sum_j^J exp(\alpha_j H_n + \Phi_j F_n + \varphi_j R_n)}, \qquad (6)$$

where $j|J$ is the alternative *j* from the *J* alternative set, β_j is set of parameters for the *j*th alternative, Z_{nj} is the variables for the *n*th observation at the *j*th alternative, $n = 1 \ldots N$ indexes the observation, and $j = 1 \ldots J$ indexes the choices.

The dependent variable is *Y*, coded as 0, 1, 2 (alternative soil conservation systems); Z_n is the explanatory vector (representing age, sex, education, extension contact, availability of family labor, risk attitude, time preference, plot size, soil type, slope, wealth and credit, etc). In order to identify unique coefficients for the alternatives, one of the outcomes in the multinomial logit model must be normalized to zero.

Even if the coefficient estimates have different interpretations depending on the omitted category, the probabilities remain the same. Alternatively, the coefficients can be used to calculate the partial changes in probabilities (marginal effect). The marginal effects measure the expected change in probability of the choice being made with respect to a unit change in an explanatory variable (Greene 2008). When there are J = 3 number of soil conservation choices, the marginal change in probability of a given soil conservation system, given the change in continuous variable Z_n, is the partial derivative of Prob ($Y = j$) with respect to Z_n:

$$\frac{\partial Prob(Y = j)}{\partial Z_n} = P_j\left[\beta_{nj} - \sum_{j=1}^{J-1} P_j \beta_{nj}\right], \qquad (7)$$

where P_j is the probability of selecting alternative *j*, and β_{nj} is the parameter estimate of the of the variable for the *n*th farmers at the *j*th alternative.

The marginal effect of a dummy variable on the event probability can always be accurately derived by taking the difference between the predicted probability when the variable is equal to 1 and when it is equal to zero:

$$\Delta Prob(Y = j) = Prob(Y = j \mid Z, Z_k = Z_1) - Prob(Y = j \mid Z, Z_k = Z_0) \quad , \qquad (8)$$

where Z is the set of explanatory variables, Z_k is the dummy variable, Z_1 represents when the dummy variable is one, ($Z_k = Z_1$), and Z_0 represents when the dummy variable is zero, ($Z_k = Z_0$).

Summing the marginal probabilities across the three soil conservation alternatives for a unit change of a given explanatory variable gives zero sums, implying that an increase in the adoption rate of the given choice due to a change in a particular characteristics' variable is compensated by a decrease in the adoption rate of other choices in the set.

Experimental Design: Risk Preference. The expected utility theory, developed by von Neumann and Morgenstern (N-M) in 1944, is of central importance in describing decisionmaking under risk. Decision under uncertainty, as described by the N-M model, defines the utility to be maximized as the expectation of the utilities of the random alternatives. The concept of lottery as a formal device to represent risky alternatives is the basic building block for the N-M expected utility theory. A simple lottery is a list, $L = (P_1, \ldots, P_N)$; $P_N \geq 0$ for all *n*; and $\Sigma_n P_n = 1$, where P_1 is the probability of the event occurring on the first outcome, P_N is the probability of the event occurring on the last outcome, and P_n is the probability of outcome *n* occurring. The concept of "risk aversion" intuitively implies that, when facing choices with comparable returns, agents tend to choose the less risky alternative—a construction we owe largely to Friedman and Savage (1948). To put it differently, an agent is risk averse if replacing an uncertain final wealth by its expected value makes the agent better off.

In our study, which follows Binswanger's (1980) framework, the experimental method through predetermined choices approach was employed to elicit farmers' risk preferences by observing the reactions of farmers to a set of actual gambles in one period. In a real context, respondents were presented with certain realistic lotteries of the form (q_{max}, q_{min}, P), promising a monetary prize for q_{max} (maximum payoff) with probability P, or q_{min} (minimum payoff) with probability $(1 - P)$. The lotteries represent different real farming conditions and were designed with six different payoff levels, given a 50% probability of bad or good harvesting conditions (table 1). Following the von N-M expected utility approach, an important ingredient is the specification of the utility function. The most popular parameter specification is the constant partial risk-aversion function, where the utility function is characterized by the risk-aversion parameter, θ. Thus, a constant partial risk-aversion function as an approximation of ($U = [1 - \theta]M^{1-\theta}$) is used in order to measure and obtain a unique risk-aversion coefficient, where U is the utility function, θ is the coefficient of risk aversion and M is the certainty equivalent of the prospect. The upper and lower limits of θ are given in table 1.

The participants in the household survey were confronted with two experiments: one involved hypothetical trade-offs and the other the possibility of real payoffs. In the real payment experiment, the average payoffs for the household in the experiment was Ethiopian birr (ETB) 25 ($1 [US] = 11.00 ETB in 2008), which was approximately five times the daily wage level of the unskilled

Table 1
Pay-offs and classifications of risk aversion associated with each option a farmer could choose.

