Environment for Development

Discussion Paper Series

October 2015 ■ EfD DP 15-26

Disadoption, Substitutability, and Complementarity of Agricultural Technologies

A Random Effects Multivariate Probit Analysis

Sied Hassen

Environment for Development Centers

Central America
Research Program in Economics and Environment for Development in Central America
Tropical Agricultural Research and Higher Education Center (CATIE)
Email: centralamerica@efdinitiative.org

Chile
Research Nucleus on Environmental and Natural Resource Economics (NENRE)
Universidad de Concepción
Email: chile@efdinitiative.org

China
Environmental Economics Program in China (EEPC)
Peking University
Email: china@efdinitiative.org

Ethiopia
Environmental Economics Policy Forum for Ethiopia (EEPFE)
Ethiopian Development Research Institute (EDRI/AAU)
Email: ethiopia@efdinitiative.org

Kenya
Environment for Development Kenya
University of Nairobi with
Kenya Institute for Public Policy Research and Analysis (KIPPRA)
Email: kenya@efdinitiative.org

South Africa
Environmental Economics Policy Research Unit (EPRU)
University of Cape Town
Email: southafrica@efdinitiative.org

Tanzania
Environment for Development Tanzania
University of Dar es Salaam
Email: tanzania@efdinitiative.org

Sweden
Environmental Economics Unit
University of Gothenburg
Email: info@efdinitiative.org

USA (Washington, DC)
Resources for the Future (RFF)
Email: usa@efdintiative.org

The Environment for Development (EfD) initiative is an environmental economics program focused on international research collaboration, policy advice, and academic training. Financial support is provided by the Swedish International Development Cooperation Agency (Sida). Learn more at www.efdinitiative.org or contact info@efdinitiative.org.

Contents

Disadoption, Substitutability, and Complementarity of Agricultural Technologies: A Random Effects Multivariate Probit Analysis.*

Sied Hassen

Environment and Climate Research Center(ECRC)/EDRI

Email: sied.hassen@outlook.com/seidy2004@gmail.com

Abstract

In this paper, we analyze what drives farmers to disadopt green revolution technologies (inorganic fertilizer and improved seed) and whether the disadoption of green revolution technologies is related to adoption/non-adoption of other sustainable land management practices (such as farmyard manure and soil and water conservation practices). Random effects multivariate probit regression results based on rich plot level data suggest that black/brown soil type, flatter slope, shorter distance to homestead and extension centers, and access to water are negatively correlated with disadoption of green revolution agricultural technologies. Further, we find that the disadoption of green revolution technologies is related to the non-adoption of other sustainable land management practices. Our results strengthen previous findings of complementarity between green revolution technologies and sustainable land management practices by showing that the latter can reduce the likelihood of disadoption of green revolution inputs.

JEL Classification: Q01, Q12, Q16, Q18

Key Words: adoption, disadoption, agriculture, technology, multivariate probit, Ethiopia

*I would like to thank Yonas Alem, Gunnar Köhlin, Peter Berck, Menale Kassie, Subhrendu Pattanayak, Thomas Sterner, Måns Söderbom, two anonymous reviewers of the Environment for Development (EfD) Initiative, and participants at the 8th annual meeting of the EfD Network, October 23-26, 2014, Dar es Salaam, Tanzania for constructive comments on earlier versions of the paper. Financial support from the Swedish International Development Cooperation Agency (Sida) through the Environmental Economics Unit (EEU) of the Department of Economics, University of Gothenburg, is gratefully acknowledged. All errors and omissions are mine

1 Introduction

Increasing agricultural productivity through the adoption and continued use of green revolution technologies (improved seed and inorganic fertilizer) and other sustainable land management practices (such as soil and water conservation practices and farmyard manure) has long been seen as a key policy option to curb undernourishment in Africa. Despite numerous efforts to enhance the adoption and diffusion of such beneficial practices, their use in rural Africa is low and thus a significant proportion of the population in Africa is malnourished (O'Gorman, 2006; Teklewold et al., 2013). Several adoption studies have been conducted in Africa and other developing countries to identify the reasons for low adoption (e.g., Croppenstedt et al., 2003; Marenya and Barrett, 2007; Kassie et al., 2009; Alem et al., 2010; Wollni et al., 2010; Dercon and Christiaensen, 2011; Teklewold et al., 2013). This paper focuses on the disadoption of green revolution technologies and on the relationship between green revolution technologies and other sustainable land management practices in disadoption decisions. These are issues which have been given inadequate emphasis in the literature.

Existing studies on agricultural technology adoption in developing countries find the following factors as the most important in limiting the take-up of new agricultural technologies: risk and uncertainty, knowledge and education, profitability, input availability, credit constraints, tenure security, labor availability, biophysical factors, market incentives and social networks (Croppenstedt et al., 2003; Pattanayak et al., 2003; Bandiera and Rasul, 2005; Doss, 2006; Marenya and Barrett, 2007; Kassie et al., 2009; Alem et al., 2010; Conley and Udry, 2010; Wollni et al., 2010; Dercon and Christiaensen, 2011; Teklewold et al., 2013). Among the studies conducted in Ethiopia, Dercon and Christiaensen (2011) find that lack of insurance or alternative consumption smoothing mechanisms lead farmers to make less investment in new agricultural technologies. Alem et al. (2010) also documented that rainfall variability raises the risk and uncertainty of inorganic fertilizer use, while abundant rainfall in previous years relaxes the liquidity constraints and affordability of fertilizer in the Central Highlands of Ethiopia. While these are the common factors limiting farmers'transition from the state of non-adoption to adoption, Doss (2006) highlighted the need for study of the continued use of agricultural technologies following initial adoption.

Disadoption is an important issue in the study of agricultural technologies adoption in helping to identify factors that boost long-term adoption/use of technologies. Neill and Lee (2001) documented that farmers in Honduras disadopt the practice of legume-maize crop rotation at a rate of 10% per year due to emergence of weed species that increase labor requirements. This increased labor requirement has also been noted as a reason for the disadoption of the Systems of Rice Intensification (SRI) in Madagascar (Moser and Barrett, 2006). Moreover, Marenya and Barrett (2007) also find that farm size, value of livestock owned, off-farm income, family labor supply, educational attainment, and female household head are significant factors in discouraging farmers'use of integrated natural resource management practices in Western Kenya. Further, Wendland and Sills (2008) document that household preference, resource endowments, risk and uncertainty affect households decisions on continued use of soybeans in Togo and Benin.

Building on the few existing agricultural technology disadoption studies (e.g., Neill and Lee, 2001; Moser and Barrett, 2006; Marenya and Barrett, 2007; Wendland and Sills, 2008), the contribution of the current study is twofold. First, using plot level data on adoption and disadoption of multiple technologies, namely, chemical fertilizer, improved seed, manure and soil conservation methods, we investigate the driving forces of the disadoption of multiple interrelated agricultural technologies. Due to lack of data on the disadoption of multiple agricultural technologies, most of the few previous studies (with the exception of Marenya and Barrett, 2007) have focused on the disadoption of a single technology in isolation. Analysis of disadoption of a technology without controlling the adoption and disadoption of other interrelated technologies could cause bias, inconsistency and inefficiency of parameter estimates (Greene, 2008). Unlike Marenya and Barrett (2007), we control for soil and other plot-related characteristics and additional socio-economic characteristics such as risk and time preference that could impede the continued use of the technologies. Furthermore, we have more than six times the sample size of Marenya and Barrett (2007), which provides an advantage in improving the precision of the estimated parameters.

Second, unlike previous studies, we analyze whether the adoption/disadoption of the green revolution techniques is related to the adoption/non-adoption of other sustainable land management practices. Agronomics literature and a few economics studies have documented complementarity of the green revolution techniques with these other sustainable land management practices (Marenya and Barrett, 2009; Chivenge et al., 2011). Application of manure and/or soil conservation enhances the organic components and water holding capacity of soil. These organic components and water holding capacity are important elements to facilitate the decomposition and release of nutrients when inorganic fertilizer is applied to the soil. However, this complementarity result is from an agronomical controlled trial experiment. The real world is different from the controlled trial experiment. Usually farmers'behavior deviates from controlled trial experiment results; agricultural economists study why this happens. This paper is one of the behavioral studies that asks whether farmers choice of these technologies and practices show substitutability or complementarity in adoption/disadoption decisions.

Due to liquidity constraints, risk, or lack of knowledge about the complementary nature of the inputs, farmers may perceive that the application of manure or soil conservation can substitute for the use of green revolution technologies. For example, farmers may perceive that manure and soil conservation practices, like chemical fertilizer, increase soil fertility, though each is adding different nutrients to the soil. Those who use manure or soil conservation may be less likely to adopt and use inorganic fertilizer. Likewise, due to these and other reasons, farmers may disadopt the inorganic fertilizer and replace it with manure or soil conservation. For example, in an area where there is erratic and meager rainfall, and where the plot's soil type lacks important minerals and nutrients, application of inorganic fertilizer can make the seedling or crop "burn"* by raising the acidity of the soil. Farmers who experienced this negative effect of inorganic fertilizer may disadopt the inorganic fertilizer and replace it with manure or soil conservation. The above examples are explanations of how farmers can perceive the green revolution techniques as substitutes with other

*When there is not sufficient rainfall or moisture in the soil, application of chemical fertilizer (UREA and DAP are types of fertilizer available in the study area) will make the seedling or crop die (burn) due to the acidic nature of these fertilizer types sustainable land management practices in adoption/disadoption decisions.

