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IMPACT OF IMPROVED WHEAT TECHNOLOGY ADOPTION ON PRODUCTIVITY AND INCOME IN ETHIOPIA

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ABSTRACT

Wheat (*Triticum aestivum* L.) is one of the most important cereal crops cultivated in wide range of agro-ecologies in Eastern Africa. However, wheat productivity has remained low. This study was carried out in Ethiopia Aris Zone to determine the level and impact of adoption of improved wheat varieties on wheat productivity and farm income level of wheat producers in the country. The study employed the propensity score matching method to carry out the impact study. It was found out that the rate of adoption of improved wheat varieties in 2013 was 56%. Probit model showed that sex of household headship and livestock ownership enhanced adoption of improved varieties, while the educational level of the household head negatively affected in enhancing the adoption of improved wheat varieties. According to the result of the propensity score matching method, improved wheat variety adoption on average increased wheat productivity of adopters by about 1 to 1.1 t ha^{-1} than the non-adopters. Similarly, the result of the propensity score matching estimates showed that the average income of adopters was 35 to 50% greater than the non-adopters.The results provide empirical evidence that agricultural technology adoption can contribute to improving productivity and raising income of farm households.

Key Words: Adoption, Probit and Propensity Score Matching, *Triticum aestivum*

RÉSUMÉ

Blé (*Triticum aestivum* L.) est l'une des cultures de céréales les plus importantes cultivées dans une large gamme de produits agro-écologiques en Afrique orientale. Cependant, la productivité du blé est restée faible. Cette étude a été réalisée en Ethiopie Aris Zone pour déterminer le niveau et l'impact de l'adoption de variétés améliorées de blé sur la productivité du blé et au niveau des producteurs de blé dans le pays du revenu agricole. L'étude a utilisé la méthode score de correspondance de propension à mener à bien l'étude d'impact. Il a été constaté que le taux d'adoption de variétés améliorées de blé en 2013 était de 56%. modèle Probit a montré que le sexe du chef de famille et la propriété de l'élevage amélioré l'adoption de variétés améliorées, tandis que le niveau d'instruction du chef de ménage affecté négativement dans l'amélioration de l'adoption de variétés améliorées de blé. Selon le résultat de la méthode score de correspondance de propension, l'amélioration du blé variété adoption sur la productivité moyenne du blé a augmenté des adoptants d'environ 1 à 1,1 t ha^{-1} que les non-adoptants. De même, le résultat des estimations d'appariement des scores de propension a montré que le revenu moyen des adoptants est de 35 à 50% plus grand que les résultats non-adopters.The fournir des preuves empiriques que l'adoption de la technologie agricole peut contribuer à améliorer la productivité et l'augmentation du revenu des ménages agricoles.

Mots Clés: Adoption, Probit et Propensity Score Matching, *Triticum aestivum*

INTRODUCTION

Wheat (*Triticum aestivum*) is one of the most important cereal crops cultivated in wide range of agro-ecologies in Eastern Africa. However; wheat productivity has remained low (Zerihun *et al*., 2014). This is attributed to the low adoption of currently released improved wheat varieties. For instance, according to a study by (Doss *et al.,* 2003) in East Africa on adoption of improved maize and wheat technologies, many farmers in the region were using improved seed, which was recycled and come from old varieties, especially in Ethiopia and Tanzania. Thus, not all of the benefits of improved wheat varieties were being realised.

In Ethiopia, wheat is the fourth most important cereal crop cultivated after Teff, maize and sorghum; and the third in production after maize and Teff and about 4.7 million farm households are directly dependent on wheat production (CSA, 2013/4).

Wheat has been recognised as a strategic food security crop in the country's attempt to bridge the persistent food gap. It contributes 16% of the kilo calorie requirement for an individual per day (FAOSTAT, 2011). Cognizant of its importance, the government of Ethiopia has been investing heavily in the development and dissemination of improved wheat technologies. Over the past years, a number of wheat technologies were developed and promoted for different agro-ecological zones of the country.
However; in recent years the productivity of wheat is significantly reduced by the occurrence of yellow (stripe) and stem rusts (Mesay *et al*., 2013). Those varieties released as rust resistant are now kicked out of the production. For instance in 2010 cropping season, yellow rust epidemics devastated wheat production areas of the country causing a major yield loss.