Choice	Payoffs (ETB)* Bad harvest	Good harvest	Expected gain (E)	Standard deviation (SD)	Trade offs (Z)†	Approximate risk aversion coefficients (θ)	Risk-aversion category
6	10.00	10.00	10.00	0.00	0.78 to 1.00	∞ to 7.47	Extreme
5	9.00	18.00	13.50	4.50	0.71 to 0.78	7.47 to 1.74	Severe
4	8.00	24.00	16.00	8.00	0.50 to 0.71	1.74 to 0.81	Intermediate
3	6.00	30.00	18.00	12.00	0.33 to 0.50	0.81 to 0.32	Moderate
2	2.00	38.00	20.00	18.00	0.00 to 0.33	0.32 to 0.00	Slight
1	0.00	40.00	20.00	20.00	−∞ to 0.00	0.00 to −∞	Neutral

* ETB = Ethiopian birr. $1 (US) = 11.00 ETB (2008).

† Z is the tradeoff between expected gains and standard deviations of two games ($Z = {dE}/{dSD}$).

laborers in the study area. Table 1 explains the basic structure of the experiment. The sample farmers were presented with a choice of six alternatives. Once the farmers selected one of the alternatives, they had a 50% probability of getting either the bad harvest or good harvest payoffs. The experiment consisted of offering farmers a set of alternatives where higher expected gain could only be obtained at the cost of higher variance—thus a decline in risk aversion.

Basically, individuals were assumed to be risk averse in cases where a certain outcome with a lower payoff was preferred over an uncertain outcome with a higher expected payoff. In contrast, risk-seeking behavior occurs when individuals consistently choose a gamble over a certain payoff with a higher payoff value. For instance, choice 1 is a safe alternative where subjects could earn ETB 10, with either a bad or good outcome. In alternative 5, a coin was tossed, and the subject received ETB 2 if the coin showed heads and ETB 38 if the coin showed tails. Compared to choice 1, the individual's expected gain now increased by ETB 10, but if heads (bad outcome) turned up, it would reduce the return by ETB 8. In the meantime, the standard deviation in gain increased from ETB 0 to ETB 18. Hence, with such uncertainty in gains, choice 5 involves more risk than the previous choices (choices 1 to 4).

Study Areas and Data. The data in this study were derived from a formal survey of a random sample of farm households, December 2003 to January 2004. The areas selected for this study, Ankober and Basona-Werena districts, are located within the North Shewa zone, in the Amhara Regional State of Ethiopia. North Shewa is a major agricultural region in the central highlands of Ethiopia, with a rugged, mountainous terrain where altitudes range from 1,600 to 3,500 m (5,249 to 11,483 ft) above sea level. The area has two periods of rainfall, averaging 900 to 1,740 mm (35 to 68 in); the main rainy season (Meher) runs from July to September, and the short rainy season (Belg) is from January to April. The concentration of rain in heavy showers, coupled with an undulating landscape, causes significant erosion throughout the area.

A two-stage cluster sampling technique was employed to randomly select one village from each district and households from each village. The list of 29 villages in the Basona-Werena district and 18 villages in the Ankober district served as the sampling frame for the choice of the two villages, while households within each village were the sampling units. The sample households were randomly selected from the villages using lists that exhaustively record all members of the two villages.

A structured questionnaire was prepared, and the sampled respondents were interviewed. Initial presurvey tests were made in the selected villages to verify the feasibility of the study and allow redesign of the questionnaire if needed. In the randomly selected farm households, the head of the household was surveyed personally by experienced interviewers under close supervision by one of the authors. The enumerators also had special training to make sure they understood each question and the reason for the information captured in the survey. The respondents were interviewed in their local language, Amharic. As a result of the careful preparations, there were no rejections of the central questions in the survey by the respondents, and we are confident that the data is of unusually high quality. Information was also gathered in discussions with other key actors (e.g., field extension agents and soil conservation experts).

The survey included a total of 143 farm households, with 597 farming plots, and gathered information on the farmers' socioeconomic characteristics (such as age, household size, educational level, land-holding status, extension contact, availability of credit, availability of modern farm inputs, community participation, social organization, transportation cost, etc.) and farm characteristics (plot size, number of plots, soil fertility, slope of each plot, soil type, distance of plot from the house, cultivation arrangements, etc.). For identification purposes, the interviewers sketched all the plots farmed by the respondent and then collected detailed information for each plot, referring to the sketch as needed. The survey also elicited information from farmers regarding their risk preferences using the experiment mentioned above.

Results and Discussion

We found that indigenous soil conservation techniques were considered part of the farming system in the study areas. Indeed, in both areas, most farmers were familiar with traditional land improvement-conservation techniques, such as stone terraces and soil bunds. These are embankments of stone or soil constructed along the contour of the land to control the surface water runoff down the slope. The two soil conservation structures require different investments in amount of time and labor and have different effectiveness against erosion (Gebremedhin and Scott 2003). In the Basona-Werena and Ankober districts, about 27% and 38% of the plots, respectively, have stone terraces. However, no more than 16% to 18% of the plots in both areas use soil bunds. In Ankober, soil

Table 2
Frequencies of farmers' responses to risk preferences corresponding to real and hypothetical experiements.