On the other hand, farmers'choices for these technologies can also be complementary in adoption/disadoption decisions. Farmers who know about scientifically proven complementarity and those who have the access and capacity to buy the green revolution technologies may use green revolution technologies with farmyard manure and/or soil conservation. These farmers are most likely to reap the benefit of the mix and are less likely to disadopt green revolution technologies. For these farmers, green revolution technologies and other sustainable land management practices are complementary in adoption/disadoption decisions, i.e., for such farmers, there may be no difference between perceived and actual substitutability and complementarity of the technologies. Which of the above behaviors prevails is an empirical issue and the substitutability and complementarity results may not be symmetric between adoption and disadoption decisions. There exist few studies that test the relationship of green revolution technologies with these other sustainable practices in disadoption decisions. In this study, the data on the disadoption of green revolution technologies can help us understand farmers'perceptions of the substitutability and complementarity of the technologies and practices in disadoption decisions. We used both fixed and random effects linear and nonlinear simultaneous equations methods with Mundlak specifications to answer our research questions.

Our results indicate that farmers who apply green revolution technologies in plots with black/brown soil type, plots that are not sloping, plots that are near the farmer's homestead and near extension centers, and plots that have access to water are less likely to disadopt the green revolution technologies. We also find that farmers who use farmyard manure and/or soil and water conservation methods are less likely to adopt inorganic chemical fertilizer. In the transition from the state of non-adoption to the state of adoption of inorganic fertilizer, farmers perceive farmyard manure and/or soil and water conservation practices as substitutes for inorganic fertilizer. However, farmers who use a mix of inorganic fertilizer and farmyard manure and/or soil and water conservation methods are less likely to disadopt the green revolution technologies. Our results also indicate that improved seed varieties and inorganic fertilizer are complementary in both adoption and disadoption decisions, implying that the disadoption of one leads to disadoption of the other.

The rest of paper is organized as follows. Section two introduces the conceptual framework and empirical strategy of our study. In section three, we describe the data source and study area. Sections four and five present descriptive statistics and econometric results, respectively. Finally, the last section concludes.

2 Conceptual framework and empirical strategy

Farmers'adoption and disadoption decisions for a single technology or multiple technologies as a package can be modeled using a random utility framework. Let U_j^n be the benefit in the state of non-adoption (n) of a technology (or package of technologies)j , U_j^a be the benefit in the state of adoption (a) and U_j^d be the benefit in the state of disadoption (d). Farmer decides to transit from the state of non-adoption to the state of adoption of a technology (or a package) j on plot p if Y_{ipj}^{*}=U_{ipj}^a - U_{ipj}^d $>$ 0 and decides to disadopt if Y_{ipj}^{*}=U_{ipj}^d - U_{ipj}^a $>$ 0 , where Y_{ipj}^{*} is the latent net benefit of adopting or disadopting a technology (package of technologies) . This latent adoption/disadoption decision is determined by:

$$Y_{ipj}^{*} = X_{ipj}\beta_j + \epsilon_{ipj} \tag{1}$$

$$\epsilon_{ipj} = \alpha_{pj} + \eta_{ij} \tag{2}$$

where X_{ipj} represents a vector of observed farmer i and plot p characteristics for adoption/disadoption of technology j [j=chemical fertilizer adoption (F^a), chemical fertilizer disadoption (F^d), improved seed adoption (V^a), improved seed disadoption (V^d), manure adoption (M^a) and soil conservation (S^a)], and β_j is a vector of unknown parameters for the j^{th} technology adoption/disadoption equation. ϵ_{ipj} is the composite error term, which consists of α_{pj} , plot-specific unobserved characteristics, and η_{ij} , unobserved individual farmer characteristics. Because the latent (unobserved) net benefit of adopting or disadopting technology j is unobservable, equation 1 is mapped to an observable binary variable indicating whether or not a farmer is adopting or disadopting technology j :

$$Y_{ipj} = \begin{cases} 1 & if\, Y^*_{ijp} > 0 \\ 0 & if\, Y^*_{ijp} \leq 0 \end{cases} \tag{3}$$

Because we have plot-varying information for every farmer and each has more than one plot, we can treat this data as a pseudo-panel data set and apply the usual fixed and random effects estimation methods of panel data. However, given that the socio-economic characteristics of farmers are plot-invariant, the application of the fixed effects method eliminates both observed and unobserved farmer-specific socio-economic characteristics. This means that estimates of plot-varying characteristics are free of bias from unobserved plot-invariant characteristics; however, one will not be able to identify the parameters of socio-economic characteristics. In order to identify the estimates of observable socio-economic characteristics, the random effect method can be applied. This model assumes that plot-invariant unobserved characteristics are independent of the observable plot and socio-economic characteristics. This is, however, unlikely because some of the plot-invariant characteristics, such a farmer's motivation or ability, may be correlated with some of the regressors in the model, such as education. To correct for this, we used the correlated random effects method, following Mundlak (1978), which involves including the averages of time-varying regressors (plot-varying, in this case) in the model. This method also controls the bias from plot-invariant unobserved characteristics. In the literature, this method is also called pseudo-fixed effects (e.g., Di Falco et al., 2012). To ensure robustness, we estimate both models and discuss the results.

Further, if we assume the error terms are independently and identically distributed across technologies for both adoption and disadoption decisions, equations 1 and 3 represent four separate adoption models and two disadoption models (for fertilizer and improved seed). This assumes no interdependency among the technologies and no correlation between adoption and disadoption decisions. However, a farmer may adopt two or more technologies simultaneously or the adoption of one technology may be conditioned on his/her adoption of another technology, either because they are substitutes or complements. Moreover, the transition of households across discrete states of adoption and disadoption is more likely to cause a correlation between the unobservable error terms of the two decisions, because the disadoption decision is contingent on the adoption decision. That is, farmers make two discrete interrelated decisions. First, households decide whether to adopt a new technology (a package of technologies). Once farmers adopt that technology (the package), they decide either to continue or discontinue using it. A single equation estimation approach could cause bias and inefficiency in the parameters if the interdependence is observed and/or if unobserved heterogeneity is correlated among these technologies in both adoption and disadoption decisions (Greene, 2008). A Multivariate Probit method (MVP) (non-linear seemingly unrelated simultaneous equation) and a linear seemingly unrelated simultaneous equation model (SURE) that allow correlation among the unobserved disturbances are best suited to the adoption and disadoption decisions for interrelated agricultural technologies and practices.

Following Teklewold et al. (2013) and Ndiritu et al. (2014), interdependence of technologies in both adoption and disadoption decisions can be tested by looking at the sign and significance of the off-diagonal elements of the variance-covariance matrix, Σ , of a Multivariate Probit Model (MVP) or SURE model, where Σ ;

$$\Sigma = \begin{bmatrix} 1 & \rho_{F^aF^d} & \rho_{F^aV^a} & \rho_{F^aV^d} & \rho_{F^aM^a} & \rho_{F^aS^s} \\ \rho_{F^dF^a} & 1 & \rho_{F^dV^a} & \rho_{F^dV^d} & \rho_{F^dM^a} & \rho_{F^dS^s} \\ \rho_{V^aF^a} & \rho_{V^aF^d} & 1 & \rho_{V^aV^d} & \rho_{V^aM^a} & \rho_{V^aS^s} \\ \rho_{V^dF^a} & \rho_{V^dF^d} & \rho_{V^dV^a} & 1 & \rho_{V^dM^a} & \rho_{V^dS^s} \\ \rho_{M^aF^a} & \rho_{M^aF^d} & \rho_{M^aV^a} & \rho_{M^aV^d} & 1 & \rho_{M^aS^s} \\ \rho_{S^aF^s} & \rho_{S^aF^d} & \rho_{S^aV^a} & \rho_{S^aV^d} & \rho_{S^aM^a} & 1 \end{bmatrix} \tag{4}$$

and $\rho_{jj'}$ is the correlation coefficient betweenϵ_{ipj} and $\epsilon_{ipj'}$.

3 Data and description of study area

The study is conducted in twelve villages of southern Tigrai, Ethiopia, using a total of 597 sample households and 1344 plots that represent the major agro-ecological conditions of the country.[§] The survey was conducted during July-October 2013 by the author through the Environmental Economics Unit of the University of Gothenburg, Sweden, in cooperation with the Department of Economics of Mekelle University, Ethiopia. The main aim of the data collection was to study intra-household decisions and adoption/disadoption of clean cookstoves and agricultural technologies. Questions about adoption and disadoption of multiple agricultural technologies were included in this survey to study the determinants and interlinkage of agricultural technologies and practices in adoption and disadoption decisions

A total of 600 sample households were randomly selected from 12 villages (kushets) in a region that represents weather conditions that are common in Ethiopia. We randomly selected 50 households from each village using a list of households obtained from each village's administrator. The survey was conducted using a group of 15 enumerators, one supervisor, and 7 village cadres, in one village at a time. All fifteen enumerators interviewed all fifty subjects in most villages, except in two villages, where 48 and 49 households were interviewed.[3] On average, the survey questions took 1.45 hours per household. In the survey, households were asked about their socio-economic characteristics, fuel use, cooking practices, adoption and disadoption of agricultural technology, household decision-making power, etc.

