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Evaluation of Modern Agricultural Technologies Adoption and Impact of Adoption on Productivity

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Abstract

Bringing about change in agricultural productivity through technology adoption is still an issue in developing countries, so is not different for Ethiopia. The study examines the determinants for adoption of agricultural technologies mainly chemical fertilizer and improved seed. It is pertinent to understand the determinants of the adoption decision of the technologies. The bivariate probit estimation result reveal that household characteristics like household size and education have a positive implication on the likelihood of adoption. Institutional factors also strongly determine the likelihood of adoption decision. In addition, the yield function estimation results also indicate that adoption of chemical fertilizer and improved seed increase wheat yield. It is only chemical fertilizer adoption that positively affect fava beans yield level.

Background

The primary engine of Ethiopian economy is the agriculture sector accounting 42 percent of the country's GDP. The sector being not only employer of the larger section of labor force; it is the principal source for fulfilling domestic food demand and unleashing food insecurity. Though the sector plays the major role, it faces huge uncertainty in the production process as it is highly reliant on nature and the sector is dominated by small-farm holders that cultivate in traditional way. According to CSA (2016), 95 percent of the country's production comes from about 15 million small holder farmers. In order to change the traditional way of cultivation and make the sector to utilize its potential, the country is in the process of transforming the sector by introducing new technologies and enhancing the adoption rate of the existing ones among the subsistence agricultural households. It is a fact that different environmental conditions demand different approaches of production in order to obtain the maximum possible productivity of crops (Yu et.al., 2011).

In Ethiopia, the most common modern technologies adopted by farmers are improved seed, chemical fertilizer, pesticide, herbicide and at some places soil and water conservation schemes. Previous literature document the relevance of such technologies in boosting productivity. For instance, Kassie et al. (2009) underlined the practice of agricultural technologies as one of the key drivers of achieving sustainable agricultural production in Ethiopia.

Despite the availability of modern agricultural technologies, the rate of adoption among the small agricultural households is still low in Ethiopia (Teklewold et. al, 2013). For instance, about 10.7 percent of total cereal cultivated land is covered by improved seed while land covered by improved seed in cultivation of pulses and oil seeds is much lower accounting 0.8 percent and 1.52 percent, respectively (CSA, 2016). The same report indicated that out of the total cultivated land, 44 percent is cultivated with application of chemical fertilizer and 38.3 percent is covered by extension package. A number of factors are ascribed for such low adoption- one key constraining factor being requirement of labor input. In this regard, Waithaka et. al., (2007) pointed-out that improved seed and fertilizer use may require more labor. The authors also mentioned these inputs are also used with abundant water, in the end constrain its adoption rate though the factors are not limited to these. In general, it is not only the availability of the technologies which is important, but also the ability of the farmers to adopt and utilize the modern technologies at their hand (Akudugu et. al., 2012).

It is reported that Ethiopian agricultural households mainly produce cereals, pulses and oil seeds that cover 80 percent, 15 percent and 6 percent of land cultivated, respectively (CSA, 2016). This study mainly focuses on the adoption of technologies among households who produced wheat and fava beans. Among the cereals wheat stands forth by the size of area coverage and fava bean is the first among pulses (CSA, 2016).

This research contributes to the literature by exploring the determinants of modern agricultural technology adoption among wheat and fava beans cultivators using bivariate probit model which allows simultaneous probit models to be estimated by allowing correlation of the error terms (Wooldridge, 2002). It is good to unravel reasons behind if some of the agricultural households

are not adopting the technologies or adopting some of the technologies among the available ones. Understanding of the factors enables the government and other partner organizations in designing appropriate strategy and guide currently on-going innovations in line with the behavior of agricultural households. After looking the adoption rate and the determinants of modern agricultural technologies, mainly improved seed and chemical fertilizer, investigation is done on the impact of such technologies on the productivity of wheat and fava beans.

The structure of the remainder of the paper is as follows. Section 2 presents the source of the data used and a brief discussion on descriptive of the variables in the data set. Section 3 discusses the descriptive on adoption of modern agricultural technologies. Section 4 and section 5 present econometric specification and discussion of results, respectively. Finally, the last section draws some conclusion from the results of the analysis.

Data

In order to evaluate productivity impact of technology adoption, this study uses annual Agriculture sample survey data of 8 years collected by central statistics agency of Ethiopia from 2006 to 2014 except 2002. The data is collected every year from more than 2000 enumeration areas. The number of enumeration areas varies in each year and circumstances. The survey covers all regions except some pastoralist regions of the country, that is, three zones from Afar and six zones from Somali regions are not covered. From each enumeration areas, 20 agricultural households are selected and interviewed basically about Meher season production. The agricultural sample survey besides crop production forecast surveys, there is also Meher season post- harvest survey which is about total area cultivated, amount of production, land use, farm management and crop utilization. The survey has also information about Belg season production but in this study, we will focus on only the Meher season production as Belg production is not common in most places. In addition, since the focus is on production of wheat and fava beans, we use only four regions- Tigray, Amhara, Oromia and Southern Nation and Nationalities of People Region (SNNPR).

Summary statistics of the variables

Table 2.1 and Table 2.2 present the summary statistics of the variables used in the analysis in the following sections. Tables indicate that the average household size of the cultivators is 5 while more than 80 percent of the holders are male. The average household size is 5 with 45 years of average age of the producers. The average land size among wheat producer is 0.19 hectares and 0.097 hectares for fava beans producers.

Table 2.1: Summary statistics of variables used among wheat cultivators

Variable	Observation	Mean	Std. Dev.	Minimum	Maximum
household characteristics					
household size	160921	5.65	2.25	0	21
holder's education(year)	157778	3.02	3.13	1	15
Holder's age	160770	45.65	15.29	15	99
holder sex (1=male)	160929	0.86	0.35	0	1
Technologies					
Extension(1=yes)	160929	0.26	0.44	0	1
Irrigation(1=yes)	160929	0.01	0.08	0	1
Total land size (hectare)	160929	2	1.85	0.002	29.23
Crop land (hectare)	161033	0.19	0.23	0.000024	8.38
fertilizer use (1=yes)	160929	0.54	0.5	0	1
Improved seed use (1=yes)	160929	0.06	0.23	0	1
Fertilizer quantity (kg)	86901	0.29	0.75	0	96
Improved seed quantity(kg)	8803	0.35	0.54	0	30
Use credit (1= yes)	159726	0.39	0.49	0	1
Use advisory service (1=yes)	159989	0.76	0.43	0	1
Woreda characteristics					
Population density	160929	170.97	302.42	7	9350
Average time to nearest town**	160929	4.57	2.69	0.1	22.1
Average elevation (meter)	160929	2157.63	369.11	690	3303
Average temperature(^{0}C)	160929	19.41	2.11	14.09	28.42
Average rainfall(mm)	160929	4.94	2.09	1.2	10.62
Rainfall standard deviation	160929	5.28	1.28	1.78	8.85

Source: Authors' computation using Ethiopian Agriculture Survey data.