	Basona-Werena		Ankober		All samples	
Risk-aversion category	Farmers (%)	Cumulative farmers (%)	Farmers (%)	Cumulative farmers (%)	Farmers (%)	Cumulative farmers (%)
Risk preferences in hypothetical experiment						
Extreme	29.6	29.6	35.7	35.7	32.6	32.6
Severe	19.7	49.3	17.1	52.8	18.4	51.0
Intermediate	25.4	74.7	7.1	59.9	16.3	67.3
Moderate	9.9	84.6	21.4	81.3	15.6	82.9
Slight	8.5	93.1	7.1	88.4	7.8	90.7
Neutral	7.0	100.0	11.4	100.0	9.2	100.0
Risk preferences in real experiment						
Extreme	31.0	31.0	32.9	32.9	31.9	31.9
Severe	21.1	52.1	21.4	54.3	21.3	53.2
Intermediate	21.1	73.2	8.6	63.1	14.9	68.1
Moderate	12.7	85.9	21.4	84.5	17.0	85.1
Slight	2.8	88.7	5.7	90.2	4.3	89.4
Neutral	11.3	100.0	10.0	100.0	10.6	100.0

conservation structures have traditionally been constructed by the farmers themselves. A majority of the farmers in Ankober are aware of the need for a continuing increment of soil conservation practices and have perceived a subsequent decline in soil erosion. However, in Basona-Werena, the government has instead implemented a huge food-for-work program since the 1980s specifically to build soil conservation structures throughout the district.

Farmers' Risk Preference. The farmers' responses regarding risk preferences corresponding to the real and hypothetical experiments are presented in table 2. The results revealed that, in both the hypothetical and the real payoff experiments, a majority of farmers fell in the intermediate, severe, and extreme risk-aversion categories. In both experiments, 73% to 75% of the farmers in Basona-Werena and 60% to 63% of farmers in Ankober preferred the alternatives representing intermediate to extreme risk-aversion. This result is slightly higher than Yesuf and Bluffstone (2009), who found that about 50% of farm households in the Ethiopian highlands chose the intermediate to extreme risk-aversion alternatives. The distribution of risk preferences in other similar studies in developing countries, such as Binswanger (1980) in India and Wik et al. (2004) in Zambia, is quite different than our result. About 83% of farmers in India and 52% of farmers in Zambia fell into the intermediate-to-moderate risk category, while only 32% of farmers in our study were in this group.

It is generally acknowledged that experiments conducted without real payment options may suffer from hypothetical bias. In order to avoid such a problem and provide enough incentive for the farmers to reveal their true preferences, our experiment included a real payoff. Comparison of the responses of the hypothetical and real experiments indicated that most of the respondents consistently maintained similar responses in both parts of the experiment. However, we saw a positive and significant correlation of responses in the risk aversion elicited with both hypothetical and real payoffs, contrary to what Wik et al. (2004) found.

Soil Conservation Decision. The major observed soil-conservation practices were stone terraces and soil bunds constructed by the farmers themselves. The decision to build soil conservation structures depends upon a wide variety of factors, many of which are specific to a particular area, household, or plot characteristic. The explanatory variables for this decision, included in our analysis are based on the theory discussed above and the literature on conservation investment. Expected effects of household, plot, and regional characteristics on choice of soil conservation practices are included in table 3.

Attitude towards risk is a variable that measures farmers' willingness to take risks and is a potentially important determinant on the decision to use soil conservation practices. Risk aversion can have important implications for the adoption of technologies and the farmers' production-consumption plans. Various studies have shown that farmers plan their investment under risk (Binswanger 1980; Yesuf and Bluffstone 2009). The use of soil conservation, on the other hand, entails subjective risk (uncertainty of yield), particularly in the short term. In the longer term, the determining factor is whether soil conservation itself increased or reduced production risk.

Time preference is a variable that measures the extent to which a household is likely to postpone current consumption for future income or the extent to which households discount future benefits for current consumption. High subjective discount rates may be associated with extreme poverty, when immediate subsistence is uncertain. More fundamentally, a high discount rate decreases the net present value of future benefits from soil conservation. Thus, there is an expected inverse relationship between farmers' discount rate and a decision to invest in soil conservation.

An expected change of land holdings is used as proxy for land tenure insecurity. It represents a variable that indexes a household's attitude toward change in land size. Farmers may be insecure (perception of insecurity) about their current farms due to frequent redistribution of lands (Admassie 2000). Studies have also shown that tenure security is essential for adoption of soil conservation practices (Gebremedehin and Scott 2003). It is, therefore, expected that tenure insecurity (expected decline of land holdings) is negatively related to soil conservation adoption.

As information and communication mechanisms, contact with various sources of

Table 3
Descriptive statistics for the multinomial logit model variables.

