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Modeling Farmers' Adoption Decisions of Multiple Crop Technologies: The Case of Barley and Potatoes in Ethiopia

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Abstract

This paper argues and provides empirical evidence that adoption decisions on multiple technologies involve a series of three sequential sub-decisions. Using a multivariate tobit and multivariate probit models and a nationally representative data from Ethiopian highlands, we find that decisions on the area shares of barley and potatoes in total farm size and the plot/field-level decision on the adoption of improved varieties of the two crops are independent. The farm-level decisions on the adoption of improved varieties of the two crops however exhibit strong simultaneity. A striking result from this analysis is that, the number of extension visits affects neither crop choice nor variety adoption decisions which, along with the relatively high density of extension agents in Ethiopia, shows the poor performance of the extension system. Targeting farmers dedicating higher proportion of their lands to the particular crop and introducing other models of extension could increase technology adoption.

Key words: *adoption, multiple technologies, simultaneity, multivariate tobit, multivariate probit*

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1. Introduction

Agriculture continues to be the dominant economic sector, contributing 42% to the gross domestic product (GDP), 85% to employment and 90% to export earnings (MEDaC, 2010). The performance of the agriculture sector until recently, however, had been unsatisfactory owing to the poor policies of the socialist oriented military regime and partly to drought and erratic rainfall. Since 2005, however, the agricultural sector rebounded registering an average annual growth rate of 11% (MOFED, 2010). However, despite the improved performance of the agricultural sector, food security is still a key development challenge for the country. Smallholder subsistence farmers cultivating small land holdings dominate the Ethiopian agricultural sector. They cultivate 95 percent of the cropped area and produce about 85 percent of the agricultural output. Cereals constitute about 73 percent of the total cropland cultivated by smallholders and account for nearly 70 percent of their caloric intake (CSA, 2011).

Barley (*Hordeum vulgare L .*) is one of the most important staple food crops in the highlands of Ethiopia. Currently, it is cultivated on about 1.13 million hectares of land and the total annual grain production in 2009/10 stands at 1.78 million metric tons. Barley accounts for about 12.2 % of the total area for major cereal crops and about 11.5% of the total annual cereal production in Ethiopia. Barley is cropped twice a year in the main season, locally known as *meher* (using the June-September rainfall), and the small rainy season, locally known as *belg* (using the March-April rainfall).

Although barley grows in all the regions, the major barley producing regions include Oromia, Amhara, Tigray and Southern Nations, Nationalities and Peoples Region (SNNPR) which all together account for 99.5% of the total annual production. Over the last 15 years, barley production has increased two fold from 8.87 million tons in 1994 to about 1.75 million tons in 2010 (FAOStat). These increases are largely attributed to area expansion and to a lesser extent to productivity gains. Given the limited scope for further area expansion, increase in barley production needs to come from productivity improvements than area expansion. The generation and transfer of sustainable crop intensification technologies, therefore, have been given a renewed priority in the country's food security strategy developed in 1996 and amended in 2002. Between 1998 and 2010 alone, 24 improved food barley and 6 improved malting barley varieties have been released along with improved crop management and crop protection practices. These technology packages have been aggressively demonstrated in the rainfall assured major barley producing areas of the country. Improvements in the input supply system (mainly chemical fertilizers) and access to institutional credit are believed to have encouraged smallholder farmers to use improved barley technologies.

In spite of the extensive technology generation and dissemination efforts, however, average cereal crop productivity has remained below expectations - averaging 1.68 tons/ha (CSA, 2010) casting doubt that the county has benefited from investments made on agricultural technology research and extension. The low crop productivity in the face of the availability of new and proven production technologies that would increase productivity by a significant margin has become a puzzle to the government and non-government organizations (NGOs) alike. The need for explanation for this dilemma has triggered high interest in agricultural technology adoption and analysis of factors that influence the adoption decision behavior of smallholder farmers who produce the bulk of the agricultural production in the country.

This study attempts to study the determinants of adoption of improved varieties of barley (IMBV) and improved varieties of potatoes (IMBV) in Ethiopian highlands. We argue that the decision on the share of a given crop in total farm size is determined by exogenous factors such as family consumption needs, crop rotation requirements, and expected price (often based on previous year's prices) independently of the decision for the area share of another crop. On the other hand, farm households who have tried and benefitted from one technology are more likely to be open [and can even be eager in some cases] to adopt other technologies as well. Moreover, given that potatoes are highly sensitive to water logging while barley generally performs relatively better even on less drained fields, we argue that at plot level, the decision on whether or not to plant IMPV do not affect the decision on planting IMBV. The hypotheses to be tested are therefore:

1) At household level, the decision on the area share of barley is independent of the decision on the area share of potatoes and vice versa.
2) At household level, the adoption decision on IMBV is likely to be affected by the adoption decisions on IMPV.
3) At plot level, the decision on planting IMBV is not affected by the decision on planting IMPV.

The next section reviews agricultural technology adoption studies in Ethiopia and identifies the gap. Section three describes the data used for this analysis. Methodological discussion is presented in section four. Sections five presents the results and discussion and with conclusions drawn in section six.

2. Review of the literature

Adoption could be understood as a decision to make full use of a new idea as the best course of action available (Shoemaker, 1971). Similarly, Feder *et al.* (1985) defined final adoption at the level of the individual farmer as the degree of use of a new technology in long run equilibrium when the farmer has full information about the new technology and its potential. Jha *et al.* (1990) and Smale *et al.* (1991) indicated that adoption is a process involving three interrelated decisions. The first adoption decision is the choice of whether to adopt the components of the recommended technology such as seed, fertilizer and herbicide and in which sequence or combination (seed only, fertilizer only, herbicide only or a combination of the three). The second decision is the extent of adoption, the choice of how much land to allocate to new and old technologies. The third decision is the intensity of adoption, the choice of the level per hectare or rate of application, if fertilizer and/or herbicide is adopted. The combination of these three decisions composes the technology adoption decision, and, aggregated over farms to the national area is the diffusion of the technology. Separating the components of the technology adoption decision helps to illustrate how farmers choose a variety of technological options in an attempt to satisfy their multiple objectives.

2.1 Adoption studies across the globe

The first studies on technology adoption were carried out during the decade following the introduction of high yielding varieties (HYVs) in the mid-1960s (e.g., Ruttan, 1977; Feder *et al.*, 1985). Ruttan (1977) based on a large body of literature on HYVs indicated that the new HYVs were adopted at exceptionally rapid rates and that their adoption is scale and tenure neutral. While smaller farmers and tenants tended to lag behind larger farmers in the early years, these lags have typically disappeared within a few years. The same study also indicated that the introduction of HYVs has resulted in an increase in the demand of labour and both landowners and tenants have gained, but landowners have gained more than proportionately.

A decade later, Feder *et al.* (1985) summarized the vast amount of empirical literature on production related adoption and indicated that the constraints to adoption of a new technology may arise from many sources, such as lack of credit, small farm size, unstable supply of complementary inputs, uncertainty and risk. Factors conditioning smallholder farmers' use of agricultural technologies summarized in the literature include: profitability of the proposed technology, household and farm characteristics, perceptions and attributes of the technology and institutional factors such as land tenure, access to markets, information and credit (Ervin and Ervin, 1982; Norris and Batie, 1987; Pagiola, 1996; Shiferaw and Holden, 1998; Hassan et al., 1998a; Hassan et al., 1998b; Lapar and Pandey, 1999; Kazianga and Masters, 2001; Bamire et al., 2002; Gebremedhin and Swinton, 2003; Nakhumwa and Hassan, 2003; Bekele and Drake, 2003). Others have also argued that besides the above factors risk considerations also affect the rate of adoption of an innovation (Grepperud, 1997b; Shively, 2001; Fufa and Hassan, 2003).

Important contributions have been made by previous adoption studies in identifying the factors constraining smallholder farmers benefiting from recommended technologies and suggesting ways of improving policy design. The studies, however, were not free from limitations. A fundamental problem characterizing all adoption studies is the absence of economic theory that could serve as a basis for the selection of the determinants of technology adoption decision variables. For example, although in principle a farmer's investment in conservation practices could be derived from the maximization of his/her utility function, the fact that the arguments of the utility function are not known makes derivation difficult (Norris and Batie, 1987).

Ghadim and Pannell (1999) noted that despite the huge number of adoption studies conducted in the last 30 years, the results in the field remained short of expectations. They indicated that most of the statistical models developed have low levels of explanatory power despite the fact that a long list of explanatory variables is used. Furthermore, the results from different studies are often contradictory regarding the importance of any given variable. Ghadim and Pannell (1999) citing Linder (1987) pointed out four major shortcomings responsible for the inconsistent results obtained by most of the empirical studies of agricultural innovations:

- Failure to account for the importance of the dynamic learning process in adoption
- Biases from omitted variables
- Poor model specification
- Failure to relate hypotheses to a sound conceptual frame work

The use of binomial and multinomial qualitative choice models in the analysis of adoption of technologies is well established in the adoption literature (Feder et al., 1985). One purpose of qualitative choice models is to determine the probability that an individual with a given set of attributes will make one choice rather than an alternative (Green, 2000). The two most popular functional forms used for adoption models are the probit and the logit models. Dimara and Skuras

(2003), however, acknowledging the contributions that previous adoption studies using dichotomous adoption decision models had made for the design of improved policies, they contended that dichotomous adoption models have got inherent weakness. They indicated that despite the fact that most decision-making processes concerning innovation adoption involve a multistage procedure, static adoption models often consider the process as a single stage. Dimara and Skuras (2003) argued that the basic tent of a single stage decision making process characterizing dichotomous adoption decision models is a direct consequence of the full information assumption embedded in the definition[1] of adoption. However, the full information assumption is often violated and hence analysis of the adoption decision using logit, probit and Tobit models may suffer from model misspecification.