**Average travel time in hours to the nearest city at least 50,000 people

Among wheat cultivators, only 26 percent of them use extension service while it is only 8 percent of fava beans cultivators. Surprisingly, a larger share of the holders (more than 70 percent) had an advisory service. Credit user holders' proportion among wheat producers is about 39 percent and 33 percent of fava beans producers.

With regard to adoption of improved seed and chemical fertilizer, the proportion of wheat producers who use chemical fertilizer is significant about 54 percent while fava beans producers are only 14 percent. Improved seed adoption is quite low in the country which accounts only 6 percent of wheat producers and about 1 percent of fava beans producers.

Table 2.2: Summary statistics of variables used among fava beans cultivators

Variable	Observation	Mean	Std. Dev.	Minimum	Maximum
household characteristics					
household size	109403	5.53	2.21	1	21
holder's education	107210	2.86	3.01	0	15
Holder's age	109322	45.89	15.28	15	99
holder sex (1= male)	109407	0.84	0.36	0	1
Technologies					
Extension	109407	0.08	0.27	0	1
Irrigation	109407	0	0.06	0	1
Total land size (hectare)	109407	1.78	1.72	0.0004	29.23
Crop land (hectare)	109587	0.097	0.123	0.000014	5.31
fertilizer use (1=yes)	109407	0.14	0.35	0	1
Improved seed use (1=yes)	109407	0.01	0.09	0	1
Fertilizer quantity (kg)	14992	0.11	0.62	0	48
Improved seed quantity(kg)	957	0.03	0.11	0	1.6
Use credit (1= yes)	108638	0.33	0.47	0	1
Use advisory service (1=yes)	108832	0.72	0.45	0	1
Woreda characteristics					
Population density	109407	172.43	167.07	6	9350
Average time to nearest town**	109407	4.88	2.85	0.1	16.6
Average elevation (meter)	109407	2098.3	409.96	684	3303
Average temperature(^{0}C)	109407	19.33	1.97	14.09	28.97
Average rainfall(mm)	109407	5.71	2.2	1.34	10.62
Rainfall standard deviation	109407	5.66	1.18	2.13	8.85

Source: Authors' computation using Ethiopian Agriculture Survey data.

** Average travel time in hours to the nearest city at least 50,000 people

Modern Technology Adoption

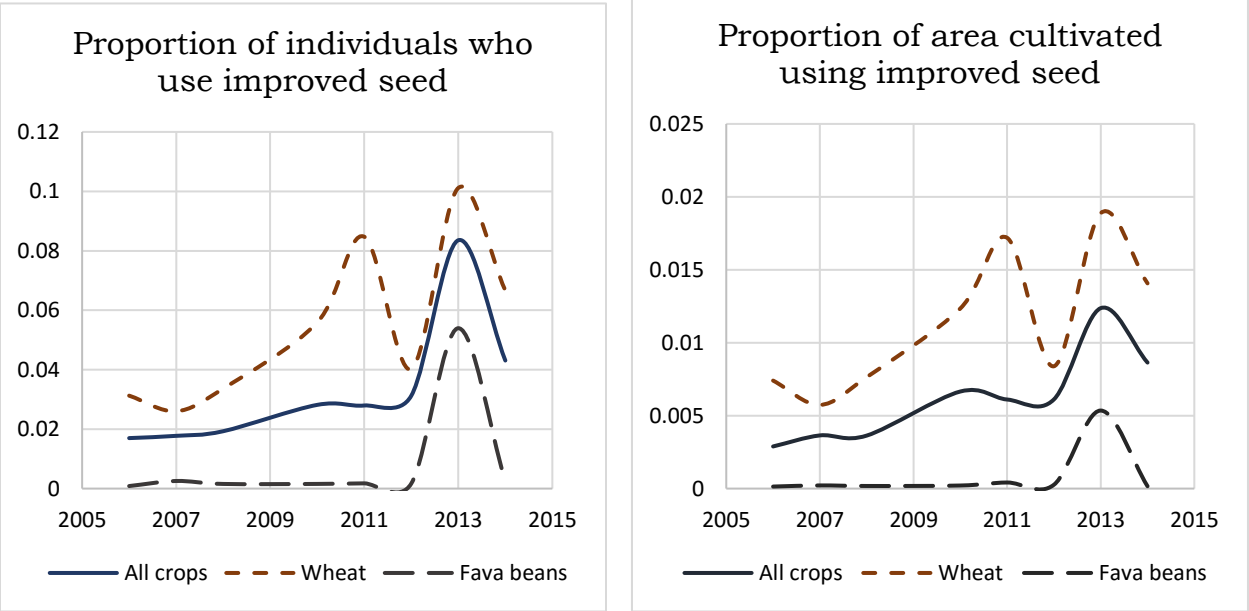
Before we move to the econometric estimation of the determining factors in improved seed and chemical fertilizer use decision, it is instructive to look at some descriptive to have the picture on the adoption of technologies in the country. Thus, this section presents descriptive analysis on the adoption of technologies among the agricultural households over the years. The section separately discusses fertilizer use, seed types, irrigation, and extension services by the type of crops – wheat and fava beans. The section also presents discussion about the implication of adoption on productivity of crops cultivated particularly on wheat and fava beans yield.

Technologies

- **Improved seed**

In the previous section, it is indicated that improved seed is one form of technology that is available and known by agricultural households though the adoption rate is low. According to the data used, the adoption rate has showed a steady increase till 2011 for all the crops and wheat while it was stagnant in fava beans cultivation (see figure 2.1). In 2011 adoption of improved seed has fallen for all crops and has showed rise in the subsequent year which again has dropped in 2014. Improved seed adoption is much better among wheat cultivating holders compared to fava beans cultivators. However, the percentage of improved wheat users is still low even in the pick year of 2013 that only 10 percent users adopted wheat. Proportion of fava beans cultivators with use of improved seed is less than 0.02 percent in all the years considered except 2013 which increased substantially in relative terms. It indicates the low rate of adoption of improved seed in both fava beans and wheat cultivations.

In the analysis, area covered in either of the technologies are calculated to examine the application rate. The right panel of Figure 2.1 reveals similar pattern in the proportion of area cultivated with application of improved seed. The fall in use of improved seed in 2014 may be associated with the Eli-no incident that drastically affected production in the country, however, it needs a careful assessment of the case.