In an effort to improve wheat productivity and reduce the effect of wheat rust disease, many stakeholders were engaged in promoting and popularisation of newly released improved wheat varieties. This was done along with recommended wheat production in various wheat-growing regions of Ethiopia. However, the impact of these technologies on farmers' livelihoods has not been determined and documented, yet information on the impact of adoption of improved wheat technologies is imperative for targeting interventions efficiently and equitably.

Different studies in Ethiopia show the positive impact of agricultural technologies on the livelihood outcomes. For instance, a study by Shiferaw *et al.* (2014) the impact of improved wheat varieties on food security in Ethiopia found that adoption can increase food security. Another study on the impact of improved maize varieties on food security in Ethiopia showed the positive impact of adoption of improved maize varieties on food security (Moti *et al*., 2015).

The objective of the study was to determine the level and impact of adoption of improved wheat varieties on wheat productivity and farm income level of wheat producers in the country.

MATERIALS AND METHODS

Description of the study area. This study was conducted in the three districts of Arsi zone namely Arsi-robe, Digelu-tijo and Hetosa Districts in Ethiopia. Arsi Robe, Digelu-Tijo and Hetosa are located from 8.4N to 8.6N and 40.1E to 40.4E; from 8.01N to 8.15N and 39.15E to 39.3E; and 7.04N to 7.06N and 39.02E to 39.04E, respectively.

Multi stages purposive and sampling techniques were used for data collection. At the first stage, Arsi-robe, Digelu-tijo and Hetosa districts were purposively selected based on wheat production potential and presence of wheat technology interventions. At the second stage, two Kebeles were randomly selected from each district and accordingly, six Kebeles were selected and used for the survey. Two sampling frames, using lists of household heads (HH) with in the Kebele, one for female headed household and the other for male headed households, were obtained.
The probability proportional to sample size technique was then performed to ultimately select a sample of 177 farmers. Sample size was determined by considering the financial constraints, and other resources availability. Overall, the sample consisted of 122 male-headed and 55 female-headed households.

Data analysis. We first used the probit regression model to estimate the determinants of adoption of improved wheat varieties and the propensity scores. After estimating the propensity score estimates, matching of observations from the treated and control groups was carried out based on their propensity scores. The effect of adoption of improved wheat varieties on productivity and income of farm households, were estimated through the two different matching methods, i.e., the nearest neighbour and the kernel-based matching methods. Ultimately, a balance test was conducted to compare the similarities of the sub-sample of control cases with the treated cases.

Descriptive statistics. A farmer was defined as an adopter if he or she was found to be growing any improved wheat variety. Thus, a farmer could be classified as an adopter, if he/she alloted at least one hectare for growing improved wheat varieties. Descriptive statistics were used to analyse and compare the socio economic characteristics and institutional variables, between adopters and non-adopters.

Propensity Score Matching Model. In observational studies, it is often not feasible to conduct a randomised controlled experiment for estimating the causal effect on a programme or intervention. But in observational study designs, selection bias becomes a problem since it is difficult to obtain a comparison group equivalent to the group of exposed or treated individuals.

Hence, Propensity Score Matching (PSM) is used for approximating a randomised experiment and reducing the selection bias in observation studies. On average, individuals with same propensity score are balanced on covariates, and the counterfactual (the result for the treated observations if they were instead not treated) can be estimated within that group.

The propensity score is the conditional (predicted) probability of receiving treatment given the relevant controls X (Rosenbaum and Rubin, 1983). It can be expressed as:

$$P(X) = Pr[D = 1/X] = E[D/X] \text{ .... Equation 1}$$

Where:

D = [0,1] is the indicator of exposure to treatment and X is the multi-dimensional vector of pre-intervention characteristic. D=1 for treated observations and D=0 for control observations. The propensity scores are estimated using the probit or logit models with dependent variable coded as 1 for rust resistant wheat varieties adopters and 0 for non-adopters of rust resistant wheat varieties. The propensity score is a single-index variable that summarises pre-treatment characteristics of each subject, which makes matching possible.

