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A Multivariate Analysis of Factors Affecting Adoption of Improved Varieties of Multiple Crops: A Case Study from Ethiopian Highlands

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Abstract

This paper analyzes the synergies/tradeoffs involved in the adoption of improved varieties of multiple crops in the mixed crop-livestock production systems of the highlands of Ethiopia A multivariate probit (MVP) model involving a system of four equations for the adoption decision of improved varieties of barley, potatoes, wheat and faba beans was estimated using a nationally representative data from a sample of 1469 farm households. Model results attested the existence of endogeneity in the adoption decisions of improved varieties of the four crops. The area shares of improved varieties of potatoes and faba beans are also found to have positive and significant effects on the likelihood of adopting improved varieties of barley and wheat and vice versa - indicating synergistic effects among the adoption decisions of the two groups of crops. On the other hand, the area share of improved varieties of wheat negatively and significantly effects the chances of using improved varieties of barley and vice versa - suggesting the existence of tradeoffs between the improved varieties of the two crops. The MVP results, therefore, provide evidence for the simultaneity and interdependence of the decisions and intensity of adoption of the improved varieties of the four crops. Practical training has positive and significant effects on the likelihood of adopting improved varieties of barley, potatoes and faba bean while secondary level education has positive and significant effects on the likelihood of adopting improved varieties of barley and wheat. Hence, efforts to increase adoption of improved barley, potatoes and wheat varieties would more likely be successful if accompanied with practical trainings and/or if directed to farmers with relatively higher levels of education. Farmers in Oromia and SNNPR Regions are found to be more likely to use improved varieties of barley, potatoes and wheat than those in Amhara Region.

Introduction

The future of agriculture in Ethiopia, largely hinges on the country's ability to generate and out scale improved agricultural technologies that not only increase total factor productivity but also improve farm income. Cognizant of this fact, the government of Ethiopia is devoting substantial amounts of resources towards strengthening the national research system. In this effort, more emphasis is given to the development of agricultural technologies in general and crop improvement and extension programs in particular. Over the last four decades, the crop improvement programs in the country have released over 73, 44, 38 and 21 improved varieties of wheat, maize, barley, and faba beans, respectively. Despite all these efforts, however, crop productivities on farmers' fields still stand at less than a third of yields obtained in research stations–leading to debates that agricultural research and development endeavors in the country have had low impacts on productivity enhancement and poverty reduction.

Studies conducted in Ethiopia in the 1970's and 1980's reported rather low adoption rates of improved varieties of wheat and maize, the two crops that had received the bulk of the research and extension effort in the country (Waktola, 1980; Kebede, 1990). These early studies identified supply constraints, weak research and extension linkage and low grain prices as major impediments for the observed low adoption rates. Later adoption studies conducted following reorganization of the research and extension systems along the lines of farmer participatory and client orientation reported rather higher adoption rates of improved wheat and maize varieties. For instance, Yirga et al., (1996) reported about 50% adoption among sample farmers in two districts in the central highlands of Ethiopia. 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.

Along with estimating the extent of improved crop variety adoption, many studies tried to explain determinants of improved agricultural technology adoption among smallholder farmers. Internal factors that affect the adoption and use of agricultural technologies include farmers' attitude towards risk, household characteristics that affects the level of production and consumption, and resource endowments (Feder et al., 1985). External factors include the lack of well-developed seed systems and markets, enabling policy environments, infrastructure and institutions (Asfaw et al., 2011; Smale et al., 2011). In Ethiopia a plethora of studies attempted to explain the adoption decision behavior of farmers (Yirga et al., 1996; Dadi, et al., 2001; Tesfaye and Alemu , 2001; Feleke and Zegeye, 2006; Tura et al., 2010). Nonetheless, most of the studies focused on single commodities of project interest such as maize and wheat; relied on small samples that lack adequate variability; and emphasized on pilot project areas where intensive agricultural extension efforts had been conducted. Doss (2006) reviewing adoption studies conducted in eastern and southern Africa concluded that results from such micro studies do not provide the information required for introducing policy changes at national and regional levels. Information on smallholder farmers decision making behavior derived from a nationally representative sample encompassing the major crops of interest, however, hardly exists in Ethiopia.

In Ethiopia, the agricultural sector is dominated by smallholder mixed-crop livestock farmers managing small and fragmented plots often with diversified crop portfolio dominate the agricultural sector. As a result, the different enterprises, crops and varieties may compete for scarce household resources such as draft power, labor and chemical inputs. Analysis of smallholder farmers decision making behavior focusing on single commodity or activity, while actually multiple commodities, activities or interdependent technological options are the norm than the exception, ignores the simultaneous nature of the decision making process and the self selection of households into and out of activities (Winters et al.,2002; Yunez-Naude and Taylor, 2001). Failure to recognize interdependencies and endogeneity of activity/technology choice in analyzing resource allocation problems results in biased and inefficient estimates.