Variable	Variable definition	Mean	Standard deviation	Minimum	Maximum	Expected effects
Dependent variables						
Stone terrace	Has stone terracing (1 = yes)	0.25	—	0.00	1.00	
Soil bund	Has soil bunds (1 = yes)	0.13	—	0.00	1.00	
Household characteristics						
Sex	Sex of household head (1 = male)	0.91	—	0.00	1.00	+/–
Age	Age of household head (in years)	45.76	13.10	19.00	84.00	+
Literacy	Education of household head (1 = able to read and write)	0.56	—	0.00	1.00	+
Labor	Labor force (man-equivalent)	2.65	1.16	0.50	6.90	+
Extension	Contact extension agent (1 = yes)	0.46	—	0.00	1.00	+
Radio	Has a radio (1 = yes)	0.10	—	0.00	1.00	+
Off-farm	Off-farm work (1 = yes)	0.39	—	0.00	1.00	+/–
Oxen ownership	Household owns oxen (1 = more than one ox)	0.69	—	0.00	1.00	+
Income	Net income (in ETB)	71.50	657.76	1,933.0	2,989.0	+
Land-holding trends	Decline/increase in land holdings (1 = decline)	0.90	—	0.00	1.00	–
Risk preference	Risk-aversion coefficient	3.14	2.89	0.00	7.50	–
Time preference	Farmers' discount rate	89.61	36.39	12.91	186.04	–
Plot characteristics						
Parcel	Number of plots	5.40	2.73	1.00	15.00	–
Plot size	Plot size, *timad** per plot	1.00	0.62	0.13	4.00	–
Tenure	Tenure arrangements (1 = owner operated)	0.93	—	0.00	1.00	+
Highly fertile soil	Fertility of soil (1 = high fertile)	0.23	—	0.00	1.00	+
Medium fertile soil	Fertility of soil (1 = medium fertile)	0.33	—	0.00	1.00	+
Soil type	Soil type (1 = vertisol)	0.50	—	0.00	1.00	+
Gentle slope	Plot has gentle slope (1 = gentle slope)	0.27	—	0.00	1.00	+
Steep slope	Plot has steep slope (1 = steep slope)	0.39	—	0.00	1.00	+
Plot distance	Distance of plot from home (in minutes walking)	18.01	17.11	1.00	90.00	–
Plot use	Plot use (1 = crop)	0.53	—	0.00	1.00	+
Regional characteristics						
District	District (1 = Basona-Werena)	0.50	—	0.00	1.00	+/–
Road distance	Distance from household to nearest road (in minutes walking)	38.81	39.43	1.00	180.00	–
Community	Community participation (1 = yes)	0.94	—	0.00	1.00	+
Idir	*Idir* membership (1 = yes)	0.10	—	0.00	1.00	+

Notes: ETB = Ethiopian birr. $1 (US) = ETB 11.00 (2008).
* 1 *timad* ≈ 0.25 ha.

information, advice from extension agents, and use of radio, are expected to positively influence adoption of soil conservation practices. Use of radio and extension activities may help farmers better understand the potential effects of soil erosion and benefits of soil conservation, as well as enhance their technical capacity to apply soil conservation technologies. The influence of off-farm work is indeterminate a priori. Income generated from off-farm work is expected to have a positive influence if it helps buffer the short-term variations in output due to soil conservation practices. In this case, the implication is that farmers with off-farm incomes are better risk takers, vis-à-vis using soil-conservation practices, than those without off-farm income. On the other hand, off-farm income may have a negative influence, if a farmer's off-farm employment opportunities cause labor shortages (from competition between agriculture and off-farm activities) that restrict the farmer's ability to build soil conservation structures.

The regional characteristics that we focused on were market access and social interactions in the community. Distance from the home to the nearest all-weather road was a proxy for market access (transport cost). Nearest roads were associated with low farm-input costs and high farm-output prices, as well as greater opportunities for income-earning activities, primarily sale of farm produce. Market access offers incentives for farmers to improve or maintain their land quality, and thus a positive effect is expected. Farmers who have the advantage of good market access (including demand for high-value crops) may find adopting soil conservation practices very attractive economically. Existence of good road networks also facilitates the availability of and exposure to information and communication, leading to a positive influence on adoption of soil conservation practices. We included a district dummy (one for Basona-Werena and zero for Ankober) in the model to control for village differences in knowledge, farming traditions, and physical characteristics, for example.

Social capital is characterized by norms, interactions, and reciprocity, leading to cooperation and information flows. It consists of discrete platforms organized and run by members of communities or groups for various purposes, notably to enhance confidence, pool resources, encourage savings, and extend credit. In addition to specialized functions, these networks act as forums for the exchange of experience and information about market behavior, the movement of goods and prices, development needs and priorities, among others. Hence, they can be used to promote development endeavors.

Two variables are proxies for social capital in this study. One, community participation, means the household is engaged in soil conservation activities organized by the farmers' association. In most cases, the farmers' association organized campaigns to reclaim and preserve the communal lands in the area. It is thus expected that the spillover effect of this variable on household adoption of soil conservation will be positive. Studies have indicated that, where public soil conservation activities take place in the same community, but not on the household's own land, farmers will be more likely to adopt soil conservation due to the experience effect of reducing real conservation investment costs and awareness of the effectiveness of conservation (Gebremedhin and Scott 2003).

The second variable for social capital uses membership in *idir*, the traditional form of social organization. In small holder agriculture, the problem of labor shortage might be solved, for example, through *idir*—a form of mutual cooperation imbued with a team spirit. In *idir*, information flows among members, and they have labor-sharing arrangements. The effect of idir on adoption of soil conservation is indeterminate a priori. If the members enter an agreement to share labor for conservation activities, *idir* will positively affect the decision to use soil conservation; otherwise, other social activities will deter adoption of soil conservation practice.