After the propensity score is estimated, the average treatment effect on the treated (ATT) can then be estimated as follows:

$$\mathrm{ATT} = \mathrm{E}\{\boldsymbol{Y_i^1} - \boldsymbol{Y_i^0} | \boldsymbol{D} = \boldsymbol{1}\},$$

$$\boldsymbol{ATT} = \boldsymbol{E}[\boldsymbol{E}\{\boldsymbol{Y_i^1} - \boldsymbol{Y_i^0} | \boldsymbol{D_i} = \boldsymbol{1}, \boldsymbol{p}(\boldsymbol{X})\}]$$

$$\boldsymbol{ATT} = \boldsymbol{E}\big[\boldsymbol{E}\{\boldsymbol{Y_i^1} | \boldsymbol{D_i} = \boldsymbol{1}, \boldsymbol{p}(\boldsymbol{X})\} - \boldsymbol{E}\{\boldsymbol{Y_i^0} | \boldsymbol{D_i} = \boldsymbol{0}, \boldsymbol{p}(\boldsymbol{X})\} | \boldsymbol{D} = \boldsymbol{1}\big]$$

.... Equation 2

$\boldsymbol{Y_i^1}$ and $\boldsymbol{Y_i^0}$ are the potential outcomes in the two counterfactual situations of (respectively) treatment and no treatment.

Once the propensity scores are estimated, each adopter is matched to a non-adopter with similar propensity score values, in order to estimate the average treatment effect for the treated (ATT). Several matching methods developed to match adopters with non-adopters of similar propensity scores. Asymptotically, all matching methods should yield the same results. The three commonly used matching algorithms (nearest neighbour matching, kernel-based matching and radius matching) were employed. In this study we employed the nearest neighbor matching and kernel-based matching.

Dependent and independent variables for estimating Propensity Score matching. In computing the propensity score matching, in this study we used the as independent variables Age, Education, Farming experience, Household head sex, Family size, Off-farm income, land fragmentation, Livestock ownership, Access to credit, and wheat disease. As a dependent variable we used improved wheat varieties adoption.

Outcome variables for the impact analysis. Wheat productivity and farm household income have been used to estimate the impact of improved wheat varieties. Wheat productivity is the wheat production obtained from one hectare. While farm income is the total income from the farm activities. We used the farm income as proxy measure for the poverty.

RESULTS AND DISCUSSION

Descriptive statistics. The average age of the household head was 43 years, which had been involved in farming for about 25 years (Table 1). The average family size was 6.5 persons and the number of livestock owned (including cattle, sheep, goat, donkey, horse, mule and poultry) was 27 for adopters and 20 for non-adopters, i.e there was a difference in livestock numbers between adopters and non-adopters. Livestock ownership is a proxy measure for asset ownership. Therefore, according to the study results, the more assets a farmer owned the more likelihood to adopt improved wheat varieties. Similarly, the average farm size was statistically different between adopters and non-adopters (10% significance level) implying the importance of farm size in adoption of improved wheat varieties.

Farmers who did not grow improved wheat varieties (non-adopters) were significantly better educated than the adopters by having one additional year of schooling on average. The extension officers may have played a significant role in sensitising farmers about the benefits of improved wheat varieties. Similar findings were reported previously in China (Lin, 1990), Afghanistan (El-Beltagy *et al.,* 2002) Kenyan (Mussei *et al.,* 2001), Ethiopia (Zegeye *et al.,* 2001) and others (Nguezer *et al.,* 2011). Informal education was also the driving force for dissemination of information about new varieties (Heisey *et al.,* 1990). Informal education may be as important as and sometimes more important than formal education in determining the rates of adoption. Mussei *et al*. (2001) found that information from other farmers was the most influential factor for production or adoption decisions followed by extension visits.

The samples were composed of both male and female-headed households (Table 2). The proportion of male-headed households was 42% for adopters and 26% for non-adopters. The female-headed households were 14% for adopters and 18% for non-adopters. The percent of male-headed households of adopters of wheat were significantly higher than that of female-headed households. This could be attributed to various reasons related to the economic or social status of female-headed households, such as shortage of labour, limited access to information and required inputs. In congruent with the finding, Tesfaye *et al*. (2015) in Ethiopia concluded that there were gender gaps in land ownership, family size, asset ownership and farm income in agricultural production.