Over the years, a number of authors have tried to overcome these limitations in a number of ways. Byerlee and Hesse de Polanco (1986) and Leathers and Smale (1991) suggested a sequential adoption decision model. Ghadim and Pannell (1999) assuming that previous adoption models did not adequately consider the dynamic learning process suggested the use of a dynamic adoption decision model, which includes farmers' personal perceptions, managerial abilities and risk preferences. Fufa and Hassan (2003) using a stochastic production function showed the importance of risk effects of factor inputs on production behavior of smallholder maize growers in Ethiopia.

Dimara and Skuras (2003) assuming that adoption of innovations involves a multistage process and drawing from literature that quite a good deal of the sample population in previous adoption studies did not have the necessary information and level of awareness concerning the new technology (violating the full information assumption) suggested a partial observability model. Likewise, Gebremedhin and Swinton (2003) recognizing that the decision to invest in soil conservation involves multiple stages and these decisions may be independent (or sequential) suggested the use of a double hurdle model where a logit or probit regression on adoption (using

[1] According to Feder et al (1985) individual adoption (adoption at the level of the farm or firm) is defined as the degree of use a new technology in the long-run equilibrium when the farmer has full information about the new technology and its potential.

all observations) is fitted followed by the use of a truncated regression on non-zero observations. Hypothesising that the variables determining the probability of using a conservation technology may be different from the factors affecting intensity of use, Nakhumwa and Hassan (2003) used a selective Tobit model to simulate the adoption decision behavior of smallholder farmers as a two-step process. Empirical results showed that for smallholder farmers in Malawi, the factors that determine the probability of use of a conservation technology (ridge marker) may be different from those that determine the intensity of use (Nakhumwa and Hassan, 2003). Yirga and Hassan (2008) recognized the simultaneity of choices and that the management of multiple plots would affect smallholder farmers' adoption decision behavior of soil fertility management practices. Their results confirmed that awareness of soil degradation, improved security of land tenure, farmers' education and access to information on soil degradation were found to be essential in influencing farmers' decision to adopt soil fertility management practices in Ethiopia. Recently, Teklewold et al. (2013) analyzed the determinants of the adoption of interrelated sustainable agricultural practices (SAPS) based on data from multiple plot level observations using Multivariate and ordered probit models. The results indicated a significant correlation between the decisions for the adoption of different SAPs revealing that adoption of SAPs is interrelated.

2.2 Empirical Adoption Studies in Ethiopia

Almost all of the technology adoption studies conducted in Ethiopia primarily aimed at assessing project success and hence were largely conducted either on pilot research and extension sites or in selected high potential but pocket areas where intensive project efforts had been conducted. Such projects aimed at assessing technology transfer efforts by government extension and other specialized development programs in pilot extension areas. Their focus was also only on relatively few cereal crops (mainly wheat and maize) and limited component technologies (improved seeds, inorganic fertilizers and herbicides). These studies revealed reasonably high rates of adoption of improved maize and bread wheat varieties and associated agronomic practices such as inorganic fertilizer use among smallholder farmers. In contrast to these studies, data from the Central Statistical Suthority (CSA) indicated that, adoption of improved crop varieties by smallholder farmers at a national level are rather low casting doubt on the usefulness of the micro studies for national policy making. The attention provided to crops other than wheat and maize such as barley and food legumes, was scanty.

The first technology adoption studies in Ethiopia were conducted in the 1980's to ascertain the successes of the Minimum Package Program in the Arsi Integrated Rural Development Project (Tecle, 1975; Aklilu Bisrat, 1977 and Waktola, 1980). Agricultural technology adoption studies, however, become more common in the 1990's following the widespread introduction of improved crop varieties and commercial fertilizer among smallholder farmers (Kebede, 1990; Hailu et al. 1998). Most of these studies focused on assessing the use of improved maize and wheat varieties and inorganic fertilizers which were believed to have been widely demonstrated to smallholder farmers. Most of the early adoption studies, however, reported rather low adoption rates of improved varieties and chemical fertilizers casting serious doubt on whether the country has benefited from agricultural research and extension investments (Kebede, 1990). The studies identified timely unavailability of inputs such as inorganic fertilizers and herbicides as well as low grain prices as the major problems for the observed low adoption rates.

Following regime change in 1991 and the subsequent market liberalization policies which were mainly implemented in the later years of the 90s and in the early years of the new millennium (MEDaC, 1999), a number of technology adoption studies were conducted in Ethiopia (Yirga et a., 1996; Bekele et al., 2000; Alene et al., 2000; Dadi, et al., 2001; Dadi, et al., 2001; Tesfaye et al., 2001a; Tesfaye et al., 2001b; Tesfaye and Alemu, 2001; Alemu et al., 2004). Like their predecessors, these studies focused on rather few commodities (mainly maize and wheat) and the use of complementary purchased inputs (inorganic fertilizer and herbicides) by smallholder farmers. Unlike the previous studies, the later studies reported relatively higher adoption rate of wheat and maize improved varieties by smallholder farmers. For instance, Yirga et al., (1996) reported that about 50% of the sample farmers in the central highlands adopted new improved varieties of wheat while very few used improved varieties of teff (9%), faba bean (13%) and barley (6%). Tesfay and Alemu (2001) indicated that improved maize variety use among smallholder farmers increased from less than 19% in 1976 to 43% in 1998 in selected areas of Northwestern Ethiopia. Similarly, Berhanu et al., (2007) reported the proportion of improved maize varieties increased from 63% in 1999 to 69% in 2001. Tesfay et al., (2001b) also reported improved wheat variety use among smallholder farmers increased from less than 1% in 1981 to 72% in 1998 in selected areas of Northwestern Ethiopia. Contrary to these studies, farming systems diagnostic studies conducted outside the project areas indicated that while adoption of improved crop technologies such as wheat and maize are widespread around research centers and pilot project areas, most of the smallholder farmers in non-project areas including those which are a short distance away from research centers rely on traditional production technologies. Consequently, crop yield levels at national level remained low and food insecurity both at household and national level continued to be a development challenge. The government and partner development organizations have come to a realization that farmers' dependence on age-old traditional technology and its accompanying effect of low productivity is not simply a technical issue, rather complex a phenomenon that involves socio-economic and behavioral factors which necessitated a change in approach. Consequently, the need for a systems approach became apparent since the early 90s in order to deal with the complex nature of low and declining agricultural productivity that gave way for biophysical and social scientists to join hands to make agricultural research more relevant to the situation of smallholder subsistence farmers (Mekuria, et al., 1992). The role of smallholder farmers in the technology generation and transfer process was formally recognized and took a new precedence known as participatory technology development and transfer; and the need to develop a better understanding of the conditions which encourage/discourage adoption of recommended agricultural technologies became a priority.

Following a change in approach and focus, interest in adoption studies of sustainable intensification technologies such as crop varieties, integrated soil fertility management, soil conservation, and minimum tillage grew. Among the noteworthy empirical studies that investigated the factors conditioning smallholder farmers' decision to invest in soil conservation in Ethiopia, Shiferaw and Holden (1998), Gebremedhin and Swinton (2003), Bekele and Drake (2003), Yirga and Hassan (2008) highlighted the magnitude and direction of influence of factors hypothesized to condition adoption as largely area specific and their importance varied among regions, agro-ecologies and specific sites within agro-ecologies. Attempts to generalize the relative importance of individual constraints across farm groups, regions and even countries are thus unlikely to be useful.

2.2.1 Gap in the literature on Ethiopia

Most of the adoption studies in Ethiopia geared towards estimating the adoption of improved wheat and maize technologies and complementary inputs such as fertilizer and herbicides among smallholder farmers. To a lesser extent, effort was exerted to assess adoption of soil conservation technologies. Available studies have not only provided levels of adoption but also illuminated many of the factors responsible for the observed low rate of adoption. Most of the econometric models developed and used to investigate the adoption decision behavior of smallholder maize growers have low levels of explanatory power, although, long lists of explanatory variables are used. The common variables considered in adoption models as factors influencing adoption decisions were extension, education, age, family size/labor, credit and income. Despite the fact that smallholder farmers in Ethiopia engage in multiple enterprises (different livestock, different crops and off-farm activities), much of the studies have modeled the adoption of single commodities disregarding the effect of land allocation decisions on technology choice. Smallholder farmers in Ethiopia not only manage multiple plots having different levels of soil fertility and other characteristics, but also cultivate several crops and varieties. The decision to adopt a certain crop type and variety depends on the decision of the other crops and varieties. Depending on the context, these decisions may be sequential or simultaneous. Despite the fact that the adoption decision involves choices among several technological options (simultaneity of choices) and interdependent decisions (e.g. the decision to use improved crop and inorganic fertilizer), with very few exceptions, pervious technology adoption studies in Ethiopia have not considered the issues of simultaneity and sequences.