Regression Results. The chi-square test statistic for the estimated multinomial logit model is 276.95, with 52 degrees of freedom. The null hypothesis that the nonintercept coefficients are jointly zero is rejected at the 0.01 probability level. This means that the empirical multinomial logit model is highly significant in explaining the choice of soil conservation practice by farmers. We used the Huber-White-Sandwich estimator of variances, instead of the conventional maximum likelihood variance estimator, in order to avoid the problem of heteroscedasticity. In the analysis of plot-level data, correlated observations may occur due to repeated measurements of the same subjects. Clustering the data allows repeated observations, which are not independent within groups, although they must be independent across groups so that standard errors can be adjusted for clustering within farm households to allow for correlation within the group. The predictive power of the model is quite appealing. The choice of none, stone terraces, or soil bunds is correctly predicted for 81%, 60%, and 53% of the sample, respectively. These results are also an indication that we have made a correct classification of soil conservation technologies for our analysis. Although there is some variation in the labor input and efficacy of other technologies applied, overall they are more similar to the "no" category than the soil and stone bunds.

As we hypothesized, the farmer's decision to build stone terraces is significantly affected by extension services, sex of the household head, expected declines in land holdings, risk aversion, discount rate, number of plots, tenure arrangement (if owner operated), slope of the plot (medium steepness), use of the plot (for cropping), community participation, and the district dummy. On the other hand, choosing soil bunds significantly depends on the sex of the household head, age of the household head, family labor force, participation in off-farm work, trend of land holdings (expected declines in land holdings), plot size, tenure arrangement (if plot is operated by the owner), soil type, steepness of the plot, use of the plot (for cropping), and the district dummy. Estimated changes in probabilities for the variables used in the regression are presented in table 4.

The farmer's attitude towards risk has a negative effect on the choice of stone terraces or soil bunds. Because conservation practices are affected by several random variables that result in uncertainty in yields, planning for soil conservation involves decision making under risk. The farmer's risk preference is thus related to such decision-making scenarios. The highly significant marginal effect coefficient on "none" indicates that the farmer's risk aversion increases the likelihood of nonadoption of soil conservation practices. The risk-averse farmers who do not invest in soil conservation may assume uncertain yield variations, increasing the probability of no soil conservation by about three percentage points. The result of the marginal effect again implies that a 1% increase in farmers' risk aversion would significantly ($p < 0.05$) decrease the probability of choosing stone terraces by three percentage points.

Farmers' risk-aversion behavior has the same negative effect on choice of soil bunds, but is statistically nonsignificant. One reason for the significant negative effect of farmers' risk preference for stone terraces over soil bunds may be that construction of stone terraces requires more labor and a longer time to produce the expected higher return in yield than soil bunds. As a result, the more risk-averse farmers may be less interested in investing in stone terraces than soil bunds. Figure 1 depicts the change in predicted probabilities of household decisions about soil conservation (none, stone terraces, or soil bunds) due to changes in risk-aversion behavior. The figure clearly shows that as risk aversion increases, the probability of adoption of stone terraces continuously declines, no conservation increases, and use of soil bunds remains unchanged.

As expected, the farmers' time preference influences patterns of resource use in the current and future period. Farmers who have a higher discount rate are less inclined to long-term investments, giving more weight to the current, rather than the future, period. Our result confirmed the hypothesized relationship: the farmers' intertemporal discount rate negatively affected the decision to adopt soil conservation practices. A higher rate of time preference leads to the significantly higher ($p < 0.05$) likelihood of nonadoption of soil conservation. The marginal effect of nonadoption of soil conservation, due to a unit percentage change in the farmers' intertemporal discount rate, is about 0.2 percentage points. Even though the farmers' time preference negatively affects the use of both stone terraces and soil bunds, its effect is statistically different from zero ($p < 0.05$) on likelihood of adoption of stone terraces only. The result of the marginal effect indicates that a unit percentage increase in the farmers' intertemporal discount rate will decrease the probability of choosing stone terrace by about 0.2 percentage points. The two choices have different effects probably because (compared to soil bunds) farmers consider stone terraces to be more labor intensive. Their longer investment (time and labor) discourages the farmers' willingness to delay current consumption for future income.

The farmers' expectation that they will lose some of their land holdings significantly reduces the likelihood of choosing either stone terraces and soil bunds to a 10% and 5% significance level, respectively. Farmers

Table 4
Marginal effects on probability of choice of soil conservation (stone terracing or soild bunds) or none.