Single probit and logit models are often employed to model discrete choices such as adoption of improved varieties. Such models, however, are inappropriate to handle simultaneous adoption of multiple decisions. Multivariate models such as multinomial logit or multinomial probit models are generally applied to gauge decisions involving interdependent choices. Dorfman (1996) acknowledging the limitation of bivariate models to handle decisions involving interdependent decisions used multinomial probit to model multiple adoption decisions. In developing country context, Yirga and Hassan (2008) used multinomial logit to model the adoption decision of interdependent soil fertility and soil conservation adoption decisions. A recent study by Teklewold et.al. (2013) analyzed the determinants of interrelated sustainable agricultural practices (SAPS) adoption using data from multiple plot level observations using multivariate and ordered probit models. The results indicated a significant correlation between SAPs revealing that adoption of SAPs is interrelated. The study, however, considered only maize despite the fact that the target population produces several crops which often compete for the same resources (land, labor and draft power).

In this paper, we argue and provide evidence that the type and mix of crops grown influence the adoption decision behavior of smallholder farmers. Particularly, this study attempts to model and test the simultaneity of adoption decisions of improved varieties of barley, potatoes, wheat and faba beans typically grown by smallholder farmers in the mixed crop-livestock production systems of the highlands. Moreover, recognizing the fact that the decisions smallholder farmers have to make on whether or not to adopt involves choices among interdependent crop technologies, this study employs a simultaneous econometric model, where the adoption of improved varieties of one crop is treated as endogenous to the decision to adopt improved varieties of another crop. Hence, study differs from previous adoption studies in at least there ways. First, our analysis considers multiple crops often neglected by previous studies. Second, the study relies on nationally representative data conducted recently in the crop-livestock mixed farming systems of the highlands of Ethiopia. Third, our analysis uses an econometric model that explicitly tests for possible simultaneity and interdependence between the adoption decisions of improved varieties of different crops.

Data and Methods

Data

The study is based on a nationally representative data set generated jointly by the Ethiopian Institute of Agricultural Research (EIAR), the International Center for Agricultural Research in the Dry Areas (ICARDA) and the International Potatoes Research Center (CIP) under the auspices of a project funded by the Bill & Melinda Gates foundation through the Standing Panel for Impact Assessment (SPIA) of the Consultative Group for International Agricultural Research (CGIAR). The project popularly referred as the Diffusion and Impacts of Improved Varieties in Africa (DIIVA) aimed, among other things, at gaining deeper understanding on the adoption and diffusion of new varieties of barley, faba beans and potatoes in Ethiopia. The survey was conducted in three regions namely Amhara, Oromiya and the Southern Nation Nationalities and Peoples (SNNP) covering more than 94%, 96% and 97% of the total national barley, faba-beans and potatoes areas, respectively (CSA 2010).

Multi-stage sampling procedure was used to select sample zones, districts and Kebeles or peasant associations (PAs) from among the three target regions. The PAs are the primary sampling units (PSUs) or clusters and then a 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, were determined to be 1100 households. However, as more than three crops were involved, the sample size has been increased to 1469 households. 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, potatoes and faba beans growers at the wereda level was used for weighting. Accordingly, the sample farm households were distributed among 122 PAs, 41 weredas (districts), 24 zones and 3 regions.

Analytical framework

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 U_j and U_k, represent a household's perceived utility for two choices *j* and *k* respectively. Suppose also that $\boldsymbol{X_j}$ and $\boldsymbol{X_k}$ are vectors of explanatory variables that influence the perceived desirability of technologies *j* and *k*. Following Green (2008) the linear random utility model could be specified as

$$U_j = \beta_j^{'}\mathbf{X_j} + \varepsilon_j \text{ and } U_k = \beta_K^{'}\mathbf{X_k} + \varepsilon_K \qquad (1)$$

where β_j and β_k are parameters to be estimated and ε_j and ε_k 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:

$$U_{ij}(\beta_j^{'}X_i+\varepsilon_j)>U_{ik}(\beta_k^{'}X_i+\varepsilon_k),k\neq j \qquad (2)$$

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 jth crop conditional on X could then be defined as:

$$\begin{aligned} P(Y=1\mid X) &= P(U_{ij}>U_{ik}) \qquad (3)\\ &= P(\beta_j^{'}X_j+\varepsilon_j-\beta_k^{'}X_i-\varepsilon_k>0\mid X)\\ &= P(\beta_j^{'}X_i-\beta_k^{'}X_i+\varepsilon_j-\varepsilon_k>0\mid X)\\ &= P(\beta*X_i+\varepsilon^*>0\mid X=F(\beta^*X_i)\end{aligned}$$

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 β^*X_i. The exact distribution of F depends on the distribution of the random disturbance term ε^*.