3. Data

A project called Diffusion and Impacts of Improved Varieties in Africa (DIIVA) funded by the Bill & Melinda Gates foundation aimed, among other things, at gaining deeper understanding on the adoption and diffusion of new varieties of barley, faba beans and potato in Ethiopia. Taking advantage of the geographical overlap of all of these food crops within the targeted regions of Ethiopia (for instance potato and barley overlap in 65% of the growing areas), it was decided to conduct a joint national survey for all three crops to generate reliable estimates of the adoption of the improved varieties at the level of different administrative units, namely: Kebele or peasant association (PA), wereda (district), zone, regional and national.

Given that Ethiopia is a big country and that only three regional states, namely Amhara, Oromiya and the Southern Nation Nationalities and Peoples (SNNP) constitute more than 94%, 96% and 97% of the total national barley, faba-beans and potato areas respectively, conducting a national survey was not justifiable both on cost and technical grounds. Hence, a decision has been made by the research team composed to focus only on the three region states. Our sample frame targeted a total of 3,509,007 barley growers, 1,869,236 potato growers, and 2,665,036 faba beans growers. It also corresponded to the production of 965,677 ha of barley, 164,146 ha of potatoes and 374,997 ha of faba beans (CSA 2002).

Multi-stage sampling procedure was used to select sample zones, districts and Kebeles or the peasant associations (PAs) from among the three target regions. The PAs are the primary sampling units (PSUs) or clusters and then the simple random sampling technique was used to subsequently select households which are the units of observation within each PSU.

Using power analysis, the minimum sample size required for observing up to 30% adoption levels of each of the crops of interest at confidence and precision levels of 95% and 3% respectively have been determined to be 1100. However, as three crops are involved, the sample size has been increased to 1469. For proportional distribution of the sample size across the different administrative units, an index using area under the three crops and the number of barley, potato and faba beans growers at the wareda level was used for weighting. Accordingly, the sample farm households were distributed among 122 PAs, 41 weredas (districts), 24 zones and 3 regions. After the survey was conducted, 191 farmers have been found to grow neither barley nor potato in the 2009/2010 cropping season. Therefore the remaining 1278 households are used in this analysis.

The average household head in the survey is about 42 years old with only 3.5 years of education. The average household size is about 7 members with a total land holding of only 1.94ha out of which 0.62ha is dedicated to barley and 0.26ha to potatoes. The area dedicated to improved varieties of barley account for about 32% of total barley area while the share of improved varieties of potatoes in total potato area is 70% (Table 1).

(Table 1 goes about here)

4. Methodology

This paper argues that smallholder households' decision to adopt improved agricultural technologies is much more complex than the way many of the existing literature attempted to model. At household level, there could be exceptional cases where an extremely successful crop variety replaced all other local varieties of the same crop as well as all or some varieties of other crops. This can happen only if the variety is very high yielding and/or costs very low to cultivate relative to all other available crop:variety combinations and hence becomes more profitable for the market-oriented farmer. Under subsistence farming systems however, due to their desire to minimize risk from depending on the market as well as due to other factors such as social taboos of buying food from the market, smallholder farmers insist on producing (even at higher opportunity costs) enough amount of each of the crops they use for their own consumption on their own farms (Yigezu and Sanders, 2012). While farmers, especially those very close to the major urban centers, are becoming more integrated to the market more recently, production in rural Ethiopia was predominantly for subsistence when data for this study was collected in 2010. Moreover, even those well integrated to the market usually base their crop choice based on historical output and input prices with more weight given to the immediate past prices. Hence, as most of the previous adoption studies assume, we argue that farmers' planting and area allocation decisions are independent across crops. Suppose the share in the total farm size of barley and potato are denoted by *barshr* and *potshr* respectively. Suppose also that *f* represents a certain functional form. Then, the area decision on barley and potatoes can be formulated as:

barshr = *f*(*t_pota_area* and household-level farm and farmer characteristics) ……………….(1)
potshr = *f*(*t_brly_area* and household-level farm and farmer characteristics) ……………….(2)

The exogenous household-level farm and farmer characteristics included in the model are: sex, age, educ, famlysize, extvist_no (see description of variables in Table 1).

Prevbarshr, model_farmer, corrugated = does the family have at least one house with corrugated sheet metal roofing (a proxy for wealth)? 0=no, 1=yes
Amhara =is the household in the Amhara region? 0=no, 1=yes
Oromia = is the household in the Oromiya region? 0=no, 1=yes
SNNPR = is the household in the SNNP region? 0=no, 1=yes. This variable is dropped to avoid perfect collinearity and hence serves as the reference variable for comparison
farmsize = total area of land operated by the household in Kert (1 Kert = 0.25 ha)
medfertshr = farmer's perception on the proportion of farm area with medium fertility level
goodfertshr = farmer's perception on the proportion of farm area with medium fertility level
fertuser = is the farmer a fertilizer user? 0=no, 1=yes

Among the major variables which take either the blame or the credit for the levels of adoption of improved agricultural technologies are access to information and extension delivery system and frequency of contacts with extension agents. Despite a sizeable national and international investment on barley research the low adoption levels of improved varieties of barley call for further inquiry in terms of what could possibly be the reason To this effect, the number of extension visits in the previous year (extvist_no) which determines the farmer's decisions and management in the previous year is included as an explanatory variable. Assuming homogeneity in the quality of extension service per visit, we hypothesize that more extension visits will have significant effects on crop and variety choices.

Once they decided on what crops to grow and on how much of their land, then comes the decision to allocate area for each crop:variety combinations. At this point the area allocation decision is made jointly for each crop and variety combinations as this decision has to be well informed from the farmer's previous experience with the crop:variety combinations and their relative performance under different biophysical farmland characteristics. The farmer therefore allocates area for all crop:variety combinations simultaneously, keeping in mind the specific characteristics of each of his plots which he then aggregates at farm-level. His area allocation is also influenced by other characteristics of his household. Suppose C_i represents crop type i, X_j represents variety type j, C_iX_j represents variety j of crop i and f represents a linear function. Then the decision on area allocation for each crop:variety combination can be formulated as:

Area (C_iX_j) = f (Area (C_kX_l) and household-level farm and farmer characteristics) ………….. (3)

Area (C_kX_l) = f (Area (C_iX_j) and household-level farm and farmer characteristics) ………..… (4)

In this study, the dependent variables Area (C_iX_j) and Area (C_kX_l) in the above equations are:
T_impbrly_area = area allocated for improved varieties of barley (equation 3) and
T_imppota_area = area allocated for improved varieties of potato (equation 4), respectively.

The same exogenous household-level farm and farmer characteristics defined for equations (1) and (2) are also used to explain the variation in the crop:variety area allocations in equations (3) and (4). In addition, *barshr* and *potshr* (the shares of barley and potato in total farm size respectively, which are determined in the first stage decision on crop choice and crop area allocation- equations 1 and 2) are also used as exogenous variables in equations 3 and 4 respectively.

Smallholder farmers as rational economic agents are assumed to be utility maximizers. Hence, the decision for using improved agricultural technologies is made when the perceived utility or net benefit from using the technology is significantly greater than would be the case without the technology. While utility is not directly observed the actions of households are observed through the choices they make. Suppose that Uj and Uk, represent a household's perceived utility for two choices j and k respectively. Suppose also that Xj and Xk are vectors of explanatory variables that influence the perceived desirability of technologies j and k. Following Green (2000) the linear random utility model could be specified as

$$U_j = \beta_j^{'}\mathbf{X_j} + \varepsilon_j \text{ and } U_k = \beta_K^{'}\mathbf{X_k} + \varepsilon_K \quad (5)$$

where βj and βk are parameters to be estimated and εj and εk are the error terms, assumed to be independently and identically distributed. It follows that the perceived utility or benefit for the i[th] household from option j is greater than the utility from other options (say k) depicted as:

$$U_{ij}(\beta_j^{'}X_i + \varepsilon_j) > U_{ik}(\beta_k^{'}X_i + \varepsilon_k), k \neq j \quad (6)$$

Supposing that Y is the decision to adopt technology j where Y takes the value of 1 if adopted and 0 otherwise, the probability that a household will adopt improved variety of the j[th] crop conditional on X could then be defined as:

$$P(Y=1|X) = P(U_{ij} > U_{ik}) \quad (7)$$

$$= P(\beta_j^{'}X_j + \varepsilon_j - \beta_k^{'}X_i - \varepsilon_k > 0 | X)$$

$$= P(\beta_j^{'}X_i - \beta_k^{'}X_i + \varepsilon_j - \varepsilon_k > 0 | X)$$

$$= P(\beta * X_i + \varepsilon^* > 0 | X = F(\beta^* X_i)$$

where P is a probability function, U_{ij}, U_{ik} and X_{ij} are as defined above, $\varepsilon^* = \varepsilon_j - \varepsilon_k$ is a random disturbance term, $\beta^* = (\beta_j^{'} - \beta_k^{'})$ is a vector of unknown parameters which can be interpreted as the net influence of the vector of independent variables influencing adoption, and $F(\beta^* X_i)$ is the cumulative distribution function of ε^* evaluated at $\beta^* X_i$. The exact distribution of F depends on the distribution of the random disturbance term ε^*.