Variables	None	Stone terracing	Soil bunds
Household characteristics			
Sex	−0.116 (0.051)**	0.084 (0.049)*	0.032 (0.011)
Age	0.007 (0.000)	0.002 (0.009)	−0.008 (0.003)**
Age-squared	−0.0001 (0.0001)	0.0001 (0.0001)	0.0001 (0.0001)
Literacy	−0.022 (0.047)	0.013 (0.042)	0.009 (0.014)
Labor force	0.011 (0.019)	−0.025 (0.017)	0.013 (0.007)**
Extension	−0.062 (0.054)	0.079 (0.049)**	−0.018 (0.016)
Radio	−0.024 (0.076)	−0.014 (0.058)	0.037 (0.041)
Off-farm	−0.105 (0.064)*	0.069 (0.055)*	0.035 (0.021)**
Oxen ownership	−0.039 (0.052)	0.048 (0.042)**	−0.009 (0.016)
Income	0.0001 (0.0001)	−0.0001 (0.0001)	−0.0001 (0.0001)
Land holding trends	0.179 (0.080)**	−0.118 (0.070)**	−0.062 (0.032)**
Risk preference	0.029 (0.017)*	−0.029 (0.015)**	−0.0001 (0.004)
Time preference	0.002 (0.001)**	−0.002 (0.001)**	−0.0002 (0.0003)
Plot characteristics			
Parcel	0.019 (0.011)**	−0.023 (0.010)***	0.003 (0.003)
Plot size	−0.049 (0.027)*	0.031 (0.024)	0.019 (0.009)*
Tenure	−0.120 (0.040)***	0.092 (0.038)*	0.028 (0.012)**
Highly fertile soil	−0.047 (0.061)	0.021 (0.053)	0.024 (0.018)
Medium fertile soil	−0.009 (0.042)	−0.013 (0.037)	0.024 (0.018)
Soil type	−0.002 (0.038)	0.040 (0.032)	−0.038 (0.015)***
Gentle slope	−0.178 (0.064)***	0.163 (0.061)***	0.016 (0.018)
Steep slope	−0.208 (0.060)***	0.164 (0.056)***	0.044 (0.020)**
Plot distance	0.001 (0.001)	−0.001 (0.001)	−0.001 (0.001)
Plot use	−0.286 (0.044)***	0.241 (0.038)***	0.045 (0.016)***
Regional characteristics			
Road distance	−0.007 (0.017)	0.013 (0.016)	−0.007 (0.005)
Community	−0.163 (0.037)**	0.152 (0.029)**	0.011 (0.020)
Idir	−0.056 (0.105)	0.056 (0.095)	0.001 (0.032)
District	0.369 (0.086)***	−0.201 (0.069)***	−0.168 (0.056)***

Note: Numbers in parenthesis are standard error.
*$p < .1$ **$p < .05$ ***$p < .01$

may be very cautious, given their tenure insecurity arising from land redistribution that may occur in response to growing population size and new membership in farmers' associations. The result of the marginal effect indicates that tenure insecurity significantly increases the likelihood of nonadoption of soil conservation by about 18 percentage points. Alternatively stated, this result implies that when farmers' security of land is not guaranteed (when farmers expect their land holdings to decline), the probability of using stone terraces or soil bunds is significantly reduced by 12 and 6 percentage points, respectively. This suggests that securing the tenure of a household's holding(s) should be an alternative policy option to encourage investments in soil conservation.

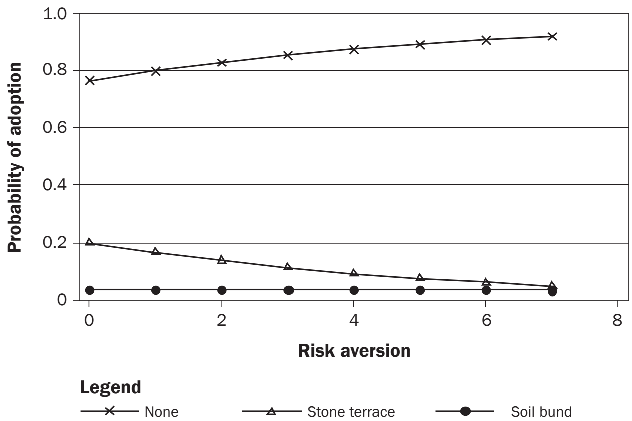
Access to extension services is another important variable, indicating that farmers can get information about better farming practices and enhance their understanding and technical capability for soil-conservation practices. The result of the marginal effect analysis indicates that access to extension services increases the probability of adopting stone terraces by about eight percentage points. The effect of this variable on the choice of soil bunds is negative, although statistically insignificant. It also suggests that the marginal effect of age on the likelihood of choosing soil bunds is negative and statistically different from zero at the 5% significance level. The probability of adopting soil bunds increases more for young farmers than old ones. The implication is that older household heads probably have shorter planning horizons and are physically weaker, more resistant to change, and hence less interested in adopting soil conservation practices that have long-term effects. Thus, targeting young farmers for soil conservation intervention is probably an advisable strategy because they tend to be quicker and more flexible in deciding to adopt new ideas and technologies. With a longer life span—because these farmers are younger—they would anticipate a longer payout period for their investment.

Families are an important source of labor for farm operations and construction of soil conservation structures. This variable has a positive and statistically significant ($p < 0.05$) effect on the likelihood of adoption of soil bunds. The result of the marginal effect suggests that a unit increase in family labor size positively changes the adoption of soil bunds by about one percentage point. Its effect on the choice of stone terraces is negative and statistically insignificant. The marginal effect of off-farm work on the adoption of soil bunds is positive and statistically different from zero at the 10% significance level, implying that the income obtained from off-farm work relaxes the liquidity constraints in conservation adoption. Participation in off-farm work increases the likelihood of adoption as evidenced by the negative and statistically significant marginal effect on the nonuse of conservation practices.