Empirical estimation

In the mixed crop-livestock production systems of the Ethiopian highlands, smallholder farmers produce several crops that may compete for scarce household resources such as land and/or complement each other through such effects as nitrogen fixation and breaking disease and pest cycles across seasons. Analysis of smallholder farmers technology adoption decision behavior, therefore, needs the use of a multivariate (instead of univariate) modeling framework to take into account the multiple commodities, and the possible simultaneity of the decision making process. Consequently, a multivariate probit model (MVP) is used in this paper for assessing the adoption decision behavior of smallholder farmers. In the MVP model estimated here, the choice of improved varieties related to each of the crop enterprises corresponds to a binary choice (yes/no) equation and the choices are modeled jointly while accounting for the correlation among disturbances. Model estimates from the multivariate specification improve over those from univariate specifications when the error correlations are significantly different from zero. Otherwise, the two modeling frameworks would lead to comparable results. Hence, if a household grows M different crops, M equations each describing a latent dependent variable that corresponds to the observed binary outcome for each crop would be needed to be estimated simultaneously.

Following Cappellari and Jenkins (2003), a system of simultaneous probit models were constructed for barley, potatoes, wheat and faba beans as follows:

$$Y_{im_i}^{*}=\beta_m{}'X_{im}+\varepsilon_{im} \qquad (4)$$

$Y_{im}=1$ $_{i}$ if $Y_{im}^{*} > 0$ and 0 otherwise

ε_{im}, m = 1, . . . , M are error terms distributed as multivariate normal, each with a mean of zero, and variance–covariance matrix V, where V has values of 1 on the leading diagonal and correlations $\rho jk = \rho_{kj}$ as off-diagonal elements. If we assume that ε_{im}, are distributed independently and identically with a univariate normal distribution, equation (4) defines M univariate probit models. The assumption of the independence of the error terms means that information about a household's choice of the type of cultivar to grow of one crop does not affect the prediction of the same household's probability of adoption of improved varieties of another crop. If the unobserved correlations among outcomes are ignored, the whole set of M equations in (4) could be estimated separately as univariate probit models. However, neglecting correlations leads to inefficient and biased estimates.

One important hypothesis to ascertain is that all cross-equation correlation coefficients are simultaneously equal to zero. The Wald test is often used to test the null hypothesis of no correlation across equations (Hausman, 1978). Lack of statistical evidence to reject the null hypothesis suggest that the choices are independent of each other implying that we could equivalently fit M independent univariate probit models for each crop enterprise. On the contrary, if the null hypothesis is rejected, it suggests that estimation of M independent univariate probit models for each crop enterprise would lead to inefficient estimates signaling the need for the simultaneous estimation of all M equations.

Hypothesis and definition of variables

The dependent variables in the MVP model include four dummy variables corresponding to use of improved varieties of barley, potatoes, wheat and faba beans (Table 1).

Exogenous variables often considered in modelling the adoption decision behaviour of farm household include farm, farmer and household characteristics, resource endowments, geographical variations and institutional factors such as access to markets, information and credit (Feder et al., 1985; Feleke and Zegeye, 2006; Yirga and Hassan, 2008). In this study also, demographic variables such as age, sex, education and family size and farm characteristics i.e., percentages of area in total landholding declared fertile and black soil, resource endowments (farm size, oxen, other livestock and house type), institutional factors (access to credit, training and off-farm employment) and, location dummies for the regions are hypothesized to influence the adoption of improved varieties of barley, potatoes, wheat and faba beans by smallholder farmers in the highland of Ethiopia (Table 1).

Theoretically, older farmers in Ethiopia who are often uneducated and uneasy towards changes may be reluctant to shift from less risky but low yielding local varieties to high yielding but potentially (until proven otherwise) risky modern varieties. Younger farmers, on the other hand, being on the average more educated with a higher disposition to change may be more likely to take up new opportunities. Age of the household head, therefore, is expected to have a negative effect on the likelihood of adopting improved varieties. Higher education is believed to be associated with the ability to collect process and utilize new information suggesting households with higher levels of education would be highly likely to adopt improved crop varieties. Wealth is believed to reflect past achievements of households and their ability to bear risk. Previous studies in Ethiopia (Yirga and Hassan, 2008) used the type of house a household owns with corrugated or grass roofed and the number of livestock as proxies for the wealth status of a household. Number of oxen and other livestock owned as well as ownership of corrugated roofed house are expected to be positively associated with the decision to adopt improved varieties of the considered crops. Large family size is normally associated with a higher labour endowment that would enable a household to accomplish various agricultural tasks on timely bases thus raise productivity. Hence, we expect a household with large family size to be more likely to adopt improved varieties.

Farm characteristics hypothesized to influence adoption of improved seeds are percent share of black soils in total farm size and percent share of fertile farm land in total farm size. The higher the share of fertile land area in total farm size, the higher the likelihood of using improved varieties of barley, potatoes and wheat. On the other hand, faba beans being a legume crop and capable of fixing nitrogen is often planted on less fertile lands. Hence, percent share of fertile land in total farm size is expected to inversely correlate to the likelihood of using improved faba beans varieties.