The study area is located in the northern part of the country, with annual rainfall averages

[§] The region contains the Dega, Weynadega and Kola agro-ecological zones. Kola, at an altitude between 500-1500 meters above sea level (m.a.s.l), is characterized by a relatively hotter and drier climate, whereas Weynadega (15002500 m.a.s.l) and Dega (25003500 m a.s.l) are wetter and cooler (Deressa et al., 2009).

[3] Two weeks before we conducted the baseline survey, the village leader and village cadres received a list of households selected for the survey. The cadres and leaders asked households if they would be available at the time we planned to conduct the survey in the village. If they would not be available, the cadres were told to replace them with the next neighbor. Because there was payment for the study, we surveyed most of the households at the appointed time. However, three households for which appointments were scheduled were not available.

between 450 and 600 mm and annual temperature between 16 and 26o C. It is an area with a mixed farming production system. Food and cash crop cultivation are practiced, along with livestock rearing. Farming activities depend on the February to May Belg rains and the July to September Kiremti rains. The main crops cultivated are sorghum, teff, wheat, and barley. Barley and wheat are cultivated mainly in the Dega and Weynadega agro-ecological zones, while teff and sorghum are mainly cultivated in the Kola agro-ecology zone. Barley and wheat are the staple foods in the Dega and Weynadega agro-ecological zones, while sorghum is the staple food in the Kola region. Teff is produced by farm households for both own consumption and market sale. Land preparation is done using oxen draught power. Cattle, goats and sheep are reared in the zone. Livestock are important as a source of draught power, income and food and also to produce manure for agriculture. Other important economic activities in the zone are local agricultural labor, petty trading and salt trading.

4 Descriptive statistics

Table 1 of Appendix A provides summary statistics of the variables in the multivariate probit and SURE regression analysis. These variables were selected following earlier studies on agricultural technology adoption decisions (e.g., Pender and Kerr, 1998; Shiferaw and Holden, 1999; Marenya and Barrett, 2007; Yesuf and Khlin, 2009; Kassie et al., 2009, 2010, 2013; Teklewold et al., 2013). We present the descriptive statistics of the variables under three headings: plot characteristics, farmers socio-economic characteristics, and technology variables.

The plot-specific characteristics include soil type, plot slope, plot level experience in applying fertilizer, experience in applying improved seed, and land ownership type. Farmers in the study area traditionally classify the soil type as $w$alka, $k$eyehtay, and $s$heshher, These three soil types differ in their color, water holding capacity, and organic and mineral content. Walka is mostly black or brown (vertisol), with higher water holding capacity and relatively more organic materials in the soil, and is classed as relatively fertile soil (Elias and Fantaye, 2000; Woldeab, 2003; Abebe, 2007). Keyehtay is a reddish, non-vertisol and non-sandy soil, with less organic material in the soil and relatively lower water holding capacity, and is classed as relatively less fertile than *w*alka soil. *S*heshher is sandy soil which is the least fertile and has the least water holding capacity and the least organic materials (Elias and Fantaye, 2000; Woldeab, 2003; Abebe, 2007). Water holding capacity and organic components of soil are important elements to facilitate the decomposition and release of nutrients when inorganic fertilizer is applied to the soil (Chivenge et al., 2011).

The water storage capacity of soil is typically important in regions with uncertain rainfall (e.g., the study area) and farmers can take into account this aspect of soil composition in the decision to adopt inorganic fertilizer. Furthermore, while the black (*w*alka) soil type is generally classified as less acidic, the reddish (*k*eyehtay) and sandy soil (*s*heshher) types are generally classified as acidic (Abebe, 2007). This is also an important element in the decision to adopt and disadopt chemical fertilizer. In the study area, farmers have been advised by agricultural extension workers to simply adopt and use the same type of chemical fertilizer without measuring acidity or the nutrient requirements of the soil. This has implications for the disadoption of chemical fertilizer. Generally, application of chemical fertilizers increases the acidity of the soil and this will be more problematic if the soil is naturally acidic. The burning potential of chemical fertilizer is high when it is applied in naturally acidic soil. Therefore, farmers with this type of soil are more likely to disadopt chemical fertilizer. In the study area, a large proportion of the soil type is *k*eyehtay (47%) and *s*heshher (28%), which implies a high risk of disadopting chemical fertilizer if farmers do not adopt other land/soil management practices (Ano and Ubochi, 2007).

(Table 1 about here)

The slope of the plot is an indicator of soil erosion potential (Lapar et al., 1999; Bekele and Drake, 2003). Plot slope is expected to positively influence the soil conservation decision; farmers are more likely to adopt both green revolution technologies (chemical fertilizer and improved seed) and farmyard manure if their plots have less slope, and are less likely to disadopt green revolution technologies in plots with less slope. In our data set, the variable plot slope is measured based on farmers'own perceptions of the slope of their plot on a 4-point scale, where 1 means flat and 4 means very sloping. On average, plots in the study area are less sloping (mean value of 1.45).

The incentives for farmers to invest in new technologies depend on whether the plot is owned by the farmer or rented in from other farmers. We expect a farmer to give greater care to his own farm land than to land which is rented in. In addition, the number of years a farmer has been applying improved seed and chemical fertilizer can be a good indicator of success in adoption. Those with longer years of experience in using the technologies are expected to have learned how to improve productivity using these technologies and are less likely to disadopt. Farmers in the study area do not have long years of experience in farming with green revolution technologies; the average experience with fertilizer and improved seed is 5 and 3.5 years, respectively.

Following the literature, in our random effect specifications, we also control for time preference, risk preference and socio-economic conditions of farm households, such as age of the household head, education, wealth and number of livestock owned. Wealth is measured by the value of assets owned by the household.

We use hypothetical risk and time preference questions to measure farmers'subjective time and risk preferences. To measure the time preference, we asked the farmers to make four choices between immediate money and varying amounts of delayed money. To reduce the cognitive burden and fatigue, we kept the payment delay constant across the questions and asked them to make only four choices, as shown in Appendix B. From these alternatives, we construct a time preference variable that ranges from zero to four, where zero refers to the most patient and four is the most impatient. Zero corresponds to a farmer's preference for 5500 Ethiopian Birr (ETB)[4] after one year to 5000 ETB today, while four represents a farmer's preference to have 5000 ETB today and unwillingness to wait at all. Our risk preference variable is also constructed from survey questions where farmers were asked to choose a preferred lottery from five hypothetical lotteries, each with an equal chance of winning, as shown in Appendix B. From these alternatives, we construct a risk preference variable that ranges from zero to four, where zero is the most risk averse and four is the least risk averse. Zero corresponds to a farmer's preference for ETB 250 without any risk, while four represents a choice of the lottery that gives either 1000 ETB or nothing, each with a

[4]The exchange rate during the study period was 1 USD= 18.85 ETB.

50% chance of winning.

The variables under the technology section include the adoption and disadoption of chemical fertilizer, improved seed, and manure and soil conservation methods. Each of these six technology variables represents the dependent variables of simultaneous equation models presented in the earlier section. The adoption of chemical fertilizer and improved seed varieties are dummy variables taking a value of one if the farmer used each of the technologies in each of the plots for the Mehar season of the 2006 Ethiopian calendar (E.C.). Table 1 shows that around 53% and 38% of the plots in the study area used chemical fertilizer and improved seed varieties, respectively, in the 2006 E.C. Mehar season.

Likewise, adoption of manure and soil conservation methods (soil bunds, stone bunds, trees/grasses on plot boundaries) are dummy variables taking a value of one if the farmer applied these practices in each plot for the Mehar season of 2006 E.C. or earlier. From Table 1, we can see that that around 25% and 51% of the plots in the study area used manure and soil conservation methods, respectively. These reported adoption rates are comparable to earlier adoption studies in Ethiopia and other African countries (e.g., Marenya and Barrett, 2007; Yesuf and Khlin, 2009; Kassie et al. 2009, 2010, 2013; Teklewold et al., 2013; Ndiritu et al., 2014). On the other hand, the disadoption of chemical fertilizer and improved seed varieties are also dummy variables taking a value of one if the farmer totally stopped using each of the technologies in each plot on or before the Mehar season of 2006 E.C. From Table 1, we can also see that around 32% and 18% of the plots in the study area have disadopted inorganic fertilizer and improved seed varieties, respectively. Moreover, from Table 2, one can see that 75% of farmers who disadopted inorganic fertilizer did so due to risk of low yield because previous trials were not successful due to crop burn/low yield with a low amount of rainfall, while 31% of those who disadopted improved seed did so because of an insignificant yield and income difference between improved and traditional seed.

(Table 2 about here)

Following Ramful and Zhao (2009) and Teklewold et al. (2013), we use simple descriptive conditional and unconditional probabilities of adoption and disadoption to show the symmetry of relationships between green revolution technologies and other land management practices in adoption and disadoption states. Starting our analysis with the relationship between chemical fertilizer and manure in farmers technological choices, Table 3 of Appendix A shows that the probability of adopting (choosing) chemical fertilizer decreases from 53% (the unconditional take-up rate) to 35% when manure is applied to the plot. Similarly, the probability of adopting manure decreases from 25% to 16% when chemical fertilizer is applied to the plot, suggesting that farmers perceived chemical fertilizer and manure as substitutes in the transition from the state of non-adoption to the state of adoption.