Assuming that the farm households are risk neutral, profit maximization could be safely assumed as the objective function for commercial farms. However, multiple and often competing objectives characterize the adoption decision of smallholder subsistent farmers' as in the highlands of Ethiopia. As a results a number of farm and farmer characteristics need to be included as explanatory variables in the model. The dependent variables in equations 1-4 above are censored from below at zero. Therefore, given the interdependence of the area allocation decisions for all the crop:variety combinations, the multivariate Tobit model for extended dimensions (Kamakura and Wedel, 2001) is adopted here for simultaneously estimating the above two equations.

After area allocation for each crop:variety combinations are made, then the farmer has to make a decision on which crop:variety combinations to plant on each plot. Sequentially, this decision is the last one in terms of area allocations. Hence, it is well informed by the previous decisions on crop choices, crop area allocation, and area allocation for all the crop:variety combinations. The second level decision (i.e., the decision on area allocation for each of the crop:variety combinations) embeds all the information from the previous decisions on crop choice and crop area allocations. Hence, the farmer will make the decision on what crop:variety combinations to plant on a given plot keeping in mind the total area he allocated for the different crop:variety combinations. For instance, when the farmer decides whether to plant improved variety of barley (IMBV) on plot A, he needs to think if it is bigger than the total area he decided to allocate for IMBV. Even if he is convinced that plot A is suitable for growing the IMBV, he might decide to plant it with the improved potato variety (IMPV) if: 1) the remaining plots do not provide adequate and suitable land to match with the total area allocation he made for IMPV; and 2) the remaining plots provide enough area suitable for the cultivation of IMBV. Given that the data is based on observed plot sizes which are now fixed, the relevant issues that need to be analyzed at this stage become whether or not a farmer will plant a given crop:variety combination on a given plot rather than on what size of the plot (i.e., plot size is indivisible at this stage). Moreover, analysis of the factors that affect the decision whether or not to plant a given plot with a given crop:variety combination is pertinent.

Suppose that C_i, X_j and *f* are as defined above. Suppose also that the planting decision on a given plot A is denoted by D_A (0 =No and 1 = yes). Then, the decision on whether to plant variety *j* of crop *i* could be formulated as:

$D_A(C_iX_j)$ = f($D_A(C_kX_l)$ and the bio-physical plot characteristics) …………………. (5)
$D_A(C_kX_l)$ = f($D_A(C_iX_j)$ and the bio-physical plot characteristics) …………………..(6)

In this study, $D_A(C_iX_j)$ and $D_A(C_kX_l)$ are the decisions to whether plant improved varieties of barley and improved varieties of potatoes respectively.

The bio-physical characteristics of the plots included as explanatory variable in this study are: *Usefert, plotsize, plotdist, plotsize, plotdist, swc, legum_rot, averagefert, deep, medium_slp, steep_slp* flat*_slp*. *(See table 1 for description and statistics).* In addition to these exogenous variables, the area share of improved barley varieties (*imbarshr*) and (*impotshr*) determined in the second stage decisions are included as explanatory variables in equations 5 and 6.

In the survey data collected, the farmer has already made the decision to plant a given crop variety on each of his plots (revealed preference). Therefore, the data would show us that at a plot level, the crop:variety combinations are mutually exclusive. Hence, regressing the area under improved variety of barley (IMBV) on the area under improved variety of potato (IMPV) and other variables to analyze the plot level adoption of the two different technologies would obviously lead to a highly insignificant coefficient on the IMPV variable with P-value of 1, which is not helpful. To go around this problem for studying the degree to which the two crop varieties are competing for a given plot of land, one can formulate the question as follows: what is the probability that a plot that has been ruled out as unsuitable for IMBV would be suitable for IMPV? And what is the probability that a plot that has been ruled out as unsuitable for IMPV would be suitable for IMBV? These two probabilities would show if the two technologies are competing for the same resources (land) or not. Therefore, *Notimppotvar* (the plot is not planted to IMPV) and *Notimpbarvar* (the plot is not planted to IMBV) are included in equations 5 and 6 respectively.

As D_A is a binary (0 or 1) variable and the interdependence of the decisions on whether or not to plant plot A with either of the varieties, the multivariate probit model (Ashford and Sowden, 1970) is used to estimate equations (3) and (4) simultaneously.

5. Results and discussion

5.1 Farm-level analysis

5.1.1 Crop choice and crop area allocation decision

The insignificant coefficient estimates for *t_pota_area* and *t_brly_area* variables (in the 3rnd and 4^{th} equations) in the multivariate tobit model show that the area allocated for one crop (e.g., potato) does not affect the area allocated for the other (e.g., barley) - supporting our hypothesis. In the face of good explanatory power of the model with significant Wald Chi squared statistic, the insignificant chi squared value for the log-likelihood ratio test shows that the two decisions are not simultaneous - also supporting our hypothesis. This is because crop choice and area allocation among crops is dictated mainly by other factors such as family consumption needs, crop rotation requirements and perhaps price expectations. The regression estimates provide evidence where the share of the crops in the previous year (a proxy for rotation demand), family size (a proxy for both consumption demand and also labor supply), whether the farmer is rich (proxied by possession of corrugated metal sheet roofed houses) and whether the farmer is fertilizer user (which can capture the responsiveness of each crop to fertilizer) are found to significantly influence the simultaneous crop choice and crop area allocation decisions (Table 2). If the farmer allocated larger share of his farm for potato in the previous year, our results show that he would allocate larger share of land for barley this year showing that crop rotation considerations are very important in determining crop choice and area allocation decisions in a given year.

Farm size is insignificant in equation 1 showing that it is not important in explaining the area share allocated for barley while it is negative and significant in equation 2 showing that farmers with larger farms are less likely to plant potatoes. The result for barley does not come by surprise as each farm household, regardless of its farm size, would try to produce certain minimum amount of barley for own consumption. However, the result for potatoes seems to confirm the usual rhetoric that potatoes are the poor man's food as larger farms are usually indicators of wealth.

(Table 2 goes here)

Male household heads are found to allocate lesser area share for barley than female household heads while the opposite is true for potatoes where male household allocate more. These results are reasonable as potatoes are more labor intensive and women in the Ethiopian highlands who are heads of their households cannot afford to spare so much time cultivating potatoes on top of their busy days taking care of a lot of household chores and other family and social demands. Age and education level of household head and number of extension visits and whether or not the household head is a model farmer do not significantly affect crop choice and area allocation decisions. These results are acceptable as there is no compelling reason to believe otherwise. Particularly, as the main focus of the Ethiopian extension program is one of increasing the use of fertilizers and improved varieties of different crops, it is not expected to have a bearing on the crop choice.

Larger families allocate larger area share for barley and smaller share for potatoes. This has more likely to do with the higher family consumption demand for barley as it is the main staple in the highlands of Ethiopia. Potatoes however are relatively new in the country and hence are not among the staples for which, most of the production is often for the market. If a farmer is fertilizer user, our results show that he will allocate lesser area for barley while he will allocate more area for potatoes. This along the negative and significant coefficient on farm size variable shows that potatoes are crops for the farmer who intensifies.

In terms of geographic locations, farmer in oromia are likely to allocate bigger area shares for barley than the SNNP while the farmers in SNNP are likely to allocate bigger shares for potato than both the Amhara and Oromia regions. This is consistent with the facts on the ground as roots and tubers are generally more commonly consumed in the south than the center and north. Farmers do not seem to discriminate crops by the share of the different levels of soil fertility.

5.1.2 Area allocation decisions for crop:variety combinations

For the second stage decision, estimates of the multivariate tobit model show that at a household level, the total amount of area allocated for a given variety of one crop has a positive influence on the total area allocated for an improved variety of another crop. This is demonstrated by the positive and significant coefficients on the *t_imppota_area* and *t_impbar_area* variables in equations 3 and 4 respectively (Table 3). As argued earlier, this is more likely because farmers who have good knowledge and experience and hence enjoyed the benefits of one technology would be motivated to adopt another technology. The significant Wald Chi square statistic along with the significant log likelihood ratio test show that the variables included in the model explain a significant proportion of the variation in the dependent variables with clear simultaneity in the decisions on intensity of adoption of each of the varieties. These results fully support our hypothesis that area allocation decisions on the different crop:variety combinations are interdependent.