Institutional factors considered to have differential impacts on improved seed adoption by smallholder farmers are access to information, institutional credit and off-farm employment. Various studies in developing countries including Ethiopia reported a strong positive relationship between access to information and the adoption behaviour of farmers (Yirga et al., 1996; Dadi, et al, 2001). Hence, it is hypothesized that the greater the number of contacts a household has with extension workers, the more likely the adoption decision. Also studies by, Yirga et al. (1996), Dadi et al. (2001) underscored the role of credit in enhancing adoption of crop technologies. It is therefore hypothesized that access to credit will have a positive impact on adoption of improved seeds. It is observed that farmers with off-farm income are less risk-averse than farmers without sources of off-farm income. Hence, off-farm income is expected to have a positive impact on the use of improved seeds.

Regional variation is believed to have a profound effect on the likelihood of adopting improved technologies. The crops considered in this study are grown all over the country within the highlands. Access to improved varieties, however, are likely to vary across locations due to variations in intensity of extension efforts, availability of agricultural research centres and specialized projects. While attempts have been made to reach farm household in distance locations, much of the research and extension efforts were targeted in the Oromia and SNNP regions by virtue of their locations. Also, most of the national agricultural research centers are located in Ormia region compared to other regional stats. Farm households in the two regions are believed to have benefited from participating in on-farm trails, demonstrations and improved technology outreach programs. Therefore, it is hypothesized that the probability of using improved seeds would be higher in Oromia and SNNP than the less targeted areas of Amhara region.

Table 1: Definition of variables included in the regression

Variable	Description	Values
Dependent variables		
Y1	Used improved barley varieties	1=yes, 0=no
Y2	Used improved potato varieties	1=yes, 0=no
Y3	Used improved wheat varieties	1=yes, 0=no
Y4	Used improved faba bean varieties	1=yes, 0=no
Independent variables		
Demographic Characteristics		
Sex	Sex of the household head	0=female, 1=male
Age	Age of the head of the farm HH	Years
Education	Education level of the HH	Dummy Variable
EDUC1	No formal schooling	1= yes, 0=no
EDUC2	Education between 1 and 8	1=yes, 0=no
EDUC3	Education greater than 8	1=yes, 0=no
Family size	Number of family members living under the same abode	Number
Asset Ownership		
Farm size	Total area (crop, fallow, grazing) managed by a HH	Area in ha
Oxen	Oxen owned by a HH	Dummy Variable
Oxen1	Do not own oxen at all	1=Yes, 0=no
Oxen2	Own one ox	1=Yes, 0=no
Oxen3	Own two or more oxen	1=Yes, 0=no
Other Livestock	Livestock other than oxen in TLU	Number
House type	If a HH owned corrugated iron roofed house or not	1= yes, 0=no
Institutional Variables		
Training	Whether a HH received training on improved crop production practices the previous crop season	0=no, 1=yes
Extension	No of contact a household had with extension during the study year	Number
Credit	HH need and received institutional credit for the purchase of improved seeds	1=yes, 0=no
Off-farm	Household participated in off-farm activities	1=yes, 0=no
Location Dummies	Regional state the household lives and farms	
Amhara	Households in Amhara regional state	0=no, 1=yes
SNNP	Households in Southern Nations Nationalities and Peoples Regional State	0=no, 1=yes
Oromia	Household in Oromia Regional State	0=no, 1=yes
Farm characteristics		
pfrtlsoil	Percent fertile land in total farm size	%
pblacksoil	Percent black soil area in total farm size	%
pimpbrly	Percent area under improved barley varieties	%
pimppota	Percent area under improved potato varieties	%
pimpwheat	Percent area under improved wheat varieties	%
pimpfbean	Percent area under improved faba bean varieties	%

Results and Discussion

Adoption Patterns

Table 2 presents the marginal distribution of the adoption of improved varieties of the four major crops grown by sample households. The majority of the households adopted improved barley and wheat varieties, averaging 37% each followed by potatoes which stands at 23%. Lower in the adoption scale is the adoption of improved varieties of faba beans averaging 6%.

Table 2: Marginal distribution of improved barley, potatoes, wheat and faba beans variety adoption (%), Ethiopia

Crop	Freq	Percent
Barley	549	36.8
Potatoes	345	23.1
Wheat	545	36.5
Faba beans	89	6.0

The probability distribution of the joint adoption probabilities of improved varieties is reported in Table 3. As is evident from the figures, the first eight combinations which involve adopting improved barley varieties account for 36.8% of all the households, of which less than 1% adopted improved varieties of the four crops while 13% used improved barley varieties only. Households simultaneously adopting improved varieties of barley and wheat, constitute 9.2% while another 6% of households adopted improved barley and potato varieties simultaneously. Joint adoption of multiple crops that involve faba beans are less frequent. The joint probability of using local varieties of all the four crops accounts the highest probability of 35.5% suggesting a lot needs to be done in popularization, farmer education and creating better access to seeds of improved crop varieties for smallholder farmers.