As hypothesized, the number of plots (fragmentation of farms) has a negative effect on adoption of soil conservation, indicated by the highly significant marginal effect on "none." One possible explanation is that with more plots, farmers may face increased transaction costs in constructing the conservation structures. Stone terraces, particularly, require the cumbersome activity of transporting stones to the different plots. This may significantly deter the adoption of stone terraces. However, the effect of the number of plots on the choice of soil bunds is positive but insignificant. The size of the fragmented plot area also positively influences the adoption of soil conservation practices. The significant marginal effect on "none" indicates that decreasing plot area increases the probability of nonadoption of soil conservation practices on a plot. This is probably because farmers may be constrained in building conservation structures because stone terraces and soil bunds are not suitable or convenient for a small plot. In addition, farmers assume that conservation structures take up space on a small plot and reduce the net cropping area. Unwillingness to invest on small plots could also be considered as an issue of economies of scale.

There is a significant difference between the two districts in terms of adopting soil conservation practices. Compared to Basona-Werena, farmers in Ankober have an increased likelihood of constructing stone terraces and soil bunds by about 20 and 10 percentage points, respectively. The adoption rate of soil conservation practice in Ankober is relatively higher (53%) than in Basona-Werena (44%). In Ankober, soil conservation and soil fertility maintenance dates back more than half a century. Personal communication and discussions with elderly people and experts from the local agricultural office revealed that construction of soil conservation structures is indigenous to the area with no government intervention so far. However, soil conservation in Basona-Werena only appeared some thirty years ago with massive government intervention. The longer and indigenous tradition of soil conservation in Ankober may be one reason for the relatively higher rate of adoption there. In addition, the topography of Ankober may also help promote soil conservation in the area. According to information from the district office of agriculture, the topography of both districts is mountainous, rugged, and plain landscape, respectively, covering 75%, 15%, and 10% of Ankober and 50%, 27%, and 23% of Basona-Werena.

Figure 1
Risk aversion and adoption of soil conservation.



Summary and Conclusions

This study uses survey data of smallholder farmers in the central highlands of Ethiopia to analyze the determinants of their choice of soil conservation practices. The study also endeavors to elicit farmers' attitudes toward risk preference using an experimental method. A link between risk aversion and resource protection in the form of soil conservation practice was found in this study. Results from the experimental method indicate that the estimated risk aversion is high, and the majority of the farmers were found to have intermediate, severe, or extreme risk aversion. Empirical results from the multinomial logit analysis demonstrate that a high degree of risk aversion has a negative effect on adoption of labor-intensive soil conservation practices. Farmer's risk aversion increases the likelihood of nonadoption of stone terraces and soil bund practices.

One implication of this work is that it is important to target the underlying reasons for nonadoption, such as high degrees of risk aversion and high subjective discount rates. Promotion of a longer-term and more effective soil conservation system (e.g., stone terraces) can not only be done through extension and programs targeting physical interventions, as indicated by the results from Basona-Werena where such activities have been common. Farmers in the study areas are poor with high estimated discount rates and levels of risk aversion. Because they are trapped in poverty, their high discount rates and risk preferences mean that they are still inclined to use erosion-prone practices to meet their present, urgent needs. The results imply that, to promote soil conservation, policies that reduce farmers' risk behavior should have priority, especially those that address land tenure security and rights, access to better education and extension services, and development of income-generating off-farm activities.

The results of this study are limited to the soil-conservation adoption decision. Because the observation is only whether a farmer uses a given practice or not, the study can only predict the effect of farmers' risk preferences and other factors on the probability that they will adopt a particular soil-conservation practice. The use of most of these soil conservation practices is considered to be a continuous investment, however. Moreover, the conservation effects of using soil-conserving practices are likely to vary according to the intensity to which they are used. Hence, it would also be important to study the extent to which such practices are used and what factors might influence the intensity of soil conservation practices.

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Appendix: Supplementary material

Parameter estimates of the multinomial logit model are presented in Table A1. It is likely that risk aversion is an endogenous variable that farmers can change through adoption decisions. Although most variables explaining risk aversion is included in the model, there might be unobservable effects (for example missing market, motivation) influencing farmers' risk aversion behavior, which also influence the decision to adopt soil conservation structures, which manifests itself through the risk aversion variable which does not represent a pure farmers' risk aversion behavior effect.

To address this issue and check the robustness of our results, we also implement a two-stage instrumental variable multinomial logit model, with identifying instruments to deal with the potential endogenity of farmers' risk aversion to the choice of soil and water conservation practices. The use of instrumental variables with in a multinomial logit model has been previously used by Deolalikar (1998)[1]. We do so using an instrument participation in farmers' socialization group (locally known as *Mahber*) and rotating saving and credit club (locally known as *Iqub*). These groups allowing individuals to spread their risks over a diversified portfolio of friends and allow information to flow among participants there by reducing information asymmetries and affect individuals risk preference. It is thus suspected that participation in such groups will affect the adoption of soil conservation through their effect on farmers' risk preference.