The positive and significant coefficient on the *barshr* and *potshr* variables indicate that a farmer's decision on the amount of area to be dedicated for a particular crop (from the first stage decision) positively influences his decision on the area size to be allocated for improved varieties of the same crop. This is consistent with the theoretical expectation, because larger area for the crop shows that the crop plays an important role in the farmers' portfolio and hence the farmer is likely to invest on new technologies. Large area allocation for a particular crop could also mean that the farmer has more room for variety diversification within the same crop to take advantage of different traits from the different varieties of the same crop. Especially in areas such as highland Ethiopia where rainfall is erratic, farmers who can afford to allocate larger area for one crop might be interested in using different varieties of the same crop to minimize the risk and maximize their expected total production.

(Table 3 goes here)

One of the most interesting results in this analysis pertains to the positive and significant coefficient estimates on the *fertuser*, *Medfertshr* and *Goodfertshr* variables in equation 3 which show that farmers who are fertilizer users and have larger shares of medium and high fertility soils are more likely to allocate more area for improved varieties of barley. On the contrary, such farmers are either indifferent or allocate less area for improved variety of potatoes. Given the high yields and revenue from potatoes, these results are counter intuitive. Two possible explanations for these results are that 1) the desire to produce adequate amount of barley for own family consumption may be overriding all economic logic that would have otherwise favored the production of potatoes. 2) due to liquidity and fertilizer supply constraints which compel farmers to ration their limited amount of fertilizer available to them, the incremental response to fertilizers from improved relative to the local barley varieties might be higher than the incremental response from improved relative to local potato varieties.

From among the characteristics of the household head, education alone is found to positively affect the adoption of improved barley varieties implying that more educated farmers are likely to allocate more barley area into the improved varieties. Sex and age of the household head are not important in influencing the intensity of adoption of improved barley varieties. On the contrary, age is found to be the only household head characteristic that significantly influences intensity of adoption of improved varieties of potatoes. This shows that older household heads tend to adopt improved varieties of potatoes. Given the labor demanding nature of potatoes the results are counter intuitive as older farmers are unlikely to meet those demands unless they have larger families.

With regard to household characteristics, while bigger families are likely to allocate more land for improved varieties of barley, they are also found to allocate smaller areas for improved varieties of potatoes. The high productivity of potatoes could provide the explanation for these results. Another result that came by surprise is that the number of extension visits does not have significant effect on the intensity of adoption of improved varieties of both barley and potatoes. This sure would raise the eye brows of both government officials and other onlookers because Ethiopia is one of the few developing countries with very high number of extension agents. Even though these results are not consistent with the theoretical expectation, they seem to be consistent with the reality. Despite the high density of extension agents, adoption rates for most crops still remain low. Therefore, the reality on the ground and the regression results could be indicative of the ineffectiveness and hence poor impact of the extension system. Model farmers are found to be likely to allocate more land for improved varieties of barley while they are not any different from the ordinary farmer in terms of the size of area they allocate for improved varieties of potatoes.

In terms of regions, the farmers in the Oromiya region are found to allocate more land for improved varieties of barley relative to those in the SNNP while those in Amhara region are not any different. The farmers in Oromiya region are found to not be any different from those in the SNNP in terms of their area allocation to improved varieties of potatoes while those in Amhara are found to allocate less.

As is the case with the crop choice and crop area allocation, the ownership of more fertile lands and fertilizer use positively influence the area that is allocated for improved varieties of barley. However, such farmers are found to allocate less land to improved varieties of potatoes.

5.2 Plot-level adoption decisions

With significant Wald Chi square statistic and insignificant Chi square statistic for the log likelihood ratio test, the results of the multivariate probit model for planting decisions at plot level (Table 4) show that the decisions whether or not to plant an improved variety of one crop is independent of the planting decision (on the same plot) for an improved variety of another crop. The insignificant coefficient on the *Notimppotvar* variable also shows that a farmer's decision to not plant a given plot with the improved potato varieties does not increase or decrease his likelihood to plant it with an improved variety of barley. Both of these results support our hypothesis that at plot level, adoption decisions for improved varieties of different crops are independent and also not simultaneous.

(Table 4 goes here)

The shares of improved varieties of barley and potatoes in total farm size (results from the second level decision in equations 3 and 4) are found to significantly influence planting decisions at the plot level. Moreover, plot characteristics such as crop type planted in the previous year (rotation requirements), the use of fertilizer on the plot (indicator of the crop's response to fertilizers), and plot size and soil color are found to be important determinants of the plot level planting decisions.

While the respective shares of the improved varieties of each of the crops directly affect the farmer's likelihood to plant the plot with the improved variety of that particular crop, he is less likely to plant barley this year if the plot was under barley the previous year showing that farmers do not practice mono-cropping of barley. However, whether or not the plot was planted with potatoes the previous year does not affect the farmer's decision whether to plant it with the same crop this year showing that they monoculture of potatoes without rotation is acceptable among farmers in the Ethiopian highlands.

Size of the plot positively and significantly affects the likelihood of planting an improved variety of barley while its effect on the decision to plant potato is negative and significant showing that potatoes are planted on small fields while barley is planted on larger fields. Along with the negative and significant coefficient on plot distance in equation 6, this result shows that potatoes are preferably planted in back yards because they require frequent visits and more labor for such activities as hoeing and protection from wild animals.

The biophysical characteristics of the plot do not have any bearing on the decision whether or not to plant improved barley varieties. However, the improved potatoes are planted on marginal lands with medium and steep slopes on which no soil and water conservation structures are built. This shows that the improved potato varieties can perform well under minimum conditions.

An interesting but less clear result from this model is that fertilizer use is found to positively affect the household level decisions on total area to be allocated for barley as well as the total area to be allocated for improved varieties of barley. The decision to use fertilizer on a given plot is also found to positively affect the decision to plant the plot with improved variety of barley. However, for potatoes, while it positively affects the household decision on total area to be allocated for potatoes and the plot level decision to plant improved varieties of potatoes, fertilizer use is found to be unimportant in the household level decision on the total area to be allocated for improved varieties of potatoes. Explaining this seemingly weird result needs further exploration which might shed light on the complex issue of technology adoption.

6. Conclusions

Given the role of personal choices, preferences and farmers' behavior towards risk, analyzing farmers' agricultural technology adoption decisions are very complex. It becomes even more so when the farming system involves many smallholder subsistence farmers for whom agricultural production is a matter of life or death. Unlike commercial farms where profit maximization could be safely assumed as the objective function, multiple and often competing objectives characterize the adoption decision of smallholder subsistent farmers' as in the highlands of Ethiopia.

With few exceptions, the literature on technology adoption predominantly focuses on the analysis of the adoption behavior of farmers towards single technology. Moreover, adoption decisions are treated as either sequential or simultaneous. This paper argues and provides evidence that adoption decisions on multiple technologies involve a series of three sequential sub-decisions each of which could be independent or simultaneous. Accordingly, we hypothesized here that adoption of improved varieties of barley and potato involves decision making at three levels. The first decision is one of what crops to plant and how much area out of the total farm size to allocate for each. This decision, we argue, is independent across crops because exogenous factors such as household consumption demand for each crop and crop rotation requirements override crop choice and area allocation decisions. Then in a second stage decision, given the total area share of each of the crops, farmers make decision on area allocation for the different crop:variety combinations, each of which is interdependent as this prior knowledge and experience with one crop variety is likely to influence the decision to adopt an improved variety of another crop. In the third and final stage, farmers have to decide which crop:variety combination to plant on which plot conditional on the total area allocated for each variety of each variety.

Model results support our hypothesis that at the household level, the decision on the area share of barley is independent of the decision on the area share of potatoes and vice versa with insignificant Chi square statistic for the log likelihood ratio test for simultaneity of the two adoption equations (one for each crop). The coefficients on the share of potatoes and barley in total farm size in the barley and potatoes area share equations respectively are also found to be insignificant reinforcing the argument.

Data from highland Ethiopia used in this analysis also provide evidence that the adoption decision on improved varieties of barley (IMBV) at household level is affected by the adoption decisions on the improved varieties of potatoes (IMPV). The area shares of the crops from the first stage decision on crop choice are also found to be significant determinants of the area allocated for the improved varieties of each crop.

At plot level, however, the data support the hypothesis that the decision on planting IMBV is not affected by the decision on planting IMPV. Instead, the second stage decision on the amount of area allocated for improved varieties of the respective crops and plot level biophysical characteristics such as crop type planted in the previous year and whether or not fertilizer is used in the current period are found to be important in determining the plot level adoption decision.

Among the traditional explanatory variables in adoption studies, family size is found to be an important factor in varietal adoption where it positively affects the area to be allocated for IMBV while negatively affecting the area allocated for IMPV. The fact that potato is relatively new in Ethiopia and hence fails to compete as a staple food to meet the consumption requirements of big families may explain the negative effect on the area allocated on IMPV. Sex, though important in crop choice, is not important in explaining varietal adoption. Education is very important in barley variety adoption with weak influence on potato variety adoption. A striking result from our analysis is that extension service (proxied by the number of extension visits to the farmer) is found to be insignificant in both crop choice and variety adoption decisions. This result is indeed supported by the reality on the ground. Despite the fact that Ethiopia is among the few developing countries with high density of extension agents, the adoption levels for most of the improved crop varieties is low. This fact along with model results suggests that despite the huge investments, the extension system in the country is not effective. These results have important policy implications where the extension system in the country needs to be thoroughly reviewed and necessary corrective measures taken to increase its efficacy and hence enhance the development of the agriculture sector.