The conditional probabilities of adopting improved varieties of interest are given in Table 4. The conditional probability of adopting improved varieties of one crop or a combination of crops, however, is generally higher suggesting the existence of synergy. For instance the probability of adopting improved barley varieties increases from 36.8% to 44%, 50% and 54% conditional on the adoption of improved varieties of wheat, faba beans and potatoes, respectively. The probability of adopting improved barley varieties further increases to 58% conditional on adopting both improved varieties of potatoes and wheat concurrently. It is worth noting, however, the conditional probability of adopting improved faba bean varieties rises marginally from 6% to 7% conditional on adopting improved varieties of wheat and from 6% to 8% conditional on adopting improved barley varieties, suggesting the existence of very weak synergy between adoption of improved faba bean varieties with the decision to adopt other improved crop varieties.

Table 3: Probability distribution for joint or individual adoption of improved barley, potato, wheat and faba bean varieties among smallholder farmers in the highlands of Ethiopia

(Y_1, Y_2, Y_3, Y_4)	Frequency	Percent	Cum. percent
1,1,1,1	6	0.4	0.4
1,1,1,0	81	5.4	5.8
1,1,0,1	9	0.6	6.4
1,1,0,0	90	6.0	12.5
1,0,1,1	15	1.0	13.5
1,0,1,0	138	9.2	22.7
1,0,0,1	15	1.0	23.7
1,0,0,0	195	13.1	36.8
0,1,1,1	6	0.4	37.2
0,1,1,0	57	3.8	41.0
0,1,0,1	6	0.4	41.4
0,1,0,0	90	6.0	47.4
0,0,1,1	19	1.3	48.7
0,0,1,0	223	14.9	63.6
0,0,0,1	13	0.9	64.5
0,0,0,0	530	35.5	100.0

Note: Y1=Barley, Y2=Potatoes, Y3=Wheat, Y4=Faba beans
1=adopt improved, 0 otherwise

Table 4: Conditional probabilities for the adoption of improved varieties of barley, potatoes, wheat and faba beans by smallholder farmers in the highlands of Ethiopia

	Crops			
Condition	Barley Y1	Potatoes, Y2	Wheat, Y3	Faba beans, Y4
Y1==1	1	0.34	0.44	0.08
Y2==1	0.54	1.00	0.45	0.07
Y3 ==1	0.44	0.28	1.00	0.08
Y4 ==1	0.51	0.30	0.52	1.00
Y2 ==1 & Y3 ==1	0.58	1.00	1.00	0.08
Y1==1 & Y4 ==1	1	0.33	0.47	1.00
Y2 ==1 & Y3 ==1	0.58	1.00	1.00	0.08
Y2 ==1 & Y4 ==1	0.56	1.00	0.44	1.00
Y3 ==1 & Y4 ==1	0.46	0.26	1.00	1.00
Y1==1 & Y2 ==1 & Y3 ==1	1	1.00	1.00	0.07
Y1==1 & Y2 ==1 & Y4 ==1	1	1.00	0.40	1.00
Y1==1 & Y3 ==1 & Y4 ==1	1	0.29	1.00	1.00
Y2 ==1 & Y3 ==1 & Y4 ==1	0.50	1.00	1.00	1.00
Y1==1 & Y2 ==1 & Y3 ==1 & Y4==1	1.00	1.00	1.00	1.00

Note: Y1=Barley, Y2=Potatoes, Y3=Wheat, Y4=Faba beans
1=adopt improved varieties, 0 otherwise

Econometric Results

Table 5 presents the estimates of pairwise correlation coefficients of the error terms in the four equations. The estimated correlation coefficients are all significant suggesting the MVP model is a better specification than the four univariate probit models for the observed data. A correlation coefficient different from zero between a pair of choices suggests that there are unobservable factors affecting both choices and reveals an association after controlling for all the covariates included in the regression.