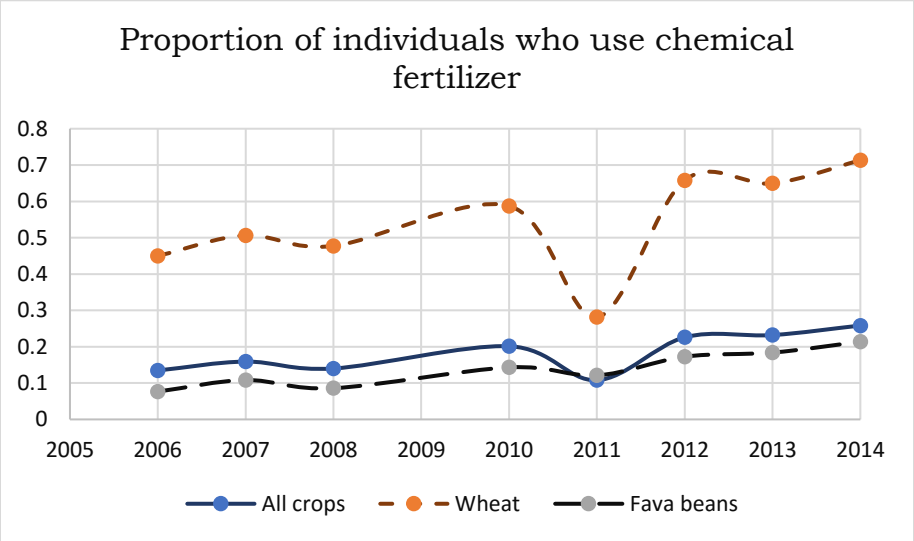
Source: Authors' calculations using Ethiopian Agriculture Sample Survey data.

Figure 2.1 Proportion of improved seed adopters (left) and proportion of land (right) cultivated with improved seed application

- **Chemical Fertilizer**

Chemical fertilizer is also a well-advertised technology by government and other organizations. Adoption rate of chemical fertilizer, when all crops are considered, there is the pattern which

shows a slow growth over the years with only a drop in 2011. After 2011, chemical fertilizer adoption rate has showed somewhat better improvement that around 71 percent of holders used it in wheat cultivation. In the same year, however, it is only about 26 percent and 21 percent holders adopt chemical fertilizers when all crops and fava bean are considered, respectively. Similar to improved seed, larger proportion of wheat cultivators use chemical fertilizers than fava bean cultivators.

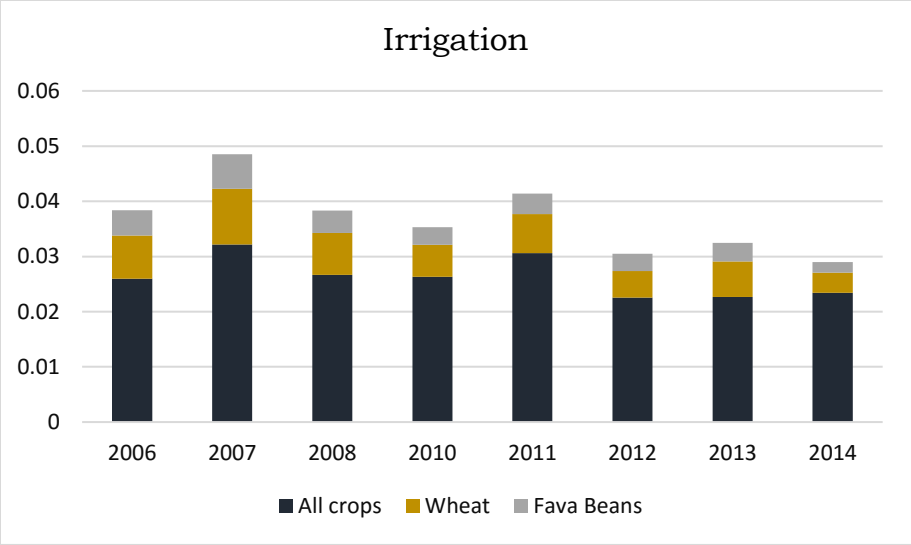


Source: Authors' computation using Ethiopian Agriculture Survey data.

Figure 2.2: Proportion of holders who use chemical fertilizer

- **Irrigation**

Agricultural households mostly produce relying on rainfall. In areas where there is a shortage of rainfall and to enable farmers to produce multiple times in a year, different forms of irrigation structures are introduced by the government. This will increase productivity as the country also faces environmental problem mainly land degradation as a result of soil erosion and nutrient depletion (Gebremedhin and Swinton, 2003; Ketema and Bauer, 2011; Wossen et. al, 2015) which causes low level of agricultural productivity. Figure 2.3 below shows that the proportion of holders who use irrigation is very low below 3 percent at most. Over the years, the proportion of holders that use irrigation for wheat and fava beans cultivation is almost stagnant.

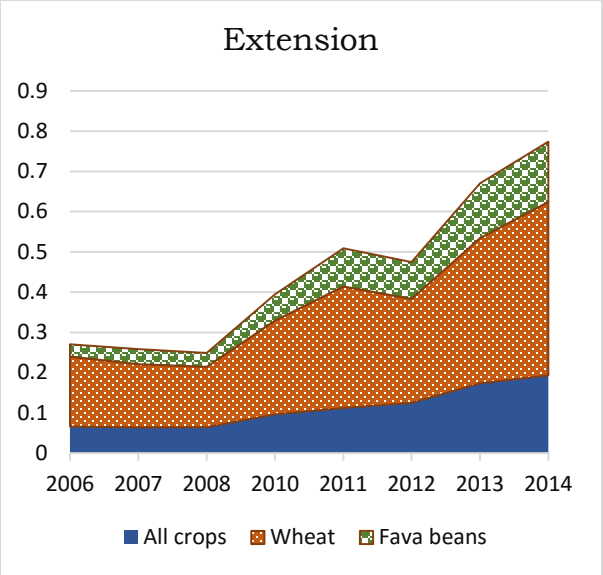


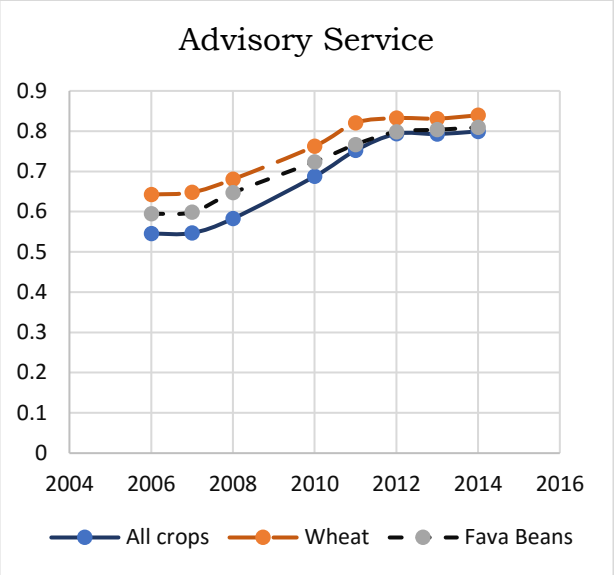
Source: Authors' computation using Ethiopian Agriculture Survey data.