References

Adugna, T., and Demeke, M. 2000. Institutional reforms and sustainable input supply and distribution in Ethiopia. p.125 - 156. In: Workneh Negatu, Legesse Dadi, Abebe Haile Gabriel and Solomon Bellete (eds.), *Institutions for Rural Development*, Proceedings of the 4th Annual Conference of Agricultural Economics Society of Ethiopia, 23-24 November 1999, Addis Ababa.

Aklilu Bisrat. 1977. Technological change in subsistence agriculture: the adoption and diffusion of fertilizer in Ethiopia's Minimum Package Area. Ph.D. Dissertation Cornell University.

Aldrich, John H. and F.D. Nelson. 1985. Linear probability, logit, and probit models. Sage University Paper Series on Qualitative Applications in the Social Sciences, Series No. 07-045. Beverely Hills, London Sage Pubns.

Alene, A.D., Poonyth, D., and Hassan, R.M. (2000). Determinants of the adoption and intensity of use of improved maize varieties in central highlands of Ethiopia. A Tobit analysis. *Agrekon,* 39(4): 633 - 643.

Ashford, J., and R. Sowden (1970): Multivariate probit analysis. *Biometrics*, 26(3): 535–546.

Bamire, A.S., Fabiyi, Y.L., and Manyong, V.M. (2002). Adoption pattern of fertilizer technology among farmers in the ecological zones of southwestern Nigeria: a Tobit analysis. *Australian Journal of Agricultural Research,* 53: 901-910.

Bekele Hundie Kotu, H. Verkuijl, W. Mwangi, and D. Tanner. (2000). Adoption of Improved Wheat Technologies in Adaba and Dodola Woredas of the Bale Highlands, Ethiopia. Mexico, D.F.: Institute of Agricultural Research and CIMMYT.

Bekele, W., and Drake, L. (2003). Soil and water conservation decision behaviour of subsistence farmers in the Eastern Highlands of Ethiopia: a case study of the Hunde-Lafto area. *Ecological economics,* 46: 437 - 451.

Berhanu, G., Hoekstra, D. and Azage, T. (2006), *Commercialization of Ethiopian Agriculture: Extension Service from Input Supplier to Knowledge Broker and Facilitator*, Improving

Productivity and Market Success of Ethiopian Farmers Project Working Paper, International Livestock Research Institute, Nairobi. Kenya.

Byerlee, D., and Hesse de Polanco, E. (1986). Farmers' stepwise adoption of technological packages: evidence from the Mexican Altiplano. *American Journal of Agricultural Economics*, August (1986): 519 - 527.

Croppenstedt, A., Demeke, M., and Meschi, M.M. 2003. Technology adoption in the presence of constraints: the case of fertilizer demand in Ethiopia. *Review of Development Economics*, 7(1): 58 - 70.

CSA (Central Statistical Agency). 2010. Agricultural Sample Survey 2010-2011. Volume I, Area and Production of Crops, Central Statistical Agency, Ethiopia.

CSA. (2011) Report on Area and Production of Major Cereals (Private Peasant Holdings, Meher Season). Agricultural Sample Survey 2110/11 (2003 E.C), Volume 1, Central Statistical Agency, Addis Ababa, Ethiopia.

Dadi, L., Burton, M., and Ozanne, A. (2001). Adoption and intensity of fertilizer and herbicide use in the Central Highlands of Ethiopia. *Agrekon*, 40(3): 316 - 333.

Demeke, M., Ali, S., and Thomas, S.J. 1997. Promoting fertilizer use in Ethiopia: the implications of improving grain market performance, input market efficiency, and farm management. *Working Paper 5*, Ministry of Economic Development and Cooperation: Grain Market Research Project, Addis Ababa, Ethiopia.

Dimara, E., and Skuras, D. (2003). Adoption of agricultural innovations as a two-stage partial observability process. *Agricultural Economics*, 28: 187 - 196.

Dorfman, J.H. (1996). Modeling multiple adoption decisions in a joint framework. *American Journal of Agricultural Economics*, 78: 547 - 557.

Ervin, C.A., and Ervin, D.E. (1982). Factors affecting the use of soil conservation practices: Hypotheses, evidence, and policy implications. *Land Economics*, 58(3): 277 - 292.

Feder, G., Richard, E.J, and David, Z. (1985). Adoption of agricultural innovations in developing countries: a survey. *Economic development and cultural change*, 33: 255-298.

FAOStat (2013). http://faostat.fao.org/site/567/default.aspx#ancor

Fufa, B., and Hassan, R.M. (2003). Stochastic maize production technology and production risk analysis in Dadar district, East Ethiopia. *Agrekon*, 42(2): 116-128.

Gebremedhin, B., and Swinton, S.M. (2003). Investment in soil conservation in northern Ethiopia: the role of land tenure security and public programs, *Agricultural Economics*, 29: 69-84.

Ghadim, A. K. A., and Pannell, D.J. (1999). A conceptual framework of adoption of an agricultural innovation. *Agricultural Economics*, 21:145-154.

Green, W. H. (2000). *Econometric Analysis*, 4th Ed., New Jersey: Prentice-Hall, 2000.

Grepperued, S. (1997). Poverty, land degradation and climatic uncertainty. *Oxford*

Hailu Beyene, H.Verkuijl, and W. Mwangi. (1998). Farmers' Seed Sources and Management of Bread Wheat in Wolmera Woreda, Ethiopia. Mexico, D.F.: Institute of Agricultural Research and CIMMYT.

Hassan, R.M., Kiarie, N., Mugo, N., Robin, O. and Laboso, A. (1998a). Adoption and performance of maize in Kenya. In: Hassan, R.M. (ed.) *Maize Technology Development and Transfer: A GIS Approach to Research Planning in Kenya*. CAB international, London.

Hassan, R.M., Onyango, R., and Rutto, J.K. (1998b). Determinants of fertilizer use and the gap between farmers' maize yield and potential yields in Kenya. In: Hassan, R.M. (ed.) *Maize Technology Development and Transfer: A GIS Approach to Research Planning in Kenya*. CAB international, London.

Jha, D., B. Hojjati., and S. Vosti. (1990). The Use of improved agricultural technology in Eastern Province. In: Adopting Improved Farm Technology: A study of Smallholder Farmers in Eastern Province, Zambia. R. Celis, J.T. Milimo, and S. Wanmali (eds.). Washington, D.C.: University of Zambia, Government of the Republic of Zambia, and IFRPI.

Kamakura, Wagner A. and Michel Wedel (2001) "Exploratory Tobit Factor Analysis for Multivariate Censored Data," *Multivariate Behavioral Research* 36(1) 53-82.

Katchova, A. L., and Miranda, M.J. 2004. Two-step econometric estimation of farm characteristics affecting marketing contract decisions. *American Journal of Agricultural Economics*, 86 (1): 88-102.

Kazianga, H., and Masters, W.A. (2002). Investing in soils: field bunds and micro-catchments in Burkina Faso. *Environment and Development Economics*, 7: 571-591.

Kebede, Y, Gunjal, K., and Coffin, G. (1990). Adoption of new technologies in Ethiopian agriculture: the case of Tegulet-Bulga District, Shewa Province. *Agricultural Economics*, 4: 27-43.

Lapar, M. L. A., and Pandey, S. (1999). Adoption of soil conservation: the case of Philippine uplands. *Agricultural Economics*, 21(3): 241-256.

Leathers, H.D., and Smale, M. (1991.) A Bayesian approach to explaining sequential adoption of components of a technological package. *American Journal of Agricultural Economics*, 73:734-742.

Lin, T., and Schmidt, P. 1984. A test of the Tobit specification against an alternative suggested by Cragg. *The Review of Economics and Statistics*, 66(1): 174-177.

Long, J. S. 1997. *Regression models for categorical and limited dependent variables: advanced quantitative techniques in the social science*, Series 7, SAGE Publications: Thousand Oaks, California.

Makken, F. 1993. Nutrient supply and distribution of country level: case studies of Malawi and Ethiopia. p.165-233. In: Reuler H. van, and Prins, W.H. (eds.). *The role of plant nutrients for sustainable food production in Sub-Saharan Africa*, Dutch Association of Fertilizer Producers, Ponsen & Looijen, Wageningen, The Netherlands.

Mekuria, M., Steven, F., and Beyene, H. (1992). Farming systems research in Ethiopia: evolution, development and organization. p.28-39. In: Franzel, S., and Houten., van H. (eds.), *Research with Farmers: Lessons from Ethiopia*, C.A.B. International, Wallingford, UK.

Million, T. and Belay, K. 2004. Determinants of fertiliser use in Gununo area, Ethiopia. pp. 21-

31. In: Tesfaye Zegeye, Legesse Dadi and Dawit Alemu (Eds.). Proceedings of agricultural technology evaluation adoption and marketing. Workshop held to discuss results of 1998-2002, August 6-8, 2002.