TABLE 1. Characteristics of adopters and non-adopters of improved wheat varieties in Ethiopia

Variable	Adopters (%) Mean	Non-adopter (%) Mean	Difference	t-value
Age	43.21	42.96	0.25	0.14
Farming experience	25.61	25.08	0.53	0.30
Total family size	6.45	6.79	-0.34	0.83
Livestock ownership	27.26	20.47	6.79	2.96***
Farm size (ha)	2.51	2.16	0.35	1.34*
Education	3.91	5.08	-1.17	-2.32**

***,* indicates significant at 1 and 10%

The descriptive results (Table 2) also revealed that out of the total adopters, 23% participated in off-farm activities; while 22% of the non-adopters participated in off-farm activities. However, no significant differences (x^2 =1.3) were found between adopters and non-adopters in terms of participation in off-farm activities. Both adopters (44%) and non-adopters (36%) reported that they had access to credit services for crop and livestock production whenever the need arose. The result shows the low credit access in the study area for crop and livestock production activities.

Determinants of adoption of improved wheat varieties. The results of the Probit Model (Table 3) revealed that four factors were significant in influencing farmers' decision to adopt improved wheat varieties. Education of the household head, sex of household head, livestock ownership and occurrence of wheat diseases in wheat fields were important variables that had an effect on the likelihood of farmers to adopt.

The effect of education level of household head on improved varieties was negative. The result is against our expectations. This implies that the level of education of a household head decreases the likelihood of improved wheat varieties adoption. A study by Uematsu and Mishra (2010) also reported a negative influence of formal education towards adopting genetically modified crops.

The effect of livestock ownership had a significant positive effect on adoption of improved wheat varieties. Suggesting that the increase in number of livestock owned increases the likelihood of farm household's choice of improved wheat varieties.

TABLE 3. Results of the probit regression for improved wheat varieties adoption of improved wheat in Digelu, Arsi-robe and Hetosa in Ethiopia

Variables	Coef.	Z
Age	-0.01445	-0.83
Education	-0.07126**	-2.13
Farming experience	0.008663	0.49
Household head sex	0.436001*	1.87
Family size	-0.05969	-1.38
Farm size	0.104456	1.3
Off-farm income	-0.1971	-0.97
Land fragmentation	-0.03885	-0.38
Livestock ownership	0.016488***,	2.34
Access to credit	-0.1842	-0.74
Wheat disease dummy	0.790298*	1.88
Constant	0.608472	1.03
Sample size	176	
Pseudo R^2	0.11	

*,**, and*** significant at 10, 5 and 1%, respectively

TABLE 2. Characteristics of adopters and non-adopters of improved wheat varieties Digelu, Arsi-robe and Hetosa in Ethiopia (summary statistics for dummy variables)

Variables	Category	Adopters (%)	Non-adopter (%)	Total (%)	Chi ^{2}(1)
Household head sex	Female	14	18	32	5.68**
	Male	42	26	68	
Religion	Muslim	29	15	44	4.95**
	Christian	25	27	51	
Participation in off-farm income	No	33	22	55	1.30
	Yes	23	22	45	
Access to credit	No	12	8	20	0.11
	Yes	44	36	20	

** indicates significant at 5%

It was also observed that the sex of household head positively affected the decision of improved wheat varieties. The result confirms that male headed households were more likely to adopt improved wheat varieties. This result is in conformity with the study by Solomon *et al.* (2014).

Occurrence of wheat rust disease in a field affected the decision of improved wheat varieties positively. This means as farmer's wheat field affected by wheat rust disease increases the more likely farmers to adopt improved wheat varieties. This might be due to the fact that the wheat rust disease causes a major yield loss. Therefore, farmers have to opt for new improved wheat varieties which allow more production.

Impact of improved wheat varieties on productivity and income. Prior to the matching analysis, adopters significantly differed from non-adopters in most characteristics (Table 4). The process of matching, thus creates a high degree of covariate balance between the treatment and control samples that were used in the estimation procedure. According to the results (Table 4), the imbalance between the treatment and control samples in propensity score, reduced much below 10% after matching; and the no case was significantly different from zero (P<0.01). This indicated that all differences in means between treatments and controls had been removed through matching in the initial period (before participation in adoption). The values of Pseudo R^2 and LR Chi-square, before and after matching, can be used as indices for the fulfilment of the balancing requirement (Table 4). The low value of pseudo-R^2 and the insignificant LR Chi-square after matching supported the hypothesis that both groups have the same distribution in covariates after matching. This implies that we have found a comparable group of non-adopters with adopters of improved wheat varieties based on similar covariates.