Figure 2.3: Proportion of holders who use irrigation

- **Institutional facilities**

The Agricultural sector, besides land degradation and unexpected short of rainfall, the sector is bogged with social, institutional and environmental problems. Institutional problems like the access to input, markets, credit (Waithaka et. al., 2007) also affect the productivity of the sector. Figure 2.4 shows the proportion of holders that use extension and advisory service. In the years spanning 2006 to 2014 proportion of holders that used extension service has increased by about 13 percent of all holders. The increase in the proportion of holders who use extension service is larger among wheat cultivators which has increased by 25 percent and fava beans cultivators is only 12 percent. Unlike other services, the use of advisory among the holders is significantly large, around 80 percent of them had the access to advisory service in 2014. Comparable percentage of wheat and fava beans cultivating holders also used advisory service (see figure 2.4).

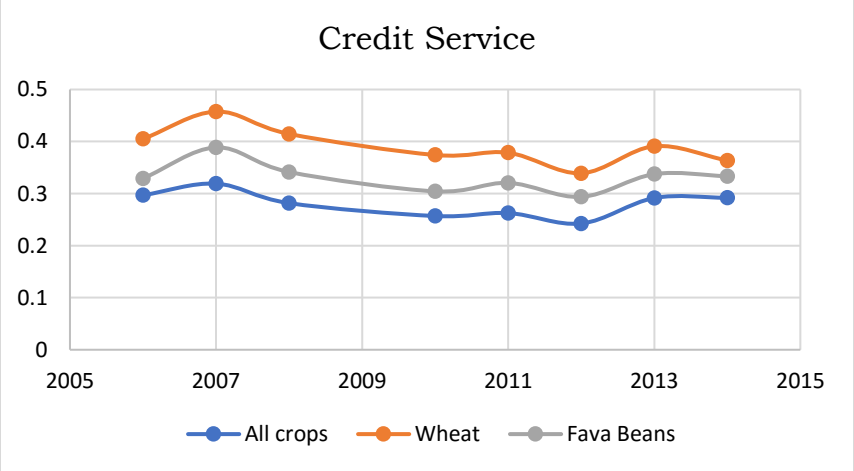




Source: Authors' computation using Ethiopian Agriculture Survey data.

Figure 2.4: Proportion of holders who used extension service or advisory service

Agricultural households though have knowledge and access to technologies, lack of money inhibit them from adopting the technologies. One remedy to alleviate shortage of finance is the provision of credit for such agricultural households. In over all, the access to credit over the years has not showed much improvement. The percentage of holders who had the access to credit in 2006 and 2014 is almost the same around 30 percent of all producers.



Source: Authors' computation using Ethiopian Agriculture Survey data.

Figure 2.5: Proportion of holders who had credit access

Technology complementarity/ correlation

Recognizing the adoption extent of each of the modern technologies separately is important but it is pertinent to examine also the combination of the technologies use. The descriptive statistics indicate in general, holders use low level of mix of the technologies. For instance, the average number of technologies that holder uses when improved seed and chemical fertilizer are

considered is about 0.33, 0.78 and 0.22 in 2014 for all crops, wheat and fava beans, respectively (See Annex 3). The average number of the two technologies over the years have increased marginally. We have also examined the average number of technologies combining improved seed, chemical fertilizer and crop rotation. For these technologies, the average number of mix of the technologies remained almost stagnant till 2011 and increased in subsequent years with a larger number of technologies in 2012.

The descriptive analysis also shows that advisory use and credit access increased the adoption of chemical fertilizer and improved seed among the cultivators. Comparison is made in the proportion of improved seed or chemical fertilizer adopters by use of advisory service and credit. Table 2.3 displays that the proportion of improved seed and chemical fertilizer adopters is higher for those who used advisory service than that did not use. For instance, the proportion of chemical fertilizer users is larger by 8 percent among advisory users than those who used chemical fertilizer without using advisory service for wheat cultivators and it is about 5 percent for fava beans cultivators in 2014.

Table 2.3 Proportion of improved seed and chemical fertilizer users by advisory service and credit use

	Wheat				Fava beans			
	Use advisory service		**no advisory service**		**Use advisory service**		**no advisory service**	
Year	**improved seed**	**Chemical fertilizer**	**improved seed**	**Chemical fertilizer**	**improved seed**	**Chemical fertilizer**	**improved seed**	**Chemical fertilizer**
2006	0.04	0.47	0.02	0.42	0.001	0.073	0.001	0.084
2007	0.03	0.50	0.01	0.52	0.004	0.096	0.001	0.127
2008	0.04	0.47	0.02	0.49	0.002	0.088	0.001	0.083
2010	0.07	0.61	0.02	0.52	0.002	0.150	0.002	0.129
2011	0.09	0.29	0.04	0.27	0.002	0.126	0.002	0.098
2012	0.04	0.68	0.02	0.59	0.002	0.180	0.001	0.148
2013	0.11	0.66	0.05	0.61	0.059	0.191	0.034	0.153
2014	0.07	0.73	0.03	0.65	0.002	0.224	0.003	0.170
	Use credit		**No credit use**		**Use credit**		**No credit use**	
Year	**improved seed**	**Chemical fertilizer**	**improved seed**	**Chemical fertilizer**	**improved seed**	**Chemical fertilizer**	**improved seed**	**Chemical fertilizer**
2006	0.051	0.634	0.018	0.325	0.001	0.135	0.001	0.049
2007	0.037	0.620	0.016	0.411	0.003	0.152	0.003	0.080
2008	0.052	0.574	0.021	0.409	0.002	0.114	0.001	0.072
2010	0.086	0.682	0.038	0.531	0.003	0.208	0.001	0.116
2011	0.110	0.282	0.059	0.290	0.004	0.173	0.001	0.091
2012	0.050	0.730	0.035	0.626	0.002	0.201	0.002	0.162
2013	0.123	0.737	0.087	0.593	0.054	0.252	0.053	0.149
2014	0.089	0.768	0.054	0.682	0.004	0.271	0.002	0.185

Source: Authors' computation using Ethiopian Agriculture Survey data.

We also examined the number of technologies holders adopt by advisory service and credit use. We have looked two technologies, improved seed and chemical fertilizer and the three technologies are the previous two with crop rotation. Table 2. 4 indicate that the average number of technologies adopted by wheat and fava bean cultivators is higher for those who used advisory service and credit. It indicates that advisory service gives them necessary information with technical support in order to use the technologies. Credit also gives the financial access to invest on the available technologies.