MOFED (Ministry of Finance and Economic Development). 2010. Growth and Transformation Plan, 2010/11-2014/15. Volume I, Main Test. Addis Ababa, Ethiopia.

Nakhumwa T.O and R.M Hassan. 2012. Optimal Management of Soil Quality Stocks and Long-Term Consequences of Land Degradation for Smallholder Farmers in Malawi. Environmental Economics, 52 (3), pp 415-433

Nakhumwa, T.O., and Hassan, R.M. (2003). The adoption of soil conservation technologies by smallholder farmers in Malawi: A selective Tobit analysis. *Agrekon*, 42(3): 271-284.

Norris, E. P., and Batie, S.S. (1987). Virginia farmers' soil conservation decisions: an application of Tobit analysis. *Southern Journal of Agricultural Economics*, 19(1): 89-97.

Pagiola, S. (1996). Price policy and returns to soil conservation in semi-arid Kenya. *Environment and Resource Economics*, 8: 255-271.

Pender, J., Gebremehin, B., and Ehui, S. 2001. Strategies for sustainable agricultural development in the Ethiopian highlands. *American Journal of Agricultural Economics*, 83:1231-1240.

Regassa, S. (2001). The economics of managing land resources towards sustainability in the highlands of Ethiopia. PhD Thesis.

Shiferaw, B., and Holden, S. 1998. Resource degradation and adoption of land conservation technologies in the Ethiopian highlands: a case study in Andit Tid, North Shewa. *Agricultural Economics*, 18:233-247.

Shively, G.E. (2001). Poverty, consumption risk and soil conservation. *Journal of Development Economics*, 65: 267 – 290.

Rogers, E.M., with F.F. Shoemaker. 1971. *Communication of Innovations: A Cross-Cultural Approach*. New York: Free Press.

Sinebo, W., and C., Yirga. 2002. Participatory Cient-Orientation of Research in Low-Input Cropping Systems of Ethiopia: A viewpoint. In Gemechu Keneni, Yohannes Gojjam, Kiflu

Bedane, Chilot Yirga and Asgelil Dibabe (Eds.). 2002. Towards Farmers' Participatory Research: Attempts and achievements in the Central Highlands of Ethiopia. Proceedings of Client-Oriented Research Evaluation Workshop, 16-18 October, Holetta Agricultural Research Center, Holetta, Ethiopia.

Smale, M., with Z.H.W. Kaunda, H.L. Makina, M.M.M. K. Mkandawire, M.N.S. Msowoya, D.J.E.K. Mwale, and P.W. Heisey. 1991. Chimanga Cha Makolo, Hybrids and Composites: An Analysis of Farmers' Adoption of Maize Technolgoies in Malawi, 1989-91. CIMMYT Economics Working Paper 91/04. Mexico, D.F.: CIMMYT.

Stoorvogel, J.J., and Smaling, E.M.A. 1990. Assessment of soil nutrient depletion in sub-Saharan Africa, 1983-2000. *Report 28*, DLO Winand starring Center for integrated land, soil and water research (CSC-DLO), Wageningen, Netherlands.

Tesfai Tecle. 1975. Application of multivariate probit analysis to adoption of new agricultural practices. Ethiopian Journal of Development Research 2(1):43-54.

Teklewold, H., M. Kassie, B. Shiferaw, G. Kohlin (2013). Cropping system diversification, conservation tillage and modern seed adoption in Ethiopia: Impacts on household income, agrochemical use and demand for laboer. Ecological Economics. Vol 93. Pp 85-93.

Tesfaye Zegeye, Girma Taye, Douglas Tanner, Hugo Verkuijl, Aklilu Agidie and Wilfred Mwangi (2001). Adoption of improved bread wheat varieties and inorganic fertilizer by small-scale farmers in Yelmana Densa and Farta districts of Northwestern Ethiopia. Mexico, D.F.: Ethiopian Agricultural Research Organization (EARO) and International Maize and Wheat Improvement Center (CIMMYT).

Tesfaye Zegeye and Alemu Haileye (2001). Adoption of Improved Maize Technologies and Inorganic Fertilizer in Northwestern Ethiopia. Ethiopian Agricultural Research Organization. Research Report No. 41. Addis Ababa Ethiopia in: Mesfin (2005).

Vella, F. (1998). Estimating models with sample selection bias: a survey. *Journal of Human Resources*, 33(1): 127-169.

Waktola, A. (1980). Assessment of diffusion and adoption of agricultural technologies in Chilallo. *Ethiopian Journal of Agricultural Sciences*, 2(2): 51-68.

Winship, C., and Mare, R.D. 1992. Models for sample selection bias. *Annual Review of Sociology*, 18:327-350.

Yigezu, Y.A. and J. H. Sanders (2012). Introducing new agricultural technologies and marketing strategies: a means for increasing income and nutrition of farm households in Ethiopia. *African Journal of Food, Agriculture, Nutrition and Development*, 12(5): 6365-6384.

Yirga, C., and R.M. Hassan. 2008. Multinomial logit analysis of farmers' choice between short and long-term soil fertility management practices in the Central Highlands of Ethiopia. Ethiopian Journal of Agricultural Economics, 7(1): 83-102.

Yirga, C., and Hassena, M. 2001. Crop-livestock farming systems in the highlands of Ethiopia: smallholder farmers' management practices and constraints. pp: 145-165. In: Wall, P.C (ed.), *Wheat and Weeds: Food and Feed, Proceedings of Two Stakeholder Workshops*. Santa Cruz, Bolivia: CIMMYT.

Yirga, C., and R.M. Hassan. 2010. Social Costs and Incentives for Optimal Control of Soil Nutrient Depletion in the Central Highlands of Ethiopia. *Agricultural Systems*, 103 (3): 153-160.

Yirga, C., Shapiro, B.I., and Demeke, M. (1996). Factors influencing adoption of new wheat technologies in Wolemera and Addis Alem areas of Ethiopia. *Ethiopian Journal of Agricultural Economics*, 1(1): 63-84.

Table 1: Descriptive statistics on important variables

	Variable description	Unit	N	Min.	Mean	Max.	Std. Dev.
Age	Age of household head (hhh)	years	1278	12	42.47	90	13.22
educ	Education level of hhh	years	1278	0	3.43	13	3.36
famlysize	Family size	No.	1278	1	6.99	25	2.77
Tot_house_unit	Number of separate housing units owned	No.	1278	0	2.25	11	1.26
farmsize	Farm size	ha	1278	0.065	1.94	16.28	1.43
oxen	Oxen owned	No.	1278	0	1.58	20	1.45
cows	Cows owned	No.	1278	0	2.17	20	2.27
offincome	Off farm income per year	Birr	1278	0	1,522	67400	4002
t_brly_area	Total barley area	ha	1278	0.012	0.623	5.45	0.61
t_impbrly_area	Total area under improved barley varieties	ha	547	0.015	0.57	5.45	0.56
lclbrly_area	Area under local barley varieties	ha	993	0.012	0.29	2.25	0.28
t_pota_ara	Total potato area in ha.	ha	876	0.02	0.258	2	0.27
t_imppota_area	Total area under improved potato varieties	ha	280	0.01	0.20	1.25	0.20
t_lpota_area	Area under local potato varieties	ha	741	0.002	0.23	2	0.24
extvist_no	Number of extension visits in the year	No.	1278	0	19.90	200	24.6
plotdist	Plot distance measured in minutes of walk	minutes	1278	0.05	10.84	120	16.12
potshr	Share of potatoes in total crop area	%			16		
barshr	Share of barley in total crop area	%			34		
impbrly	Share in total barley area of improved barley	%			32		
imppot	Share in total potato area of improved potatoes	%			71		
Sex	Household head is male (0=No, 1=Yes)	% of Yes			92		
usedap	Farmer applies DAP fertilizers (0=No, 1=Yes)	% of Yes			58		
useurea	Farmer applies Urea fertilizers (0=No, 1=Yes)	% of Yes			22		
usefert	Farmer applies fertilizers (0=No, 1=Yes)	% of Yes			59		
vertshare	Soil on the plot is vertisol (0=No, 1=Yes)	% of Yes			28		
redsoilsh	Soil on the plot is reddish (0=No, 1=Yes)	% of Yes			35		
Othercolor	Soil on the plot is black or gray (0=No, 1=Yes)	% of Yes			37		
Goodfertshr	Soil on plot has good fertility (0=No, 1=Yes)	% of Yes			38		
Medfertshr	Soil on plot has medium fertility (0=No, 1=Yes)	% of Yes			46		
swc	Plot has soil & water conservation structures	% of Yes			29		
legumerot	Legumes are rotated on the plot (0=No, Yes)	% of Yes			21		
deep	Soil on plot is deep (0=No, Yes)	% of Yes			47		
medium_slp	Plot has medium slope (0=No, Yes)	% of Yes			52		
steep_slp	Plot has steep slope (0=No, Yes)	% of Yes			39		

Table 2: Parameter Estimates from the multivariate Tobit model for crop area allocations (Equations 1 and 2)