Results with instrumented risk aversion are presented in table A2. Standard errors are corrected to account for the presence of a predicted regressor. The instruments are jointly strongly significant with a statistics of 28.89 (p-value = 0.000) in the first stage reduced model. On the other hand, we cannot reject the hypothesis (p-value = 0.446) that the instrumental variables have no impact on the adoption of soil conservation. This generates a test of exogenity, which suggests unobservable effects are not correlated with adoption decision. However, in our case there is no appreciable difference between those estimates treating farmers' risk preference as exogenous, and those treating as endogenous variable. The negative and significant effect of risk aversion on adoption of soil conservation still remains[2].

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[2] We also experimented with random effects probit regression. Results are very similar to those reported in table A2 and are omitted here for the sake of space.

Table A1. Parameter estimates of the multinomial logit estimates of the probability of adoption of stone terracing and soil bunds

	Stone terracing		Soil bunds	
Variables	Coefficient	Robust Standard Error	Coefficient	Robust Standard Error
Household characterstics				
Sex	0.855	0.599	1.562*	0.847
Age	0.002	0.073	-0.214**	0.094
Age-squared	0.001	0.001	0.002*	0.001
Literacy	0.113	0.331	0.284	0.419
Labor	-0.177	0.132	0.365*	0.195
Extension	0.578	0.355	-0.420	0.413
Radio	-0.065	0.495	0.761	0.652
Off-farm	0.566	0.405	0.986**	0.501
Oxen ownership	0.381	0.379	-0.181	0.456
Income (10^{-3})	-0.298	0.214	-0.196	0.236
Land holding trends	-0.847**	0.410	-1.308***	0.424
Risk preference	-0.225*	0.115	-0.036	0.138
Time preference	-0.013**	0.007	-0.007	0.008
Plot characerstics				
Parcel	-0.173**	0.083	0.061	0.085
Plot size	0.263	0.186	0.567**	0.287
Tenure	0.977*	0.531	1.382	0.847
High fertile soil	0.189	0.391	0.669	0.504
Medium fertile soil	-0.081	0.292	0.596	0.392
Soil type	0.267	0.263	-0.994***	0.313
Gentle slope	1.095***	0.376	0.631	0.473
Steep slope	1.227***	0.399	1.322***	0.482
Plot distance	-0.004	0.010	-0.007	0.014
Plot use	1.968***	0.305	1.646***	0.403
Regional characterstics				
Road distance	0.102	0.125	-0.182	0.143
Community	2.444**	1.055	0.534	0.763
Idir	0.390	0.608	0.094	0.934
District	-1.682***	0.464	-3.148***	0.631
Constant	-4.471*	2.339	0.559	2.143
Log-likelihood ratio:	-339.44			
Wald $\chi^2(54)$	301.79***			
Number of observations:	597			

Note: none is the reference category; *, ** and *** indicate statistical significance difference at 10%, 5% and 1% level, respectively.

Table A2. Two stage instrumental variable multinomial logit estimates of the probability of adoption of stone terracing and soil bunds

	Stone terracing		Soil bunds	
Variables	Coefficient	Robust Standard Error	Coefficient	Robust Standard Error
Household characterstics				
Sex	0.516	4.429	1.265	7.221
Age	-0.013	0.124	-0.222	0.175
Age-squared	0.000	0.001	0.002	0.002
Literacy	0.226	0.372	0.311	0.739
Labor	-0.201	0.187	0.305	0.355
Extension	0.592	0.481	-0.358	0.766
Radio	-0.077	0.625	0.682	0.723
Off-farm	0.554	0.594	1.090	0.779
Oxen ownership	0.711	0.520	0.156	0.806
Income (10^{-3})	-0.300	0.317	-0.255	0.449
Land holding trends	-0.921*	0.470	-1.425***	0.550
Risk preference	-1.617*	0.931	-1.723	1.609
Time preference	-0.016*	0.009	-0.020	0.014
Plot characterstics				
Parcel	-0.227**	0.115	0.057	0.159
Plot size	0.339	0.246	0.651	0.425
Tenure	0.894	0.876	1.351	4.376
High fertile soil	0.186	0.476	0.684	0.691
Medium fertile soil	-0.061	0.390	0.626	0.552
Soil type	0.283	0.307	-0.946**	0.471
Gentle slope	1.050**	0.482	0.678	0.564
Steep slope	1.176**	0.483	1.326*	0.714
Plot distance	-0.001	0.012	-0.004	0.018
Plot use	1.937***	0.369	1.593**	0.646
Regional characterstics				
Road distance	0.088	0.163	-0.183	0.240
Community	2.318	7.025	0.330	6.921
Idir	0.899	0.689	0.563	2.927
District	-1.661**	0.695	-3.226***	1.220
Constant	-3.248	9.236	2.644	12.086
Log-likelihood ratio	-340.22			
Wald $\chi^2(54)$	255.16***			
Number of observations:	597			
Joint significance of instruments:				
First stage: $\chi^2(2)$:	28.89***			
Second stage: $\chi^2(2)$:	3.71			

Note: none is the reference category; *, ** and *** indicate statistical significance difference at 10%, 5% and 1% level, respectively.

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