(Tables 3 and 4 about here)

However, we observe a difference in the transition from the state of adoption to the state of disadoption of inorganic fertilizer. As shown in Table 3 of Appendix A, the disadoption rate increases from 32% (unconditional disadoption rate) to 42% when farmers do not use manure and decreases to 2% when farmers apply manure to their plots. This suggests that the use of manure significantly reduces the disadoption of chemical fertilizer and implies the complementarity of the two inputs in the disadoption of chemical fertilizer. This result is consistent with the literature in plant science and some economics literature that the integrated use of farmyard manure and chemical fertilizer sustains the health of the soil, increases the efficiency and uptake of nutrients from chemical fertilizer, balances soil acidity, and hence improves the productivity of fertilizer (Kramer et al., 2002; Satyanarayana et al., 2002; Bayu et al., 2006; Marenyan and Barrett, 2009; Chivenge et al., 2011). We also observe a similar difference in the substitutability and complementarity between chemical fertilizer and soil conservations methods in the adoption and disadoption states (see Tables 3 and 4).

Unlike the result with chemical fertilizer, we do not see a difference in the substitutability and complementarity of improved seed with manure and soil conservation methods in either adoption or disadoption decisions. From Table 3, we can see that the adoption rate increases from 38% (unconditional uptake) to 61% when manure is applied and 59% when a soil conservation method is applied. From Table 4, we also observe that the rate of disadoption of improved seed increases from 18% (unconditional disadoption rate) to 22% when manure is not applied and also increases from 18% to 22% when a soil conservation method is not applied. Conversely, the unconditional disadoption rate decreases from 18% to 9% when manure is applied and decreases from 18% to 15% when a soil conservation method is applied (see Table 4). This result suggests complementarity of improved seed with both manure and soil conservation methods in the decision to transit from non-adoption to adoption and adoption to disadoption states.

Regarding the interdependence of fertilizer and improved seeds, we observe that the uptake of chemical fertilizer increases from 53% (unconditional uptake) to 66% when improved seed is adopted. Likewise, the uptake of improved seed increases from 38% (unconditional uptake) to 48% when chemical fertilizer is adopted (see Table 3). From the disadoption side (Table 4), it can be seen that the rate of unconditional disadoption of chemical fertilizer increases from 32% to 65% when improved seed is disadopted and the rate of unconditional disadoption of improved seed increases from 18% to 37% when chemical fertilizer is disadopted. This descriptive statistics result may imply that farmers simultaneously adopt both fertilizer and improved seed as a package and that the two inputs are complementary in both adoption and disadoption decisions.

5 Econometrics results

MVP and SURE results: Interdependencies and determinants of disadoption of green revolution technologies

Results from the maximum likelihood estimation of the correlated random effect MVP are presented in Table 5. The Wald chi-square (χ^2) test statistics presented in Table 5[$\chi^2(195) = 1987.51, prob > \chi^2 = 00$] indicate the fitness of the Multivariate Probit (MVP) Model with the data and the relevance of the chosen explanatory variables in explaining the model. The likelihood ratio test result confirms not only the existence of the correlation between adoption and disadoption decisions but also the existence of interdependencies among agricultural technologies in both adoption and disadoption decisions. In addition, the mean values of plot-varying covariates are jointly significant, implying the relevance of the Mundlak approach in controlling the bias from unobserved plot-specific factors.

(Table-5 about here)

The likelihood ratio test of independence tells us the existence of interdependence without showing the type of relationship or interdependence among these technologies. The type of relationship can be shown through the signs of the correlation coefficients of the models (Table 5) (Teklewold et al., 2013; Ndiritu et al., 2014). Starting our analysis with the results of the interdependence between chemical fertilizer and other land management practices (soil conservation and farmyard manure), in line with the descriptive statistics results, we observe that their relationship is asymmetric in adoption and disadoption decisions. For example, looking at the estimates of correlation coefficients of the MVP model (Table 5), we observe that inorganic fertilizer has negative and significant correlation with manure and soil conservation $[\rho_{F^aM^a} = -40\%]$ and $[\rho_{F^aS^s} = -25\%]$. These negative correlations may indicate farmers'substitution of inorganic fertilizer (green revolution technology) with manure and soil conservation methods, despite the fact that green revolution technology and the aforementioned sustainable land management practices are complementary in production. Farmers may substitute green revolution technology with these sustainable land management practices due to liquidity constraints, labor market constraints, risk preference and lack of knowledge about the complementary nature of these techniques. As shown in Table 5, wealth, participation in off-farm activities, education and risk preferences of the farmers are significant determinants of adoption of this green revolution technology. These results are consistent with the findings of Yusuf and Köhlin (2009) and Teklewold et al. (2013).

In the disadoption decision, the correlations are still negative and significant $[\rho_{F^dM^a} = -20\%]$ and $[\rho_{F^dS^a} = -12\%]$. These negative correlations, however, may indicate complementarity of inorganic fertilizer with manure and soil conservation, which is consistent with the complementary nature of the inputs. This means that farmers who combine inorganic fertilizer with both manure and soil conservation methods may be less likely to disadopt and may also be more likely to reap the benefit of combining these inputs. This is consistent with the findings in plant science

(Kramer et al., 2002; Satyanarayana et al., 2002; Bayu et al., 2007; Chivenge et al., 2011) and economics literature (Marenya and Barrett, 2009).

Unlike the case of inorganic fertilizer, the relationship of improved seed varieties with manure and soil conservation is not different in adoption and disadoption decisions. As shown in Table 5, improved seed is complementary with both soil conservation methods and manure in both adoption and disadoption decisions [$(\rho_{V^aM^a} = 34\%; \rho_{V^aS^a} = 56\%)$, $(\rho_{V^dM^a} = -18\%; \rho_{V^dS^a} = -21\%)$]. Farmers are more likely to adopt and less likely to disadopt improved seed when these other land management practices are also implemented on the plot. While inorganic fertilizer can be a close substitute for manure and soil conservation methods in terms of investments to improve a plot's soil fertility, improved seed cannot be a close substitute for manure and soil. However, one may argue that farmers who are resource (liquidity) constrained or risk averse may substitute improved seed for manure and soil conservation to pursue the overall goal of higher yield. Nonetheless, as can be seen from Table 5, we do not find liquidity constraints, labor market constraints or risk factors as significant determinants of improved seed adoption. This may be because improved seed is not as expensive as inorganic fertilizer and can be bought in a small quantity (e.g., 5 kg maize per timad, which equals 1/4 hectare), while inorganic fertilizer is sold in bulk (at least a 50 kg/sack). Knowledge about improved seeds (proxied by education and distance to extension center) and experience in farming with improved seed are found to be strong correlates of adoption and disadoption of improved seed varieties.

From the estimated correlation coefficients (Table 5), we can also see that inorganic fertilizer and improved seed varieties are complementary in both adoption and disadoption decisions. This complementarity in adoption may imply the take-up of the two green revolution techniques as a package. Furthermore, the positive and significant correlation (Table 5) of the disadoption of the two green revolution technologies could further strengthen take-up of the inputs as a package. However, compared to the long time during which extension services have been available (more than 20 years), the reported percentage (20%) of complementarity is still low. This is consistent with earlier studies in the same country (e.g., Teklewold et al., 2013) and neighboring countries (e.g., Ndiritu et al., 2014).

Looking at the estimates of determinants of adoption and disadoption of green revolution technologies and the aforementioned other sustainable land management practices [Table 5], it can be seen that farmers with walka (brown/black) soil are more likely to adopt and less likely to disadopt inorganic fertilizer, which implies that farmers are aware of the compatibility of inorganic fertilizer with this soil type. We observe a similar relationship between the walka soil type and disadoption of improved seed varieties. However, we observe a negative relationship between the walka soil type and the application of soil conservation methods. Farmers are more likely to apply soil and water conservation methods to keyehtay and sheshher soil types than to black and brown soil types. This result may also imply that keyehtay and sheshher are more vulnerable to soil erosion and that farmers are doing more soil and water conservation activities in plots with these soil types, but the result for manure is not significant.

As expected, the plot slope variable is negatively related with the application of both green revolution technologies and farmyard manure. However, it is positively and significantly related with soil and water conservation methods and disadoption of green revolution technologies. Further, distance of the plots from the homestead is negatively correlated with adoption of green revolution technologies and these other land management practices and is related positively with disadoption of green revolution technologies. This implies that higher transport and monitoring costs are among the reasons for disadoption of green revolution technologies and non-adoption of other sustainable land management practices. Water availability (proxied by access to irrigation) and tenure security (proxied by owned or rented plot) are a significant determinant of adoption and disadoption of green revolution technologies.

With regard to farmers'socio-economic characteristics, it can be seen that farmers who have had experience in farming with green revolution technologies are less likely to disadopt these technologies. This implies that farmers who adopt for a longer period of time might have learnt how to use these green revolution technologies effectively and efficiently and hence they are more likely to reap the benefit of using these technologies. From Table 5, it can also be seen that risk preference is a significant determinant of both adoption and disadoption of inorganic fertilizer; however, it is insignificant in the adoption of improved seed. The significance of risk in the adoption of inorganic fertilizer may be attributed to the burning potential of inorganic fertilizer and the uncertainty of rainfall. This means that only those who are not risk averse are more likely to adopt inorganic fertilizer. On the disadoption side, the significance of the risk preference variable may imply a change in the risk aversion behavior of farmers over time; in other words, the use of inorganic fertilizer may reduce risk-taking behavior. However, we find the opposite for the time preference variable in the adoption and disadoption of improved seed varieties. The results also show that more patient households are more likely to apply manure and soil conservation practices. Education is positively related to adoption and negatively related to disadoption of green revolution technologies practices. Distance to extension center (a proxy for access to agricultural innovations and practices) is negatively related to adoption and positively related to disadoption of both green revolution technologies.