Table 2.4 Average number of technologies adopted by credit and advisory service use

	Wheat				Fava Beans			
	Used credit		**No credit use**		**Used credit**		**No credit use**	
Year	**Two technologies**	**Three technologies**	**Two technologies**	**Three technologies**	**Two technologies**	**Three technologies**	**Two technologies**	**Three technologies**
2006	0.686	1.667	0.343	1.284	0.136	1.116	0.050	0.972
2007	0.657	1.635	0.427	1.372	0.154	1.135	0.083	1.023
2008	0.626	1.609	0.429	1.371	0.115	1.090	0.073	0.994
2010	0.767	1.746	0.569	1.510	0.210	1.188	0.117	1.050
2011	0.392	1.377	0.350	1.313	0.177	1.160	0.092	1.040
2012	0.780	1.767	0.661	1.633	0.203	1.192	0.163	1.121
2013	0.860	1.845	0.680	1.639	0.306	1.292	0.203	1.160
2014	0.857	1.845	0.736	1.708	0.275	1.261	0.187	1.142
	Use advisory service		**No advisory service**		**Use advisory service**		**No advisory service**	
Year	**Two technologies**	**Three technologies**	**Two technologies**	**Three technologies**	**Two technologies**	**Three technologies**	**Two technologies**	**Three technologies**
2006	0.507	1.484	0.435	1.358	0.074	1.046	0.085	0.981
2007	0.532	1.505	0.533	1.468	0.099	1.076	0.128	1.052
2008	0.513	1.488	0.507	1.431	0.090	1.056	0.083	0.974
2010	0.674	1.645	0.544	1.447	0.151	1.121	0.130	1.017
2011	0.379	1.356	0.314	1.264	0.128	1.099	0.100	1.018
2012	0.719	1.699	0.615	1.575	0.182	1.164	0.148	1.054
2013	0.768	1.741	0.664	1.616	0.250	1.227	0.187	1.115
2014	0.799	1.780	0.680	1.643	0.226	1.205	0.172	1.082

Source: Authors' computation using Ethiopian Agriculture Survey data.

*The two technologies refers to improved seed and chemical fertilizer and three technologies refers improved seed, chemical fertilizer and crop rotation.

Agricultural technologies by their nature may be complementary or substitutes. In a simple statistical analysis, the correlation between the technologies can be evaluated as presented in Table 2.5. All the correlations are significant, and all exhibit a positive relationship. Particularly there is a strong correlation between chemical fertilizer and improved seed use and extension

service with all the other technologies. The table reveals that though the level of adoption of the mix of the technologies is low, there is a positive correlation among them.

Table 2.5: A pairwise correlation between the technologies

Technologies	Improved seed	Chemical fertilizer	Credit use
Chemical fertilizer	0.193		
Credit use	0.048	0.155	
Advisory use	0.068	0.106	0.215

Source: Authors' computation using Ethiopian Agriculture Survey data

Technology adoption and productivity

This section discusses the yield level of wheat and fava beans producers by comparing between adopters and non-adopters. This enables to understand that yield level improves by using the available technologies.

Table 2.6 presents yield level of wheat and fava beans with and without improved seed. Yield level of both wheat and fava beans in general has increased over the years. However, the yield levels of adopters of improved seed are better than the non-adopters. Likewise, wheat and fava beans yields are 5.4 quintal per hectare and 3.2 quintal per hectare more, respectively, for chemical fertilizer users in 2014. It is not only the yield level are better for improved seed and chemical fertilizer users, the yield level of extension service users also is higher.

Table 2.6 Yield level by improved seed, chemical fertilizer and extension service

	Wheat yield		fava beans yield	
Year (EC)	no improved	Use improved seed	no improved	Use improved seed
2006	14.9	16.7	11.4	12.3
2007	15.1	16.5	13.1	23.6
2008	16.0	16.5	12.6	12.2
2010	17.1	18.8	14.7	16.3
2011	18.2	20.1	14.7	19.3
2012	19.5	21.4	15.9	20.1
2013	21.9	21.9	17.1	16.0
2014	22.4	26.3	17.7	18.3

	No chemical fertilizer	Chemical fertilizer	No chemical fertilizer	Chemical fertilizer
2006	13.5	16.7	11.3	12.6
2007	13.7	16.5	13.0	13.8
2008	14.4	17.7	12.5	13.4

2010	15.4	18.5	14.5	16.0
2011	17.5	20.6	14.4	16.6
2012	17.3	20.8	15.5	17.7
2013	19.5	23.1	16.6	18.8
2014	18.8	24.2	17.0	20.2

	No Extension	**Use Extension**	**No Extension**	**Use Extension**
2006	14.8	15.8	11.4	12.1
2007	14.9	16.3	13.0	14.2
2008	15.8	16.8	12.5	14.5
2010	16.8	18.7	14.7	15.3
2011	18.3	18.5	14.5	16.3
2012	19.1	21.0	15.7	17.2
2013	21.4	22.8	16.8	18.2
2014	21.4	24.4	17.3	19.9

Source: Authors' computation using Ethiopian Agriculture Survey data.

Table 2.7 shows yield level of producers; those who adopt either improved seed or chemical fertilizer or both. The table reveals, yield level of improved seed adopters without application of chemical fertilizers is higher than those who do not use both. The wheat yield levels with both application of improved seed and chemical fertilizer is better than wheat yields with only chemical fertilizer. This Indicates the advantage of using mix of technologies rather than sticking with one. Some technologies will work as a catalyst for other technologies and hence boosts productivity. This emanates from the fact that some technologies are complementary while others are substitutes. Hence, it is important to identify those technologies that go together so that producers get better yield.

Table 2.7: Holders who use improved seed and chemical fertilizers for wheat cultivation

	No fertilizer		**Use fertilizer**	
Year	**No improved seed**	**Use improved seed**	**No improved seed**	**Use improved seed**
2006	13.5	15.6	16.7	17.0
2007	13.7	15.2	16.5	17.0
2008	14.4	14.0	17.7	17.3
2010	15.4	16.3	18.4	19.1
2011	17.3	19.6	20.5	21.1
2012	17.3	16.7	20.7	22.0
2013	19.3	20.9	23.2	22.9
2014	18.8	18.3	24.0	26.8

Source: Authors' computation using Ethiopian Agriculture Survey data.

Econometric Specification

Bivariate probit model

In order to examine the determinants of improved seed and fertilizer adoption decision, the most common method of evaluation is using univariate probit models or logit model. However, estimation of the decision to use improved seed and chemical fertilizer separately ignores the correlation between the decisions on adoption of the technologies- that is, the correlation of the error terms. The bivariate probit model allows a correlation between corresponding error terms by applying a pair of binary variables provides unbiased and efficient estimate (Belderbos et al., 2004, Kassie et al., 2009 and Lin et. al., 2005). Allowing the correlation between the two univariate probit equations captures the unobserved characteristics of agricultural households that influence their decision to adopt.