Table 6 presents the coefficients of the MVP adoption model. The Wald test for the hypothesis that all coefficients in each equation are jointly equal to zero is rejected suggesting that the variables included in the model explain significant portions of the variations in the dependent variables. As apparent from the MVP regression results, percent area share of improved varieties of potatoes and faba beans had significant and positive impacts on the probability of adopting improved varieties of barely. A unit increase in the area share of improved varieties of potatoes and faba beans would raise the chances of adopting improved barley varieties by 1.8% and 2.2%, suggesting the diffusion of improved varieties of potatoes and faba beans would enhance the chances of a household adopting improved barley varieties. Similarly, the higher the proportion of area under improved varieties of barley, the better the chances of adopting improved varieties of potatoes and faba beans further suggesting the complementarities between the adoption decision of improved barley and improved varieties of potatoes and faba beans. Focus group discussions with farm communities in the study area indicated that potatoes and faba beans are the two preferred rotation crops with barley. On the contrary, the likelihood of adopting improved barley variety is significantly and adversely affected by percent area share of improved wheat varieties. A unit increase in the area share of improved wheat varieties would reduce the chances of using improved barley varieties by 0.69% indicating the competitive nature of the two crops. The results further indicate that the likelihood of adopting improved wheat varieties is significantly and positively impacted by percent area under improved potatoes and faba beans. The MVP results, therefore, provide sufficient evidence for simultaneous and interdependent adoption decisions. .

Apart from these main variables of interest, the MVP model results revealed that a number of hypothesized demographic, farm, institutional and location variables have a significant and differential effect on improved variety adoption. Education of the household head positively and significantly influenced the chances of adopting improved varieties of barley and wheat. The likelihood of using improved barely and wheat varieties would be higher for a household with a formal schooling of 8 or more years of formal education by 18.9 % and 12.3%, respectively signifying the important role that attaining a relatively higher level of education on the adoption decision of farm households. On the contrary, the chances of using improved faba beans would be lower by about 4.2% for households attaining 8 or higher grades compared to households who do not have any formal schooling. This could probably be due to the fact that faba beans is a legume crop often cultivated in rotation with cereals. Recently, farm households facing decreasing landholdings and motivated by the higher wheat and barley productivity are moving away from the century old legume-cereal cropping system to mono-cropping of cereals.

Access to training on improved varieties significantly and positively influenced the chances of adopting improved varieties of barley, potatoes and faba beans. The likelihood of using improved varieties of barley, potatoes and faba beans for a typical household having received training on the use of improved technology would be higher by about 13.6%, 6.5% and 3.8% compared to a household who did not receive practical training signifying the importance of providing practical hand on training for persuading farmers to adopt improved agricultural technologies. Number of extension contacts does not have significant effects on the adoption of the improved varieties of the 4 crops suggesting that mere provision of information would add little to changing the mindset of farmers. One interesting finding is that being a model farmer has positively and significantly increased the chances of using improved faba beans by about 3.3 % compared to ordinary farmers, which could possibly be because model farmers are usually brighter and more innovative or the individual attention they receive in extension services makes a difference in their adoption decisions calling for a closer study of the adoption decision of these particular farmers.

The type of house a household lives in and the number of livestock owned is often used as indicators of the wellbeing of smallholder farmers in Ethiopia. Ownership of corrugated house have a positive and significant effect on the likelihood of using improved varieties of potatoes but significantly reduced the chances of using improved barley varieties. For a typical household owning and living in a corrugated roofed house, the chances of using improved potato varieties would be higher by 5.7% whereas the chances of using improved barley varieties would be lower by 7.7%. Barley in Ethiopia is considered a poor man's crop often cultivated with very little external inputs. The cultivation of potatoes, however, requires external inputs such as pesticides for the control of late blight. The variable, house type therefore indicates a households' ability to access complimentary inputs. Oxen and the number of other livestock a housed owns have a significant and differential effect on the decision to use improved crop varieties. While oxen ownership has not significantly affected the adoption decision of improved barley varieties, it raised the chances of adopting improved varieties of wheat and faba beans. The likelihood of adopting improved varieties of wheat and faba beans would be higher by 9.4% and 3.8%, respectively, for a household owning a pair of oxen compared to households who do not own oxen at all. The number of livestock owned other than oxen, however, increased the chances of using improved barley and potato varieties. A unit increase in the non-oxen livestock would have the effect of raising the chances of using improved varieties of barley and potatoes by about 1% and 0.5%, respectively. Livestock besides its benefit as a store of value that can be liquidated in times of cash needs provide manure critical for replenishing nutrients extracted through cropping. The results, therefore, suggest that institutional interventions targeted at improving ownership of livestock will have a positive impact on raising adoption of improved crop varieties.

Among the farm characteristics, proportion of area declared fertile in total landholdings has marginal negative effect on improved potatoes variety adoption. Similarly, proportion of black soil area in total farm size positively and significantly influenced adoption of improved potato varieties but a negative and significant effect on the adoption of improved wheat adoption.

Another significant result worth noting is the differential effect of location on the adoption decision of improved crop varieties. All else being the same, the chances of using improved varieties of barley, potatoes and wheat in Oromia would be higher by about 36%, 8% and 20%, respectively compared to a typical households in the Amhara regional state, the comparison group. Similarly, the chances of using improved potatoes and faba beans varieties would be higher by 8% and 4%, respectively, for a typical household in SNNP compared a similar household in the Amhara region. In case of the adoption of improved wheat varieties, however, the chances of a household residing in

SNNP would be lower by 9.5% compared to a similar household in Amhara region. Hence, efforts to increase adoption of improved barley, potatoes and wheat varieties in the short term would more likely be successful if directed towards farmers in SNNP and Oromia regions. Conversely, concerted effort would be needed to improve the use of improved varieties of these crops in the Amhara region.