Robustness checks

An alternative method to control for unobserved heterogeneity is to use the standard fixed effects estimator. This estimator relies on data transformation, whereby variables are transformed into deviations from their means. Because estimation of standard fixed effects for an MVP is not possible[5] , a standard fixed effects model is estimated for the linear multivariate model (SURE Model). Linear probit models are convenient and computationally tractable for estimating marginal effects, and some empirical literature has documented that there is an insignificant difference between linear and non-linear marginal effects (Angrist and Pischke, 2009, pp. 94-107). Therefore, standard linear fixed and correlated random effects multivariate models are estimated to check the robustness of our results in terms of sign and significance of the coefficients. Tables 6 and 7 in Appendix A present the correlated random effect and standard fixed effects estimates, respectively.

[5]Because MVP is a family of the probit model which uses the CDF of the standard normal distribution in the likelihood function, it is impossible to use the fixed effects transformation (Green, 2008; Wooldridge, 2010).

(Tables 6 and 7 about here)

Like the correlated MVP Model estimated above, the χ^2 test statistics and Breusch-Pagan test results also confirm the relevance of the chosen explanatory variables, interdependencies among technologies, and appropriateness of the Mundlak approach in controlling the bias from unobserved plot-specific factors. Further, the estimated correlation coefficients of unobserved error terms in both linear correlated random effects and standard fixed effects estimates are comparable to the sign and magnitude of the correlation coefficients of the MVP Model. Similarly, the sign and significance of plot and socio-economic characteristics of the linear correlated random effects and the standard fixed effects estimates are mostly comparable to estimates of MVP.

The consistency of linear and non-linear as well as random and fixed effects simultaneous equation estimates of correlations of farmers'technological choices implies robustness of the above results. In all the models, consistent with the results of descriptive statistics, manure and soil conservation practices are substitutes with inorganic fertilizer in adoption decisions, while manure and soil conservation are complementary in disadoption of inorganic fertilizer. The burning effect can be reduced by application of farmyard manure, long-term application of crop residuals, or soil and water conservation methods (Kramer et al., 2002; Satyanarayana et al., 2002; Bayu et al., 2007; Ano and Ubochi, 2007; Chivenge et al., 2011). In the study area, as can be seen from Table 2, 75% of farmers who disadopted inorganic fertilizer pointed out a risk of crop burning as their main reason for the disadoption of chemical fertilizer. This may have an effect on disadoption of other complementary inputs. For example, in the study area, farmers who disadopt inorganic fertilizer are at least 14% more likely to disadopt improved seed.

6 Conclusion

Since the advent of the Asian green revolution, there has been hope that the use of green revolution technologies in sub-Saharan Africa would curb undernourishment and create the foundation for sustainable growth. However, crop productivity has not been significantly increased and undernourishment has declined by only an insignificant amount. This could be due to the low rate of adoption of these green revolution technologies and due to the fact that farmers have been offered the same type of technology without testing the differing nutrient requirements and acidity of their soil. As a result, some farmers do not continue to use these technologies. Using a sample of 1344 plots and 597 farm households, this paper studies the driving forces for the disadoption of two green revolution technologies. The paper also studies the relationship between green revolution technologies and other sustainable land management practices such as soil conservation practices and farmyard manure in adoption and disadoption decisions. We use fixed and random effects linear and non-linear econometric methods to answer these questions.

From both the descriptive and econometric results, we find that farmers who use farmyard manure and/or soil conservation practices are less likely to adopt inorganic chemical fertilizer. In the transition from the state of non-adoption to the state of adoption of inorganic fertilizer, farmers perceive soil and water conservation practices and/or farmyard manure as substitutes for inorganic fertilizer. Farmers may substitute this green revolution technology with these other sustainable land management practices due to liquidity constraints, labor markets constraints, risk preference and lack of knowledge about the complementary nature of these inputs. These results are consistent with the findings of Yesuf and Khlin (2009) and Teklewold et al. (2013). However, farmers who use a mix of inorganic fertilizer and these other land management practices are less likely to disadopt the modern technology and are more likely to reap the benefit of the mix. Farmers who use the inorganic fertilizer without applying other sustainable land management practices are more likely to disadopt inorganic fertilizer.

With regard to improved seed, we find that it is complementary with soil and water conservation practices and farmyard manure in both adoption and disadoption decisions. Unlike inorganic fertilizer, we do not find liquidity or labor constraints as significant determinants of improved seed adoption or as factors that causes farmers to substitute improved seed with these other land management practices. This may be because improved seed is not as expensive as inorganic fertilizer and can be bought in a small quantity, while inorganic fertilizer is sold in bulk. Knowledge about improved seed (proxied by education and distance to extension center) and experience farming with improved seed are found to be significant determinants of adoption and disadoption of improved seed varieties. Unlike the finding of Teklewold et al. (2013), in our study area, we find complementarity of improved seed with these other land management practices.

Our results indicate that farmers who apply green revolution technologies in plots with black/brown soil type are less likely to disadopt the green revolution technologies. This result is consistent with the literature in plant science, which finds that black/brown soil has relatively higher organic components and higher water holding capacity. Water holding capacity and organic components of soil are important elements to facilitate decomposition, normalize acidity and release nutrients when inorganic fertilizer is applied to the soil. This particularly fits the following two conditions in the study area. First, the study area is subject to frequent drought and erratic rainfall. Second, farmers in this region are offered the same type of inorganic fertilizer without testing the differences in nutrient requirements and acidity of their soil. In line with this, we find that risk averse farmers are less likely to adopt inorganic fertilizer. This could be attributed to the burning potential of inorganic fertilizer with insufficient rainfall. We also find that disadoption of green revolution technology is more common on rented plots, plots placed far from the homestead, and plots with steep slope with no application of soil conservation methods.

Consistent with the findings of Teklewold et al. (2013) and Ndiritu et al. (2014), we find that improved seed varieties and inorganic fertilizer are complementary, implying take-up of both inputs as a package. However, considering the long years of effort of agricultural extension workers, the rate of complementarity is not large. We also find complementarity on the disadoption side. Farmers who disadopt inorganic fertilizer are more likely to disadopt improved seed. However, this simultaneous disadoption can be reduced if farmers use a mix of green revolution techniques and other sustainable land management practices. This result implies that agricultural extension workers can expand their work, not only to propagate the take-up of green revolution technologies as a package but also to encourage a mix of these technologies and other sustainable land management practices such as soil and water conservation practices and/or farmyard manure.

However, this paper is not without limitations. The paper estimates the substitutability and complementarity of the technologies in adoption and disadoption decision through the correlation of error terms. Due to lack of exogenous instruments in the data, we have not incorporated each technology as a determinant of the other technology in each of the adoption and disadoption equations. Estimates of substitutability and complementarity in technologies based on correlation of error terms are subject to omitted variable bias and hence our estimates are correlations, not causal relationships. Further, the disadoption of agricultural technologies may be better dealt with using multiple rounds of panel data and dynamic panel data models. Therefore, future research can investigate substitutability and complementarity of multiple agricultural technologies in adoption and disadoption decisions with exogenous instruments and with many years of panel data where the time gap between the rounds is long enough to reveal the dynamics. However, even in the absence of such panel data, the current paper sheds light on how farm households disadopt interrelated technologies and the relationships among technologies in adoption and disadoption decisions.

References

Abebe, M. 2007. Nature and Management of Acid Soils in Ethiopia. Addis Ababa, Ethiopia Available at [http://www.eiar.gov.et/Soil/soils_acid.pdf](acceced in April, 2013)

Alem, Y., M. Bezabihb, M. Kassie, and P. Zikhalic. 2010. Does fertilizer use respond to rainfall variability? Panel data evidence from Ethiopia. Agricultural Economics 41: 165175.

Ano, A. O., and C. I. Ubochi. 2007. Neutralization of soil acidity by animal manures: mechanism of reaction. African Journal of Biotechnology 6(4): 364-368

Angrist, J. D, and J. S. Pischke. 2009. Mostly harmless econometrics: An empiricist's companion. Princeton, NJ: Princeton University Press.

Bayu, W., G. Rethman, P. Hammers, and G. Alemu. 2006. Effects of farmyard manure and inorganic fertilizers on sorghum growth, yield, and nitrogen use in a semi-arid area of Ethiopia. Journal of Plant Nutrition 29(2): 391-407.

Bekele, W., and L. Drake. 2003. Soil and water conservation decision behavior of subsistence farmers in the Eastern highlands of Ethiopia: A case study of the Hunde-Lafto area. Ecological Economics 46(3): 43751.

Central Statistical Agency. 2011. Agriculture in figures: Key findings of the 2008/09 2010/11 Agricultural Sample Surveys for all sectors and seasons. Addis Ababa: The Federal Democratic Republic of Ethiopia Central Statistical Agency.

Chivenge, P., B. Vanlauwe, and J. Six. 2011. Does the combined application of organic and mineral nutrient sources influence maize productivity? A meta-analysis. Plant Soil 342: 1-30.

Cornejo, J. F., C. Alexander, and E. Oodhue. 2002. Dynamic diffusion with disadoption: The case of crop biotechnology in the USA. Agricultural and Resource Economics Review 31(1): 112-126.