The bivariate probit in terms of latent variables is given as:

$y_{ji}^{*} = x_{ji}\beta_j + \varepsilon_j \quad , \; j = F, I$ which represents chemical fertilizer and improved seed

$i =$ refers the i^{th} household

where,

$$y_{ji} = \begin{cases} 1 & if \;\; y_{ji}^{*} > 0 \\ 0 & Otherwise \end{cases}$$

That is the dependent variable captures whether the household adopts improved seed and/or chemical fertilizer. The dependent variable y_{Ii} have a value of 1 if the i^{th} household adopts improved seed and 0 if otherwise. Likewise, the dependent variable y_{Fi} takes the value 1 if the i^{th} household adopts chemical fertilizer and 0 if otherwise. The x_{ji} are vectors of exogenous variables which include demographic, community level characteristics and agro-ecology identifiers. The error terms are assumed to be distributed as bivariate normal distribution each with mean or zero and variance covariance matrix Ω, that is $(\varepsilon_1, \varepsilon_2) \sim N(0, \Omega)$ which allows the inter-relationship in adoption decision making of chemical fertilizer and improved seed.

The covariance matrix is given as:

$$\Omega = \begin{bmatrix} 1 & \rho_{IF} \\ \rho_{FI} & 1 \end{bmatrix}$$

In the bivariate probit model there are four possible outcomes. First, there is a possibility that a household adopt both improved seed and chemical fertilizer. Second and third possibilities are adoption of only improved seed and only chemical fertilizer, respectively. The last option is the non- adoption of both technologies.

The possibility of writing the probability of the four outcomes as a function of the explanatory variables and the unknown parameters using the assumption that the error terms are distributed normally with mean zero and covariance matrix Ω allows the model to be estimated using maximum likelihood method.

The maximum likelihood estimation of the bivariate probit model is provided in Green (2003). For the given model above, the cumulative probability of the bivariate probit model with the joint distribution of two normally distributed variables is given as:

$$Prob(X_F < x_F, X_I < x_I) = \int_{-\infty}^{x_I}\int_{-\infty}^{x_F} \phi_I(z_F, z_I, \rho) dz_F dz_I = \Phi_I(x_F, x_I, \rho)$$

Where, ρ is the correlation between chemical fertilizer and improved seed.

The corresponding probability density function is:

$$\phi_I(x_F, x_I, \rho) = \frac{e^{*(1/2)(x_F^2 + x_I^2 - 2\rho x_F x_I)/(1-\rho^2)}}{2\pi(1-\rho^2)^{1/2}}$$

Where Φ_I and ϕ_I are bivariate normal cumulative distribution function and the probability density function, respectively.

Then, the likelihood function will be:

$$Prob\big(Y_F = y_{Fi,} Y_I = y_{Ii} \big| x_F, x_I\big) = \Phi_I(w_{Fi}, w_{Ii}, \rho_i)$$

With the corresponding maximum likelihood function:

$$logL = \sum_{i=1}^{n} ln\Phi(w_{Fi}, w_{Ii}, \rho_i)$$

Where, $q_{1i} = 2y_{Fi} - 1, q_{Ii} = 2y_{Ii} - 1$, for $j = F, I$; when $y_{ji} = 1$, then $q_{ji} = 1$; when $y_{ji} = 0$, then $q_{ji} = -1$.

z_{ji}, w_{ji} *and* ρ_i are defined as $z_{ji} = x'_{ji}\beta_j$, $w_{ji} = q_{ji}z_{ji}$ and $\rho_i = q_{1i}q_{2i}\rho$

The above given distribution is independent if the Wald test of $\rho = 0$ is insignificant. In such a case, the decision about improved seed and chemical fertilizer is independent that separate estimation of univariate probit for each technology which will provide unbiased and efficient estimates.

The bivariate model has covariates that capture household characteristics, woreda characteristics and agro-ecological factors. Demographic characteristics like holder age, sex, education level and household size are used while woreda level characteristics like population density and time to the nearest town are used. Beside these variables, average temperature, average rainfall average elevation at woreda level are also included to control for the agro-ecological effects.

Household head age implication on adoption of technologies is mixed. The argument is elder household heads accumulate more experience and also have more information, and hence,

increases the likelihood and intensity of using agricultural technologies (Adesina and Baidu-Forson, 1995; Nkamleu and Adesina, 2000 and Challa and Tilahun, 2014). On contrary, elder household heads may resist to resort to new modern agricultural technologies as they have already accumulated experience of farming throughout their life (Akudugu *et. al*., 2012). Young household heads may be better in adopting agricultural technologies as they are relatively risk takers (Zhou *et. al*., 2010,) and older farmers are risk averse (Adesina and Baidu-Forson, 1995).

In most developing countries women are marginalized section of the society who are deprived of access to information and particularly access to new technologies (Meinzen-Dick et. al., 2011 and Nkamleu and Adesina, 2000). Hence, male headed households tend to adopt more agricultural technologies than female headed ones. In addition to the lack of information and access, women also spend their time in taking care of the household members than engaging in the agricultural activities (Martey et. al., 2014). Such households, furthermore, tend to have less labor within the household which puts a pressure on decision to use modern technologies (Ndiritu et. al., 2014). On the other hand, Men are the major decision makers on agriculture and productive agricultural assets in developing countries (Akudugu *et. al*., 2012). Hence, it is expected that male heads are more likely to embrace modern agricultural technologies than women headed households.

Availability of labor also affects the adoption of technologies as some of the technologies are labor intensive (Waithaka et. al., 2007). In this study, household size is used as proxy of availability of labor (Doss and Morris, 2001).

Education is considered to be associated with technology adoption positively as it makes households to understand the technologies use and to easily adopt the technologies (Teklewold et. al., 2016). The problem in rural settings is the prevalence of illiteracy or low level of education which create difficultly in understanding the effect of education. However, in studies like Minten and Barret (2008), it is found that though there is low level of education, there is significant effect of additional level of education on the adoption probabilities of households.

Lack of financial capabilities besides the availability of information is also a factor for determining the decision to adopt. Credit access by households intends to fill the financial gap they face and hence have a positive implication on the probability of adoption.

Market access may also affect the decision to adopt, hence, distance to the nearest town which implicitly captures access to market can be used as a proxy. It is clear that the farther away is the distance to the nearest town, the less likely to adopt the technologies.

Yield equation

The study has also intended to examine the impact of adoption of modern agricultural technologies on yield level. In order to see that a Cobb-Douglas yield equation will be estimated controlling for socio-economic, demography and agro-ecology variables.

$$lnY = \beta_0 + \beta_0 x_i + \beta_2 z_i + \varepsilon_i$$

The dependent variable is yield of wheat/fava bean in logarithmic form. The x_i variables capture demographic variables while z_i are agro-ecology variables. Estimation is done by taking zonal level fixed effect.