	Coef.	Std. Err.	z	P>|z|	[95% Conf. Interval]	
Barshr(eq)						
t_pota_ara	-0.010	0.017	-0.59	0.55	-0.042	0.023
prevbarshr	0.417	0.028	14.69	0.00	0.361	0.472
SEX	-0.067	0.024	-2.84	0.01	-0.113	-0.021
AGE	0.001	0.001	1.14	0.25	0.000	0.002
educ	0.001	0.002	0.52	0.60	-0.003	0.005
famlysize	0.007	0.002	2.74	0.01	0.002	0.012
extvist_no	0.000	0.000	1.64	0.10	0.000	0.001
model_farmer	0.021	0.013	1.55	0.12	-0.005	0.047
corrugated	-0.031	0.008	-4.01	0.00	-0.046	-0.016
AMHARA	-0.027	0.017	-1.56	0.12	-0.060	0.007
OROMIA	0.078	0.017	4.47	0.00	0.044	0.112
farmsize	0.000	0.001	0.4	0.69	-0.002	0.003
Medfertshr	0.018	0.024	0.74	0.46	-0.030	0.066
Goodfertshr	0.028	0.025	1.12	0.26	-0.021	0.076
fertuser	-0.071	0.018	-3.96	0.00	-0.107	-0.036
_cons	0.175	0.045	3.89	0.00	0.087	0.264
Potshr(eq)						
t_brly_area	-0.003	0.007	-0.50	0.62	-0.016	0.010
prevpotshr	0.586	0.025	23.58	0.00	0.538	0.635
SEX	0.029	0.016	1.78	0.08	-0.003	0.060
AGE	0.000	0.000	-1.34	0.18	-0.001	0.000
educ	0.002	0.001	1.40	0.16	-0.001	0.005
famlysize	-0.001	0.002	-0.37	0.71	-0.004	0.003
extvist_no	0.000	0.000	1.21	0.23	0.000	0.001
model_farmer	0.007	0.009	0.77	0.44	-0.011	0.024
corrugated	0.012	0.005	2.24	0.03	0.001	0.022
AMHARA	-0.044	0.011	-3.82	0.00	-0.066	-0.021
OROMIA	-0.024	0.013	-1.86	0.06	-0.049	0.001
farmsize	-0.004	0.002	-2.00	0.05	-0.007	0.000
Medfertshr	0.024	0.016	1.51	0.13	-0.007	0.056
Goodfertshr	-0.016	0.017	-0.95	0.34	-0.049	0.017
fertuser	0.040	0.013	3.17	0.00	0.015	0.065
_cons	0.000	0.031	0.02	0.99	-0.059	0.060
/lnsigma1	-1.555	0.023	-68.62	0.00	-1.600	-1.511
/lnsigma2	-2.002	0.027	-74.78	0.00	-2.054	-1.949
/atrho12	-0.142	0.114	-1.25	0.21	-0.365	0.081
sigma1	0.211	0.005	44.12	0.00	0.202	0.221
sigma2	0.135	0.004	37.36	0.00	0.128	0.142
rho12	-0.141	0.112	-1.27	0.21	-0.350	0.081
Log likelihood =	144.7338	Wald chi2(32)=		1097	Prob>chi2 =	0
Likelihood ratio test of rho12 =		0:00	chi2(1)	1.53846	Prob>chi2 =	0.2148

Table 3: Parameter estimates from the multivariate tobit model on intensity of varietal adoption (equations 3 and 4)

	Coef.	Std.Err.	z	P>|z|	[95% Conf. Interval]	
t_impbrly_area(eq 3)						
barshr	5.702654	0.450565	12.66	0	4.819563	6.585745
sex	-0.01995	0.330578	-0.06	0.952	-0.66787	0.627974
age	-0.00427	0.007187	-0.59	0.552	-0.01836	0.009817
educ	0.081905	0.029239	2.8	0.005	0.024597	0.139212
famlysize	0.178834	0.032972	5.42	0	0.114211	0.243457
extvist_no	0.004952	0.003654	1.36	0.175	-0.00221	0.012113
model_farmer	0.543468	0.186097	2.92	0.003	0.178725	0.908211
farmsize	0.098418	0.016243	6.06	0	0.066583	0.130253
corrugated	-0.33441	0.103639	-3.23	0.001	-0.53754	-0.13128
Amhara	0.042368	0.268176	0.16	0.874	-0.48325	0.567982
Oromia	1.882625	0.233815	8.05	0	1.424357	2.340894
Medfertshr	0.906554	0.355363	2.55	0.011	0.210055	1.603053
Goodfertshr	1.240456	0.360502	3.44	0.001	0.533885	1.947027
fertuser	1.497826	0.31088	4.82	0	0.888513	2.10714
t_imppota_area	1.940983	0.204666	9.48	0	1.539846	2.34212
_cons	-7.92742	0.738782	-10.73	0	-9.37541	-6.47944
t_imppota_area(eq 4)						
potshr	3.516261	0.376397	9.34	0	2.778538	4.253985
sex	-0.25117	0.176537	-1.42	0.155	-0.59718	0.094833
age	0.009014	0.003895	2.31	0.021	0.001381	0.016647
educ	0.02444	0.015798	1.55	0.122	-0.00652	0.055403
famlysize	-0.05691	0.01856	-3.07	0.002	-0.09329	-0.02054
extvist_no	0.001794	0.001879	0.96	0.34	-0.00189	0.005477
model_farmer	0.079201	0.100248	0.79	0.429	-0.11728	0.275683
farmsize	0.004602	0.010048	0.46	0.647	-0.01509	0.024297
corrugated	0.139228	0.054484	2.56	0.011	0.032441	0.246015
Amhara	-0.48041	0.138802	-3.46	0.001	-0.75246	-0.20837
Oromia	-0.10959	0.127452	-0.86	0.39	-0.35939	0.140212
Medfertshr	-0.11574	0.183742	-0.63	0.529	-0.47587	0.244385
Goodfertshr	-0.3394	0.190405	-1.78	0.075	-0.71258	0.033789
fertuser	0.115092	0.160331	0.72	0.473	-0.19915	0.429335
t_impbrly_area	0.343225	0.038719	8.86	0	0.267338	0.419112
_cons	-1.45973	0.373471	-3.91	0	-2.19172	-0.72774
/lnsigma1	0.900174	0.035155	25.61	0	0.83127	0.969077
/lnsigma2	0.200454	0.048187	4.16	0	0.10601	0.294899
/atrho12	-0.72521	0.085615	-8.47	0	-0.89301	-0.55741
sigma1	2.46003	0.086483	28.45	0	2.296234	2.635511
sigma2	1.221958	0.058882	20.75	0	1.111833	1.34299
rho12	-0.62013	0.052691	-11.77	0	-0.71288	-0.50605
Log likelihood=	-2105.5818,	Waldchi2(32) =		1329.30,	Prob>chi2=	0
Likelihood ratio test of rho12=	0:00		Chi2(1)	24.7368	Prob >=chi2	0

Table 4: Parameter estimates of the multivariate probit model for plot level planting decisions (equations 5 and 6)

	Coef.	Std. Err.	z	P>|z|	[95% Conf. interval]	
Impbarvar						
imbarshr	3.873	0.118	32.8	0.0	3.642	4.105
Notimppotvar	6.068	233.979	0.0	1.0	-452.522	464.658
Prevbar	-0.562	0.062	-9.0	0.0	-0.683	-0.440
usefert	0.895	0.057	15.7	0.0	0.784	1.007
SUBPLTSIZE	0.050	0.019	2.7	0.0	0.014	0.086
PLOTDIST	0.000	0.001	0.2	0.8	-0.002	0.002
swc	0.011	0.054	0.2	0.8	-0.096	0.117
average	0.007	0.073	0.1	0.9	-0.137	0.151
deep	0.019	0.051	0.4	0.7	-0.081	0.119
medium_slp	-0.072	0.091	-0.8	0.4	-0.250	0.107
steep_slp	-0.016	0.091	-0.2	0.9	-0.195	0.162
_cons	-8.638	233.979	0.0	1.0	-467.228	449.952
Imppotvar						
impotshr	7.865	0.333	23.6	0.0	7.212	8.517
Prevpot	0.008	0.077	0.1	0.9	-0.143	0.159
usefert	0.622	0.066	9.4	0.0	0.493	0.751
SUBPLTSIZE	-0.579	0.057	-10.1	0.0	-0.691	-0.467
PLOTDIST	-0.009	0.003	-3.4	0.0	-0.014	-0.004
swc	-0.409	0.077	-5.3	0.0	-0.559	-0.258
average	-0.142	0.098	-1.4	0.1	-0.334	0.051
deep	-0.082	0.066	-1.3	0.2	-0.211	0.047
medium_slp	0.584	0.166	3.5	0.0	0.258	0.909
steep_slp	0.463	0.167	2.8	0.0	0.136	0.789
_cons	-2.448	0.184	-13.3	0.0	-2.809	-2.087
/athrho	0.054	0.143	0.4	0.7	-0.227	0.335
rho	0.054	0.143	-0.2	0.3		

Log likelihood=-2949.12 Wald chi2(23)= 2065.43 Prob>chi2=0

Likelihood-ratio test of rho=0 chi2(1)= 0.1382 Prob>chi2=0.710