Conley, T. and C.Udry. 2009. Learning About a New Technology: Pineapple in Ghana, with Tim Conley. American Economic Review, 100 (1), 3569.

Dercon, S., and L. Christiaensen. 2011. Consumption risk, technology adoption and poverty traps: Evidence from Ethiopia. Journal of Development Economics 96(2): 159173.

Deressa, T., and R. Hassan. 2009. Economic impact of climate change on crop production in Ethiopia: Evidence from cross-section measures. Journal of African Economies 18(4): 529554.

Di Falco, S., M. Yesuf, G. Kohlin, and C. Ringler. 2012. Estimating the impact of climate change on agriculture in low-income countries: Household level evidence from the Nile Basin, Ethiopia. Environmental and Resource Economics 52: 457478.

Doss, C. R. 2006. Analyzing technology adoption using microstudies: Limitations, challenges, and opportunities for improvement. Agricultural Economics 34(3): 207219.

Deressa, T., and R. Hassan. 2010. Economic impact of climate change on crop production in Ethiopia: Evidence from cross-section measures. Journal of African Economies 18(4): 529-554.

Duflo, E. 2003. Durosomo, B. 1993. Technology adoption and Sub-Sahara African agriculture: The sustainable development option. Agriculture and Human Values 10(4): 58-70.

Feder, G., R. E. Just, and D. Zilberman. 1985. Adoption of agricultural innovations in developing countries: A survey. Economic Development and Cultural Change 33(2): 255298.

Feder, G., and D. L. Umali. 1993. The adoption of agricultural innovations: a review. Technological Forecasting and Social Change 43(3-4): 215219.

Greene, W. H. 2008. Econometric analysis. 7th Ed. San Francisco: Prentice Hall

Grilli, L., and C. Rampichini. 2007. Multilevel factor models for ordinal variables. Structural Equation Modeling 14(1): 1-25.

Jansen, H. G. P., J. Pender, A. Damon, W. Wielemaker, and R. Schipper. 2006. Policies for sustainable development in the hillside areas of Honduras: A quantitative livelihoods approach. Agricultural Economics 34(2): 141153.

Kassie, M., M. Jaleta, B. Shiferaw, F. Mmbando, and M. Mekuria. 2013. Adoption of interrelated sustainable agricultural practices in smallholder systems: Evidence from rural Tanzania. Technological Forecast and Social Change, 80(4): 525-540.

Kassie, M., J. Pender, M. Yesuf, G. Kohlin, R. A. Bluffstone, and E. Mulugeta. 2008. Estimating returns to soil conservation adoption in the northern Ethiopian highlands. Agricultural Economics 38(2): 213232.

Kassie, M., Zikhali, P., Pender, J. and Kohlin, G. 2010.The economics of sustainable land management practices in the Ethiopian highlands, Journal of Agricultural Economics, Vol. 61, pp. 605627

Kassie M., P. Zikhali, K. Manjur, and S. Edwards. 2009. Adoption of organic farming technologies: Evidence from semi-arid regions of Ethiopia. Natural Resources Forum 33: 189198.

Kramer, A. W., T. A. Doane, W. R. Horwath, and C. V. Kessel. 2002. Combining fertilizer and organic inputs to synchronize N supply in alternative cropping systems in California. Agriculture, Ecosystem and Environment 91: 233243.

Lapar, M. L. A., and S. Pandey. 1999. Adoption of soil conservation: The case of the Philippine Uplands. Journal of the International Association of Agricultural Economists (IAAE) 20(3): 241-256.

Marenya P. P., and C. B. Barrett. 2007. Household-level determinants of adoption of improved natural resources management practices among smallholder farmers in western Kenya. Food Policy 32(4): 515536.

Marenya, P., and C. B. Barrett. 2009. Soil quality and fertilizer use rates among smallholder farmers in western Kenya. Agricultural Economics 40(5): 561572.

Moser, C. M., and C. B. Barrett. 2006. The complex dynamics of smallholder technology adoption: The case of SRI in Madagascar. Agricultural Economics 35(3): 373-388.

Moser, C. M. and C. B. Barrett. 2003. The disappointing adoption dynamics of a yield increasing, low external-input technology: The case of SRI in Madagascar. Agricultural Systems 76(3): 1085-1100.

Mundlak, Y. 1978. On the pooling of time series and cross section data, Econometrica, Vol. 64, pp. 6985.

Ndiritu, W. S., M. Kassie, and B. Shiferaw. 2014. Are there systematic gender differences in the adoption of sustainable agricultural intensification practices? Evidence from Kenya. Food Policy 49(1): 117-127.

Neill, S. P., and D. R. Lee. 2001. Explaining the adoption and disadoption of sustainable agriculture: The case of cover crops in Northern Honduras. Economic Development and Cultural Change 49(4): 793-820.

O'Gorman, M. 2006. Africa's missed agricultural revolution: A quantitative study of technology adoption in agriculture. Working Paper, University of Toronto.

Organization for Relief and Development of Amhara. 2008a. Activity performance reports. Central Western Ethiopia: Office of Agricultural and Rural Development.

ORDA. 2008b. Activity performance reports. Central Western Ethiopia: Office of Agricultural and Rural Development.

Pattanayak, S. K., D. E. Mercer, D.E., E. Sills, and J. C. Yang. 2003. Taking stock of agroforestry adoption studies. Agroforestry Systems 57(3): 173186.

Pender, J., and J. Kerr. 1998. Determinants of farmers indigenous soil and water conservation investments in semi-arid India. Agricultural Economics 19: 11325.

Ramful, P., and X. Zhao. 2009. Participation in marijuana, cocaine and heroin in Australia: A multivariate probit approach. Applied Economics 41(4): 481496.

Satyanarayana, V., P. V. V. Prasad, V. R. K. Murthy, and K. J. Boote. 2002. Influence of integrated use of farmyard manure and inorganic fertilizers on yield and yield components of irrigated lowland rice. Journal of Plant Nutrition 25: 20812090.

Shiferaw, B., and S. Holden. 1999. Soil erosion and small holders'conservation decisions in the highlands of Ethiopia. World Development 27(4): 73952.

Somda J., A. J. Nianogo, A. Nassa, and S. Sanov. 2002. Soil fertility management and socio-economic factors in crop-livestock systems in Burkina Faso: A case study of composting technology. Ecological Economics 43: 17583.

Teklewold, H., M. Kassie, and B. Shiferaw. 2013. Adoption of multiple sustainable agricultural practices in rural Ethiopia. Journal of Agricultural Economics 64(3): 597-623.

Wendland, K.J., and E. O. Sills. 2008. Dissemination of food crops with nutritional benefits: Adoption and disadoption of soybeans in Togo and Benin. Natural Resources Forum 32: 3952.

Woldeab T. 2003.Irrigation Practices, State Intervention and Farmers Life-Worlds in Drought-Prone Tigray, Ethioia, Ph.D. Thesis, Wageningen University.

Wollni M., D. R. Lee, and L. T. Janice. 2010. Conservation agriculture, organic marketing, and collective action in the Honduran hillsides. Agricultural Economics 41: 373384.

Wooldridge, J. M. 2010. Econometric analysis of cross section and panel data. 2nd Ed. Cambridge, MA: The MIT Press.

Yesuf, M. and G. Khlin. 2009. Market imperfections and farm technology adoption decisions: Case study from the highlands of Ethiopia. Unpublished manuscript. University of Gothenburg, Department of Economics.

Appendix A: Tables of descriptive statistics and regression results

Table 1: Descriptive statistics of individual and household characteristics(one)

Technology *variables*	**Description of the variable**	**mean**	**SD**
Adopt_Ferti	If the farmer used chemical fertilizer in the 2006 E.C Maher season (1=yes, 0=no)	0.53	0.49
Dis_Fertilizer	If the farmer stopped using chemical fertilizer (1=yes, 0=no)	0.32	0.47
Adopt_Imvseed	If the farmer used improved seed in the Maher 2006 E.C season (1=yes, 0=no)	0.38	0.48
Dis_Seed	If the farmer stopped using improved seed (1=yes, 0=no)	0.18	0.38
Adopt_manure	If the farmer used manure in the Maher 2006 E.C season or before (1=yes, 0=no)	0.25	0.43
Adopt_soil cons	If the farmer has used soil conservation methods on the plot((1=yes, 0=no)	0.51	0.50
Plot characteristics	**Description of the variable**	**mean**	**Std. Dev**
walka_soil	If the soil type/color is black /brown (1=yes, 0=no)	0.25	0.43
Keyehtay	If the soil type is reddish (1=yes, 0=no)	0.47	0.49
Sheshher	If the soil type/color is sandy (grey color) (1=yes, 0=no)	0.28	0.45
Experience_ fertilizer	Number of years using inorganic fertilizer before stopping using it on the plot	5.0	3.2
Experience_ seed	Number of years using improved seed before stopping using it on the plot	3.5	4.2
Owner_type	If the plot is owned or rented in (1=owned, 0= rented in)	0.84	0.36
plottslope	Slope of the plot as perceived by the farmer on a 4-point scale where 1 means flat and 4 means very sloping	1.45	0.73
Irrigation	If the farmer uses irrigation on this plot (1=yes, 0=no)	0.18	0.38
lndistancetohome	Distance from the homestead to the plot (in minutes and log form)	2.3	1.35
Socio-economic characteristics	**Description of the variable**	**mean**	**Std. Dev**
gender	Gender of the household head	0.89	0.30
age	Age of the household head	46.5	13.00
educationlevel	Education of the household head (in years of schooling)	1.5	2.10
Risk_pref	Subjective risk preference on a 5-point scale, where 0 means most risk averse and 4 means least risk averse	0.81	0.99
Time-pref	Subjective time preference on a 5-point scale, where 0 means most patient and 4 means least patient	2.5	1.24
hhsizze	Household size	5.4	1.94
lnwealth	Value of assets in 1000 ETB (in log)	3.0	1.16
Off-farm work	If the farmer participates in off-farm income generating activities (1=yes, 0=no)	0.54	0.50
Livestock_TLU	Number of livestock in Tropical Livestock Units (TLU)	4.13	2.98
lndistance_extcenter	Distance from the homestead to the extension center (in minutes and log form)	3.27	1.92
lndistance_market	Distance from the homestead to the nearest market (in minutes and log form)	3.78	0.64
Observations		1,344	