Surprisingly, among the hypothesized variables, farm size and credit did not have a significant effect on the adoption of any of the improved varieties of the considered crops. One explanation would be that improved varieties being divisible and scale neutral may not be affected by farm size. Also in the Ethiopian context where formal land markets are missing and intra-household variations are small, lack of association between farm size and the decision to use improved varieties should not be surprising. The lack of statistical association between access to credit and improved variety could be explained by the nature of the crops considered and the seed use behavior of smallholder framers The considered crops being self pollinated, seed quality of improved varieties and hence potential productivity largely remain intact as long as farmers manage fields in certain ways. Hence, access to credit by smallholder farmers for self-pollinated crops for which seed quality are not adversely affected (unlike hybrid varieties) is unlikely to affect the adoption decisions as most depend on own saved seeds from previous harvest.

In summary, these results indicate unequivocally that any conclusion concerning patterns of improved crop variety adoption and their link with demographic and farm characteristics, resource endowments, institutional support and geographical variations depends heavily on the set of enterprise choices considered as the outcome variable. Several comparisons could be realized based on joint probability distributions as there are 16 combinations from the four crop enterprises. Unfortunately however, computational limitations prevented us from presenting the results. The information provided suffices to confirm the importance of using a multivariate framework to gain a full understanding of smallholder farmers' technology adoption behavior in a multiple crop enterprise set-up.

Table 5: Estimates of correlation coefficient for the error terms from the four adoption equations for barley, potatoes wheat and faba beans

Parameter	Coefficient	Standard Error	P-value	95 % Confidence Interval	
ρ21	-0.3929	0.0730	0.0000	-0.5258	-0.2412
ρ31	0.6416	0.0504	0.0000	0.5321	0.7300
ρ41	-0.5214	0.0707	0.0000	-0.6461	-0.3696
ρ32	-0.5989	0.0560	0.0000	-0.6976	-0.4779
ρ42	0.7536	0.0526	0.0000	0.6306	0.8397
ρ43	-0.6922	0.0514	0.0000	-0.7801	-0.5776

Likelihood ratio test of rho21 = rho31 = rho41 = rho32 = rho42 = rho43 = 0:
chi2(6) = 83.2903 Prob > chi2 = 0.0000

Note: The indexes refer to the equations: 1=barley, 2=potatoes, 3=wheat, 4=Faba beans.

Table 6: Multivariate probit estimates and marginal effects for the simultaneous adoption of improved varieties of barley, potatoes, wheat and faba beans, Ethiopia