Results and Discussion

Bivariate probit model result

The decision on adoption of agricultural technologies is not only confined to the characteristics of the household itself. The decision can be affected by the socio-economic conditions and physical environment besides the household characteristics. These different factors are used a control in estimation of bivariate probit model. The log-likelihood ratio test rejects the null hypothesis that the error terms across equations are not correlated. This confirms the appropriateness of bivariate probit estimation than univariate probit estimation. The Wald test is significant that rejects the hypothesis of all coefficients are jointly zero that makes the model suitable for the data set.

The result indicate that the likelihood of adopting chemical fertilizer decreases with age confirming the argument by (Zhou *et. al*., 2010 and Akudugu *et. al*., 2012). That is, the likelihood of adoption of technologies is better among young producers. The result further show that the coefficient of household size is positive, implying households with larger household size leads to higher probability of improved seed and chemical fertilizer adoption. This might be due to the need of labor for applying technologies (Waithaka et. al., 2007).

The other factor in adoption decision of improved seed and chemical fertilizer is the total land size the producer cultivates. Land size is found to be positively associated with the probability of adoption of chemical fertilizer for both crops. Land size also have a non-linear relationship with probability chemical fertilizer adoption. Producers with large land size have a lower likelihood of adoption of chemical fertilizer in both wheat and fava beans cultivation. The land size effect is the reverse in decision making likelihood of adoption of improved seed.

Besides the household characteristics, extension service and positively affects the likelihood of adoption improved seed and chemical fertilizers. In addition, advisory service increases the likelihood of adopting improved seed but the result is insignificant for chemical fertilizer.

Households' access to information and the access to the technologies also affect the adoption decision of households. Producers can get information from extension service and advisory services. Extension service and advisory service are significant in case of improved seed adoption in both wheat and fava beans cultivation. However, it is only extension service that is significant in case of chemical fertilizers for both crops. Further, households with credit access have a better likelihood of adopting both technologies in both crops cultivation.

Households' access to technologies is affected by their access to markets of integration with towns. In the analysis, the time it takes to reach the nearest town is considered. The coefficient of distance to the nearest town is negative and significant; households' likelihood of adoption decreases the further away they are from towns. As noted by Moshi et. al., (2016) is farther

households from towns face the difficulty of accessing information and inputs and hence low likelihood of adoption.

Table 2.8: Bivariate probit estimation of improved seed and chemical fertilizer adoption in wheat production

Variables	Chemical fertilizer			Improved seed		
	Coef.	Robust Std. Err.	Marginal effect	Coef.	Robust Std. Err.	Marginal effect
Household size	0.012***	0.002	0.018	0.035***	0.003	0.007
Holder education	0.026***	0.001	0.039	0.033***	0.002	0.006
Credit use	0.372***	0.007	0.560	0.244***	0.012	0.045
Advisory use	0.160***	0.009	0.241	0.324***	0.017	0.06
Crop rotation	0.218***	0.019	0.328	0.05	0.035	0.009
Holder age(log)	-0.127***	0.011	-0.191	-0.049**	0.018	-0.009
Holder sex (1=male)	-0.123	0.01	-0.186	-0.076	0.017	-0.014
Irrigation	-0.03	0.042	-0.045	0.450***	0.054	0.084
log land size(hectare)	0.331***	0.027	0.498	-0.100*	0.04	-0.019
log land size squared(hectare)	-0.055***	0.011	-0.082	0.045**	0.017	0.008
Population density	0.000	0.000	0.000	0.000	0.000	0.000
Average travel time	-0.097***	0.002	-0.146	-0.015***	0.003	-0.003
Average elevation	-0.000***	0.000	0.000	-0.000*	0.000	0.000
Average temperature	-0.397***	0.026	-0.599	-0.089*	0.037	-0.016
Average temperature squared	0.006***	0.001	0.009	0.002*	0.001	0.000
Average rainfall	-0.257***	0.017	-0.387	0.061*	0.027	0.011
Average rainfall squared	0.007***	0.001	0.010	-0.006**	0.002	-0.001
Rainfall standard deviation	0.133***	0.008	0.200	-0.035*	0.015	-0.006
Year (base=1999)						
Year_2000	-0.026	0.014	-0.040	-0.087**	0.027	-0.016
Year_2001	-0.094***	0.014	-0.142	0.04	0.026	0.007
Year_2003	0.345***	0.014	0.520	0.272***	0.024	0.051
Year_2004	-0.631***	0.015	-0.950	0.451***	0.024	0.084
Year_2005	0.490***	0.014	0.738	0.105***	0.025	0.019
Year_2006	0.518***	0.014	0.780	0.385***	0.024	0.072
year_2007	0.681***	0.014	1.025	0.347***	0.023	0.065
Region (Base= Tigray)						
Amhara	-0.333***	0.014	-0.501	-0.162***	0.022	-0.03
Oromia	0.194***	0.016	0.292	-0.229***	0.025	-0.043
SNNP	0.310***	0.021	0.467	0.107***	0.032	0.02
Constant	5.913***	0.281	0.000	-1.033*	0.402	0

Number of observations = 107038			
Log pseudo likelihood = -35647.49		Prob > chi2 = 0.0000	
Wald test of rho=0:	chi2(1) = 4.85281	Prob > chi2 = 0.0276	

***, ** and * refers to 1%, %5 and 10% level of significance

The effect of rainfall variability captured by standard deviation of rainfall have significant effect though the sign is not the same for wheat and fava beans. Rainfall variability increases the probability of adoption improved seed adoption in wheat cultivation while it decreases probability of adoption in fava beans cultivation. However, the result is in the same direction for both crops that rainfall variability increases the likelihood of adopting chemical fertilizer unlike Teklewold et at (2016) who found that rainfall variability decreases the likelihood of adoption of fertilizer. Finally, over the years, the likelihood of adoption of the two technologies has increased. This indicates the progress made so far and the change in the decision making of the producers.