Table 2: Reasons for disadoption of inorganic fertilizer and improved seed

Reason for disadoption of inorganic fertilizer	percent	Reason for disadoption of improved seed	percent
1.Increase in price and I can't afford to buy it anymore	12.79%	1.Increase in price and I can't afford to buy it anymore	18.62%
2.I do not get much difference in yield and income in good rains and hence I do not need to use it again	6.51%	2.I do not get much difference in yield and income in good rains and hence I do not need to use it again	31.58%
3.It is not available in a nearby market	2.56%	3.The type I need is not available in a nearby market	17.81%
4.Risk of low yield because previous trial was not successful due to crop burn/low yield with low amount of rainfall	75.12%	4.Risk of low yield because previous trial was not successful due to low amount of rainfall	22.27%
5.Other	3.02%	5.Other	9.72%

Table 3 The conditional and unconditional probabilities in ***Adoption decision***

	Fertilizer	Seed	manure	Soil conserv.
P(y=1)	53%	38%	25%	51%
P(y=1/fertilizer=1)	100%	48%	16%	44%
P(y=1/seed=1)	66%	100%	40%	79%
P(y=1/manure=1)	35%	61%	100%	81%
P(y=1/soil consv=1)	46%	59%	40%	100%
P(y=1/soil consv=1, manure=1)	23%	55%	100%	100%
P(y=1/improved seed=1, manure=1)	35%	100%	100%	74%
P(y=1/fertilizer=1, manure=1)	100%	62%	100%	20%
P(y=1/fertilizer=1, improved seed=1)	100%	100%	21%	68%
P(y=1/fertilizer=1, soil=1)	100%	73%	20%	100%
P(y=1/improved seed=1, soil=1)	57%	100%	37%	100%
P(y=1/improved seed=1, manure=1 and soil=1)	12%	100%	100%	100%
P(y=1/fertilizer=1, manure=1 and soil=1)	100%	29%	100%	100%
P(y=1/fertilizer=1, improved seed=1 and soil=1)	100%	100%	8%	100%
P(y=1/fertilizer=1, improved seed=1 and manure=1)	100%	100%	100%	25%

Where y= {chemical fertilizer, improved seed, manure and soil conservation methods}

Table 4 The conditional and unconditional probabilities in ***Disadoption and non-adoption decisions***

	Disadopt fertilizer	Disadopt improved seed	Non-adopt manure	Non-adopt-Soil
P(y=1)	32%	18%	75%	49%
P(y=1/Dis Adopt_fertilizer=1)	100%	37%	98%	60%
P(y=1/Dis Adopt_Seed=1)	65%	100%	88%	58%
P(y=1/manure_NA=1)	42%	22%	100%	59%
P(y=1/manure=1)	2%	9%	-	-
P(y=1/Soil_NA=1)	39%	22%	90%	100%
P(y=1/Soil=1)	25%	15%	-	-
P(y=1/Dis Adopt_fertilizer=1,Dis Adopt_Seed=1)	100%	100%	64%	46%
P(y=1/Dis Adopt_fertilizer=1,manure_NA=1)	100%	37%	100%	60%
P(y=1/Dis Adopt_Improvedseed=1,manure_NA=1)	72%	100%	100%	65%
P(y=1/Siol_NA=1,manure_NA=1)	43%	24%	100%	100%
P(y=1/Dis adopt_Fertilizer=1 Soil_NA=1)	100%	44%	99%	100%
P(y=1/Dis adopt_Seed=1 Manure_NA=1)	72%	100%	100%	65%

Where y= {disadoption of chemical fertilizer, disadoption of improved seed, adoption of manure (manure), non-adoption of manure (manure_NA), adoption of soil conservation methods (Soil) and non-adoption of soil conservation methods (Soil_NA)} and NA=non-adoption

Table 5: Random effect Probit Multivariate Regression Results of Adoption and Disadoption of Agricultural Practices

	Adopt Inorganic Fertilizer		Disadopt Inorganic Fertilizer		adopt Improved seed		Disadopt Improved seed		Adopt Manure		Adopt Soil. Conserv.	
VARIABLES	Coef	R.SE	Coef	R.SE	Coef	R.SE	Coef	R.SE	Coef	R.SE	Coef	R.SE
Walka soil	0.97***	0.15	-1.11***	0.18	0.22	0.16	-0.51**	0.23	0.21	0.15	-0.30**	0.14
Plot slope	-0.65***	0.09	0.52***	0.10	-0.43***	0.11	0.69***	0.14	-0.29**	0.11	0.20**	0.09
Use irrigation	0.50***	0.17	-0.76***	0.22	0.62***	0.17	-0.28	0.30	0.25	0.19	0.36**	0.17
Land ownership type	0.48***	0.16	-0.55***	0.19	0.32	0.20	-0.55**	0.23	0.14	0.21	-0.06	0.17
Plot size	0.02	0.06	-0.04	0.06	0.00	0.07	0.09	0.06	-0.01	0.06	0.02	0.06
Plot distance	-0.04	0.05	0.13**	0.06	-0.35***	0.05	0.54***	0.08	-0.21***	0.06	-0.22***	0.05
Number of years the modern technology applied in the plot			-0.07***	0.02	-0.24***	0.03						
Risk preference	0.20***	0.04	-0.13***	0.05	0.05	0.04	-0.20***	0.07	-0.16***	0.04	-0.01	0.04
Time preference	-0.10***	0.04	-0.01	0.04	-0.39***	0.05	-0.17***	0.06	-0.14***	0.04	-0.29***	0.04
Gender	0.12	0.13	-0.08	0.15	0.18	0.17	0.53***	0.19	0.14	0.15	0.18	0.14
Wealth (log)	0.13***	0.03	-0.11***	0.04	0.07*	0.04	0.03	0.06	0.02	0.04	0.06*	0.03
Participation in off-farm Income	0.51***	0.08	-0.17*	0.09	0.06	0.09	0.03	0.12	-0.10	0.09	-0.09	0.08
Education level	0.04*	0.02	-0.04*	0.02	0.12***	0.02	-0.11***	0.03	0.02	0.02	0.03	0.02
Household size	0.01	0.02	-0.07***	0.02	0.13***	0.02	-0.15***	0.03	0.09***	0.02	0.11***	0.02
Age of the household head	0.00	0.00	0.00	0.00	0.00	0.00	0.01**	0.01	-0.00	0.00	0.00	0.00
Distance to extension center	-0.00	0.04	0.09**	0.04	-0.19***	0.05	0.10*	0.05	-0.16***	0.04	-0.15***	0.04
Distance to market	-0.01	0.07	-0.00	0.08	0.01	0.07	-0.00	0.12	0.01	0.08	0.20***	0.07
Number of livestock (in TLU)									0.49***	0.12		
Village dummies	Yes		Yes		Yes		Yes		Yes		Yes	
Constant	-0.78**	0.39	0.60	0.46	0.67	0.47	-3.69***	0.73	-1.11**	0.51	-0.57	0.42
correlations of error terms	Coef.	R.SE	corr.	Coef.	R.SE	corr.	Coef.	R.SE				
$\rho_{F^{d}F^{a}}$	-0.74***	0.041	$\rho_{V^{a}F^{d}}$	-0.41***	0.049	$\rho_{M^{a}V^{a}}$	0.34***	0.049				
$\rho_{V^{a}F^{a}}$	0.20***	0.058	$\rho_{V^{d}F^{d}}$	0.14*	0.075	$\rho_{S^{a}V^{a}}$	0.56***	0.042				
$\rho_{V^{d}F^{a}}$	-0.10	0.070	$\rho_{M^{a}F^{d}}$	-0.20***	0.06	$\rho_{M^{a}V^{d}}$	-0.18***	0.050				
$\rho_{M^{a}F^{a}}$	-0.40***	0.051	$\rho_{S^{a}F^{d}}$	-0.12**	0.058	$\rho_{S^{a}V^{d}}$	-0.21***	0.061				
$\rho_{S^{a}F^{a}}$	-0.25***	0.054	$\rho_{V^{d}V^{a}}$	-0.36***	0.083	$\rho_{M^{a}S^{a}}$	0.53***	0.04				
Joint significance of correlation of unobservables in all equations [likelihood ratio test]: $\chi^2(15)$ = 952.734 Prob > χ^2 = 0.0000												
Joint significance of mean of plot-varying variables in the model: $\chi^2(36)$ = 60.72, Prob > chi2 = 0.006												
Wald $\chi^2(195)$ = 1987.51, Prob > χ^2 = 0.0000												
Observations	1,344		1,344		1,344		1,344		1,344		1,344	1,344