	Barley			Potatoes			Wheat			Faba beans		
Variable	Coef.	Std. Err.	Marginal Effect	Coef.	Std. Err.	Marginal Effect	Coef.	Std. Err.	Marginal Effect	Coef.	Std. Err.	Marginal Effect
pimpbrly	"n.a"	"n.a"	"n.a"	0.0170***	0.0031***	0.0047	-0.0250***	0.0025	-0.0096	0.0205***	0.0035	0.0027
pimppota	0.0461***	0.0076	0.0176	"n.a"	"n.a"	"n.a"	0.0488***	0.0061	0.0188	-0.0488***	0.0085	-0.0065
pimpwheat	-0.0180***	0.0027	-0.0069	0.0276***	0.0026***	0.0076	"n.a"	"n.a"	"n.a"	0.0283***	0.0028	0.0038
pimpfbean	0.0587***	0.0095	0.0224	-0.0613***	0.0087***	-0.0169	0.0597***	0.0066	0.0230	"n.a"	"n.a"	"n.a"
SEX	-0.3153**	0.1409	-0.1206	-0.1476	0.1363	-0.0407	-0.0334	0.1212	-0.0129	0.2362	0.2107	0.0315
AGE	0.0003	0.0030	0.0001	0.0019	0.0029	0.0005	0.0062**	0.0026	0.0024	0.0030	0.0036	0.0004
ed2	0.1806**	0.0912	0.0691	0.1759	0.0923	0.0485	0.0497	0.0800	0.0192	0.0646	0.1137	0.0086
ed3	0.4948***	0.1174	0.1892	-0.0142	0.1196	-0.0039	0.3203***	0.1060	0.1235	-0.3170**	0.1570	-0.0423
famlysize	0.0502***	0.0150	0.0192	-0.0171	0.0143	-0.0047	0.0046	0.0132	0.0018	-0.0171	0.0181	-0.0023
housetype	-0.3884***	0.0771	-0.1485	0.2051***	0.0770	0.0565	-0.0694	0.0703	-0.0268	0.0788	0.0981	0.0105
model_farmer	0.1236	0.0778	0.0473	0.1014	0.0767	0.0280	0.0204	0.0704	0.0079	0.2440**	0.0978	0.0325
extvist_no	0.0027*	0.0016	0.0010	0.0022	0.0015	0.0006	0.0024*	0.0014	0.0009	-0.0009	0.0020	-0.0001
traning	0.3571***	0.0795	0.1365	0.2366***	0.0766	0.0652	-0.0508	0.0679	-0.0196	0.2836***	0.0985	0.0378
credit	-0.1440	0.1395	-0.0551	0.0552	0.1335	0.0152	0.0924	0.1224	0.0356	0.0347	0.1787	0.0046
oxen_dm2	-0.0105	0.0998	-0.0040	0.0654	0.1014	0.0180	0.0590	0.0918	0.0228	0.5469***	0.1409	0.0730
oxen_dm3	0.0891	0.1037	0.0341	-0.1274	0.1045	-0.0351	0.2431***	0.0949	0.0938	0.2872*	0.1522	0.0383
tluother	0.0258***	0.0098	0.0099	0.0194**	0.0094	0.0054	-0.0016	0.0088	-0.0006	-0.0111	0.0144	-0.0015
offincome_dm	0.0186	0.0749	0.0071	0.0390	0.0740	0.0107	0.0849	0.0685	0.0327	0.0861	0.0958	0.0115
SUBPLTSIZE	-0.0026	0.0072	-0.0010	0.0035	0.0074	0.0010	0.0031	0.0066	0.0012	-0.0025	0.0106	-0.0003
pfrtlsoil	0.0012	0.0010	0.0004	-0.0020**	0.0010	-0.0006	0.0009	0.0009	0.0003	-0.0014	0.0013	-0.0002
pblacksoil	0.0002	0.0010	0.0001	0.0025**	0.0010	0.0007	-0.0026***	0.0009	-0.0010	0.0014	0.0013	0.0002
OROMIA	0.9390***	0.1033	0.3591	0.3140***	0.1163	0.0865	0.5120***	0.0928	0.1975	-0.0134	0.1355	-0.0018
SNNP	-0.1760	0.1131	-0.0673	0.2863***	0.1104	0.0789	0.2459**	0.0984	-0.0949	0.3016**	0.1419	0.0402
_cons	-1.2637***	0.2331	"n.a"	-1.5944***	0.2232	"n.a"	0.8894***	0.2028	"n.a"	-2.4672***	0.3194	"n.a"

Note: n.a=not applicable

Summary, Conclusions, and Lessons Learned

Using data from a sample of 1469 nationally representative farm households, the decision for adoption of improved varieties by smallholder farmers who are engaged in the production of multiple crops in the Ethiopian highlands were analyzed. Particularly, the adoption decision for improved varieties of four major crops, namely, barley, wheat, potatoes and faba beans are analyzed using a multivariate modeling framework which accounts for possible interdependence among individual decisions. A simultaneous-equation system of four probit equations for the adoption decision of improved varieties of each of the four crops was estimated with the same set of covariates appearing in each equation.

The Hausman (1978) specification test indicated a significant endogenous relationship among the adoption of improved varieties of barley, potatoes, wheat and faba beans. The MVP regression results, also, indicated that area share of improved varieties of wheat had a significant and negative impact on the likelihood of using improved varieties of barley. Similarly, area share of improved faba bean varieties negatively and significantly influenced the chances of using improved varieties of potatoes suggesting tradeoffs/competition among the two crops. Apart from these main variables of interest, practical training has positive and significant effects on the area share of improved varieties of barley, potatoes and faba beans while secondary level education has positive and significant effects on the area share of improved varieties of barley and wheat. Hence, efforts to increase adoption of the improved barley, potatoes and wheat varieties would more likely be successful if accompanied with practical trainings and/or if directed to farmers with relatively higher levels of education as appropriate. Additionally, regional variation proxied by regional dummies produced significant and positive coefficients in almost all equations reflecting past agricultural research and extension efforts in the Oromia and SNNPR regions than the Amhara region, which is the reference. Thus, barley, potatoes and wheat farmers in Oromia and SNNPR regions are more likely to adopt the improved varieties than fellow farmers in the Amhara region. Considered in isolation, farm size, access to credit and off farm jobs, were not significant factors in determining all of the considered improved crop varieties.

On the whole the information provided suffice to confirm the importance of using a multivariate framework to gain a better understanding of smallholder farmers' technology adoption decisions in a mixed crop-livestock production systems involving multiple crop enterprises. One limitation of this study is that the data are cross-sectional and might not appropriately capture farmers' adjustments of area allocations in response to their adoption of improved varieties and variations in weather and markets and vice versa. Also, due to computational difficulties we could not provide the marginal effects for the conditional adoption decisions.

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