Table 2.9: Bivariate probit estimation of improved seed and chemical fertilizer adoption in fava beans production

Variables	Chemical fertilizer			Improved seed		
	Coef.	Robust Std. Err.	Marginal effect	Coef.	Robust Std. Err.	Marginal effect
Household size	0.034***	0.001	0.012	0.078***	0.0005	0.005
Holder education	0.019***	0.001	0.006	0.032***	0.0003	0.002
Credit use	0.312***	0.004	0.106	0.038	0.002	0.002
Advisory use	0.130***	0.004	0.044	0.228***	0.003	0.013
Holder age(log)	-0.122***	0.006	-0.041	-0.246***	0.004	-0.014
Holder sex (1=male)	-0.104	0.005	-0.036	-0.044	0.003	-0.003
Irrigation	0.444***	0.026	0.15	0.512*	0.012	0.03
log land size(hectare)	0.008	0.004	0.003	0.198***	0.002	0.012
Population density	0.000***	0.000	0.000	0.000***	0.000	0.000
Average travel time	-0.491***	0.004	-0.166	-0.053	0.002	-0.003
Average elevation	-0.216***	0.013	-0.073	-0.048	0.008	-0.003
Average temperature	-0.954***	0.028	-0.322	-0.513	0.015	-0.03
Average rainfall	0.206***	0.013	0.07	0.075	0.009	0.004
Rainfall standard deviation	-0.131*	0.02	-0.044	-0.502*	0.012	-0.03
Year (base=1999)						
Year_2000	0.175***	0.008	0.059	0.370**	0.007	0.022
Year_2001	0.047*	0.008	0.016	0.198	0.007	0.012
Year_2003	0.328***	0.008	0.111	0.168	0.007	0.01
Year_2004	0.233***	0.008	0.079	0.16	0.007	0.009
Year_2005	0.515***	0.008	0.174	0.145	0.007	0.009
Year_2006	0.565***	0.008	0.191	1.121***	0.006	0.066
year_2007	0.665***	0.008	0.225	0.313**	0.007	0.018

Region (Base= Tigray)						
Amhara	-0.206***	0.008	-0.07	-0.183*	0.005	-0.011
Oromia	-0.156***	0.01	-0.053	-0.195*	0.006	-0.011
SNNP	-0.183***	0.011	-0.062	0.06	0.006	0.004
Constant	3.740***	0.5		-0.421	1.598	
Number of observations = 107038						
Log pseudo likelihood = -35647.49			Prob > chi2 = 0.0000			
Wald test of rho=0:		chi2(1) = 6.08639	Prob > chi2 = 0.0136			

***, ** and * refers to 1%, %5 and 10% level of significance

Yield estimation result

Once we see the determinants in adopting improved seed and chemical fertilizers, we opt to investigate the effect of adopting these modern technologies on the productivity of wheat and fava beans. Table 2.7 presents a production function estimation to explore the correlation of improved seed and chemical fertilizer adoption on yield levels of wheat and fava beans.

Theories and experiments indicate a modern agricultural technologies improve yield level. In this study by using a yield equation it is observed that wheat yield level increases by about 5.1 percent and 3.5 percent for those who use chemical fertilizer and improved seed, respectively. Besides the use of technologies, the land size the household owns determine the yield level that households with very large land size have a higher level of yield compared to small sized land owners. This might be the case that households with large land size are relatively in a better wealth level and are capable of investing in technologies and are less risk averse. In addition, elder holders have better yield than the young ones as shown by the age and age squared variables which might be due to the experience in farming.

The fava beans yield level estimation result indicate that it is only chemical fertilizer use that has significant result on yield increasing it by 4.6 percent. The other important variables have similar effect on fava beans yield level as wheat yield estimation.

Table 2.10: Ordinary least square estimation of Cobb-Douglas yield equation

	Wheat		Fava Beans	
Yield(log)	**Coef.**	**Robust Std. Err.**	**Coef.**	**Robust Std. Err.**
Household size	0.00	0.001	0.001	0.001
Holder education	0.002***	0.000	0.00	0.0000
Holder age(log)	-0.122**	0.056	0.189**	0.073
Holder age squared(log)	0.016**	0.007	-0.025**	0.01
Holder sex (1=male)	-0.003	0.003	0.002	0.004
Extension	0.037***	0.003	0.039***	0.005
Irrigation	-0.004	0.013	0.002	0.021
use fertilizer (1=yes)	0.051***	0.003	0.046***	0.004
use improved seed (1=yes)	0.035***	0.005	-0.03	0.022
Credit use	-0.008***	0.002	0.001	0.003
Advisory use	0.018***	0.003	0.006	0.003
log land size(hectare)	-0.122***	0.007	-0.051***	0.009
log land size squared(hectare)	0.043***	0.003	0.018***	0.004
Population density(log)	0.019***	0.003	-0.03***	0.005
Average travel time (log)	-0.01***	0.001	-0.006***	0.001
Average elevation(log)	0.014	0.009	0.155***	0.011
Average temperature(log)	-0.279***	0.02	0.178***	0.029
Average rainfall(log)	-0.076***	0.014	0.066***	0.018
Rainfall standard deviation(log)	0.093***	0.017	0.025	0.022
Year(EC) (base=1999)				
Year_2000	0.021***	0.004	0.117***	0.005
Year_2001	0.063***	0.004	0.115***	0.005
Year_2003	0.1***	0.004	0.211***	0.006
Year_2004	0.178***	0.005	0.205***	0.006
Year_2005	0.185***	0.004	0.26***	0.005
year_2006	0.314***	0.004	0.321***	0.005
Year_2007	0.342***	0.004	0.364***	0.006
Zone Fixed Effect	Yes			
Constant	3.536***	0.161454	0.361**	0.197
Number of observations	= 157484		107035	

Conclusion

Improving productivity of the agriculture sector is key to ameliorate food security and improve welfare of the people of Ethiopia. Productivity gain is achieved through practice of modern agricultural technologies as the available land size is limited and there is no possibility to increase the size. Farmer's adoption decision of modern agricultural technologies is affected by different factors emanating from the household characteristics to the institutional factors. This study examined determining factors of adoption of improved seed and chemical fertilizer use by using Ethiopian Agriculture Sample Survey data of eight years.

The analysis indicates that there is a very slow growth in adoption rate among the agricultural households. The percentage of wheat and fava beans producers who adopt chemical fertilizer and improved seed is not significant though there is slight increase over the years. However, there is a significant increase in use of extension service and also significant share of the producers use advisory service. The result has confirmed the low adoption of agricultural technologies. Thus, it is valid to design different strategies to disseminate the technologies and encourage farmers to adopt more. This is possible through extension service and advisory service as majority of producers have access to such services.

In the study we found that there is productivity gain among those who adopt the technologies shown by higher wheat and fava beans yield levels of adopters. Not only use of a single technology, use mix of technologies improves yield better than the single technologies. The study has found the yield level of adopters of both improved seed and chemical fertilizer have higher yield than those who adopt only one of the technologies.

The bivariate probit estimation results of the study revealed demographic factors like gender, level of education and age of producer affects the likelihood of adopting improved seed and chemical fertilizers. The likelihood of adoption of the technologies are lower for older producers and producers with low level of education. Farm land size has a mixed result for the two technologies. A larger land size decreases the likelihood of using chemical fertilizer while it increases the likelihood of using improved seed. Moreover, institutional factors like extension and advisory service also plays a role on adoption decisions. This indicates the vitality of information for producers in the adoption decision.

The examination of the effect of modern technologies adoption on wheat and fava beans yield revealed that chemical fertilizer, improved seed, extension service, advisory service and crop rotation enhance both wheat and fava beans yields.

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