Note:*, **, *** indicate statistical significance at 10, 5 and 1%, respectively. R.SE is robust standard error

Table 6: A Random Effects Linear Multivariate Regression Results of Adoption and Disadoption of Agricultural Practices

	Adopt Inorganic Fertilizer		Disadopt Inorganic Fertilizer		adopt Improved seed		Disadopt Improved seed		Adopt Manure		Adopt Soil. Conserv.	
VARIABLES	Coef	B.SE	Coef	B.SE	Coef	B.SE	Coef	B.SE	Coef	B.SE	Coef	B.SE
Walka soil	0.28***	0.04	-0.20***	0.04	0.04	0.04	-0.06**	0.03	0.04	0.04	-0.09*	0.05
Plot slope	-0.22***	0.03	0.18***	0.03	-0.08***	0.03	0.13***	0.02	-0.05*	0.03	0.08***	0.03
Use irrigation	0.14***	0.05	-0.15***	0.04	0.18***	0.05	-0.03	0.03	0.08	0.06	0.12**	0.05
Land ownership type	0.12**	0.05	-0.16***	0.05	0.05	0.05	-0.12***	0.04	0.06	0.05	0.02	0.06
Plot size	0.00	0.02	-0.00	0.02	-0.00	0.02	0.02	0.01	-0.01	0.02	-0.00	0.02
Plot distance	-0.01	0.01	0.02*	0.01	-0.09***	0.01	0.08***	0.01	-0.06***	0.01	-0.08***	0.02
Number of years the modern technology applied in the plot			-0.00*	0.00	-0.02***	0.00						
Risk Preference	-0.04***	0.01	-0.04***	0.01	0.00	0.01	-0.02**	0.01				
Time preference	0.03***	0.01	-0.00	0.01	-0.11***	0.01	-0.04***	0.01	-0.03***	0.01	-0.10***	0.01
Gender	0.03	0.04	-0.03	0.04	0.05	0.04	0.06**	0.03	0.05	0.04	0.06	0.04
Wealth (log)	0.03***	0.01	-0.03***	0.01	0.01	0.01	0.00	0.01	0.00	0.01	0.03**	0.01
Participation in off-farm income	0.15***	0.03	-0.03	0.02	0.01	0.02	0.01	0.02	-0.04	0.02	-0.02	0.03
Education level	0.01*	0.01	-0.01**	0.01	0.03***	0.01	-0.02***	0.00	0.01	0.01	0.01*	0.01
Household size	0.00	0.01	-0.02***	0.01	0.03***	0.01	-0.02***	0.00	0.02***	0.01	0.04***	0.01
Age of the household head	0.00	0.00	0.00	0.00	-0.00	0.00	0.00**	0.00	-0.00*	0.00	0.00	0.00
Distance to extension center	-0.00	0.01	0.02**	0.01	-0.04***	0.01	0.01	0.01	-0.05***	0.01	-0.05***	0.01
Distance to market	-0.00	0.02	0.01	0.02	0.01	0.02	0.00	0.02	0.01	0.02	0.06***	0.02
Number of livestock (in TLU)									0.05**	0.02		
Village dummies	Yes		Yes		Yes		Yes		Yes		Yes	
Constant	0.33**	0.14	0.42***	0.13	0.74***	0.12	-0.06	0.09	0.21*	0.12	0.31**	0.14
correlations of error terms	Coef.	corr.	Coef.	corr.	Coef.							
$\rho_{F^dF^a}$	-0.58	$\rho_{V^aF^d}$	-0.22	$\rho_{M^aV^a}$	0.14							
$\rho_{V^aF^a}$	0.24	$\rho_{V^dF^d}$	0.18	$\rho_{S^aV^a}$	0.33							
$\rho_{V^dF^a}$	-0.11	$\rho_{M^aF^d}$	-0.34	$\rho_{M^aV^d}$	-0.22							
$\rho_{M^aF^a}$	-0.34	$\rho_{S^aF^d}$	-0.16	$\rho_{S^aV^d}$	-0.23							
$\rho_{S^aF^a}$	-0.18	$\rho_{V^dV^a}$	-0.11	$\rho_{M^aS^a}$	0.29							
Joint significance of correlation of unobservables in all equations [likelihood ratio test]: $\chi^2(15)$ = 1217.102, Prob > χ^2 = 0.000												
Joint significance of mean of plot-varying variables in the model: χ^2(36) = 75.13 Prob > chi2 = 0.000												
Joint significance of all explanatory variables in the model $\chi^2(122)$ 7479.38, Prob > χ^2 = 0.000												
Observations	1,344		1,344		1,344		1,344		1,344		1,344	
R-squared	0.30		0.34		0.41		0.48		0.17		0.23	

Note:*, **, *** indicate statistical significance at 10, 5 and 1%, respectively. B.SE is bootstrap standard error

Table 7: Fixed effect Linear Multivariate Regression Results of Adoption and Disadoption of Agricultural Practices

	Adopt Inorganic Fertilizer		Disadopt Inorganic Fertilizer		adopt Improved seed		Disadopt Improved seed		Adopt Manure		Adopt Soil. Conserv.	
VARIABLES	Coef	B.SE	Coef	B.SE	Coef	B.SE	Coef	B.SE	Coef	B.SE	Coef	B.SE
Walka soil	0.30***	0.03	-0.22***	0.03	0.05*	0.03	-0.10***	0.02	0.06*	0.03	-0.09**	0.04
Plot slope	-0.05***	0.01	0.02**	0.01	-0.01	0.01	0.04***	0.01	-0.02***	0.01	0.05***	0.01
Use irrigation	0.17***	0.04	-0.17***	0.03	0.20***	0.04	-0.08***	0.02	0.09*	0.04	0.11**	0.05
Land ownership type	0.17***	0.04	-0.21***	0.04	0.08**	0.03	-0.15***	0.03	0.07**	0.03	0.01	0.04
Plot size	0.01	0.01	-0.00	0.01	-0.00	0.01	0.02**	0.01	-0.01	0.01	-0.00	0.01
Plot distance	-0.00	0.01	0.03***	0.01	-0.10***	0.01	0.10***	0.01	-0.06***	0.01	-0.08***	0.01
Number of years the modern technology applied in the plot			-0.01***	0.00			-0.01***	0.00				
Constant	-0.00	0.01	-0.00	0.01	-0.00	0.01	-0.00	0.00	-0.00	0.01	-0.00	0.01
Correlations of error terms	Coef.	corr.	Coef.	corr.	Coef.							
$\rho_{F^d F^a}$	-0.58	$\rho_{V^a F^d}$	-0.31	$\rho_{M^a V^a}$	0.25							
$\rho_{V^a F^a}$	0.36	$\rho_{V^d F^d}$	0.22	$\rho_{S^a V^a}$	0.30							
$\rho_{V^d F^a}$	-0.21	$\rho_{M^a F^d}$	-0.45	$\rho_{M^a V^d}$	-0.21							
$\rho_{M^a F^a}$	-0.30	$\rho_{S^a F^d}$	-0.13	$\rho_{S^a V^d}$	-0.25							
$\rho_{S^a F^a}$	-0.22	$\rho_{V^d V^a}$	-0.27	$\rho_{M^a S^a}$	0.28							
Joint significance of correlation of unobservables in all equations[likelihood ratio test]: $\chi^2(15)$ = 1494.831, Prob > χ^2 = 0.0000												
Joint significance of all explanatory variables in the model $\chi^2(36)$ = 647.66, Prob > χ^2 = 0.0000												
Observations	1,344		1,344		1,344		1,344		1,344		1,344	
R-squared	0.17		0.17		0.15		0.26		0.07		0.08	

Note:*, **, *** indicate statistical significance at 10, 5 and 1%, respectively. B.SE is bootstrap standard error

Appendix B

Risk and Time Preference Questions

B1.Risk preference

In what follows, we ask you to make a decision based on a hypothetical game of random chance by flipping a 5 cent coin (Ethiopian currency). As you know, the 5 cent coin has two sides, identified as 'lion head'and 'man'(Enumerator: Use the coin to explain). If we flip the coin, either the 'lion head side'or 'man side'will appear with equal chance and a monetary amount is attached to either outcome (Enumerator: Flip the coin as a practice to explain equal chance).

A1.1. Before we continue, we would like to ask you your understanding of a random chance. If we flip the coin, which side will appear? (Enumerator: After writing down the answer, explain the correct answer.)

A. Lion head

B. Man

C. One of them will appear with equal chance

D. I do not know

A1.2. Now we are going to flip the coin. Before that, which one of the monetary values associated with one of the outcomes of the flipping coin do you choose?

A. 250 Birr regardless of whether it is lion or man

B. 200 Birr if it is lion, 400 Birr if it is man

C. 150 Birr if it is lion, 550 Birr if it is man

D. 100 Birr if it is lion, 700 Birr if it is man

E. 0 Birr if it is lion, 1000 Birr if it is man

B2.Time preference

Imagine now that you have won a lottery and that the prize can be paid at different points in time: today or after one year. *What amount of money would you prefer in each choice situation A-D?*

A. 5,000 ETB today or 5,500 ETB after one year, amount chosen——————

B. 5,000 ETB today or 7,000 ETB after one year, amount chosen——————

C. 5,000 ETB today or 9,000 ETB after one year, amount chosen——————

D. 5,000 ETB today or 11,000 ETB after one year, amount chosen——————