Estimation of treatment effect-matching algorithms. The impact of adoption of improved wheat varieties on productivity is presented in Table 5. Adoption of improved wheat varieties significantly affected wheat productivity. According to the Nearest Neighbour, causal effect of technology adoption on wheat productivity is highly significant and equal to 11.3, which is the average wheat productivity difference between adopters and non-adopters, i.e. adopters were significantly (P<0.01) better than non-adopters by 1.13 tonnes in wheat productivity using Nearest Neighbour matching method.

Using Kernel-based matching method, the effect of wheat technology on wheat productivity was positive and highly significant (Table 5). The average treatment effect on the treated (ATT) estimates suggest that improved wheat varieties adoption significantly increased the wheat productivity by about 1 ha^{-1}. This is the average change in productivity ha^{-1} of farm households that contributed by a change in technological status. These results confirm that adoption of improved wheat varieties improved or increased the wheat productivity of the adopters. A study by (Awotide *et al.*, 2012) in Nigeria using a Local Average treatment effect (LATE) found that a positive impact of improved rice varieties on rice productivity.

TABLE 4. Overall covariate balance test for adoption of improved wheat varieties in Digelu, Arsi-robe and Hetosa in Ethiopia

Criteria	Before matching	After matching			
		Nearest Neighbour		Kernel matching	
		Income	Productivity	Income	Productivity
Pseudo R^2	0.109	0.029	0.037	0.018	0.01
LR X^2	29.93	6.29	9.12	3.92	2.45
P- value X^2	0.002	0.853	0.611	0.972	0.996
Mean bias	18.2	7	9.8	4.9	6.8
Percent bias reduction		61	46	73	63

Data for the causal impact of adoption of improved wheat varieties on wheat productivity, by different levels of wheat technology adoption, are presented in Table 6. The study goes beyond the usual binary variable treatment of adoption status of improved wheat varieties in impact assessment. Assuming and treating the adopters as a homogeneous group in terms of their adoption leads to inaccurate impact estimates, wrong conclusions and implications. The results showed impact variation by level of adoption (area of wheat under improved wheat varieties). According to the Nearest Neighbour matching method, among the adopters, farmers who allocated 25, 25-50, 50-75 and 75-100% of their wheat area to improved wheat varieties, obtained 1, 2.5 and 1.1 t ha^{-1} more than the non-adopter counterparts, respectively (Table 6). Similarly, the result of the kernel-based matching showed that farmers who allocated 25, 25-50, 50-75 and 75-100% of their wheat area to improved wheat varieties obtained 1, 2.3 and 1.1 t ha^{-1} more than the non-adopter counterparts, respectively. In both matching algorithms, the result shows that productivity gains from adoption of improved wheat varieties are the highest for those farmers allocated their wheat farms from 25 to 50% to improved wheat varieties. The plausible explanation might be allocating their improved wheat farm to improved wheat varieties beyond 50% may demand to invest more to the associated improved wheat packages. Hence, this result reveals that the heterogeneous effects of adoption of improved wheat varieties.

Farm household income. The two matching estimates showed that improved wheat varieties adoption had a positive and significant effect (Table 7). The nearest matching algorithm indicated that the effect of adoption of improved wheat varieties was significant ($P<0.05$) and equal to 0.401. Since income was expressed in logarithmic terms, the average income ratio between adopters and non-adopters was 1.50 implying that the income of adopters was almost 50% higher than income of non-adopters. Similarly, the estimates of the Kernel-based matching showed that the income of adopters was almost 35% higher than income of non-adopters. This result suggest that adoption of improved wheat varieties make adopters on average better off by 35 to 50% compared to the non -adopter counterparts.

The sampled wheat farmers were stratified by quintiles based on area under improved wheat varieties to observe effect of wheat technology on household income using level of wheat technology adoption among adopters (Table 8). Nearest Neighbour matching method revealed that farmers who allocated 20-80% of their wheat area to improved wheat varieties earned two times more than the non-adopters. Similar results were

TABLE 5. Impact of improved wheat varieties adoption on productivity in Digelu, Arsi-robe and Hetosa in Ethiopia

Matching Algorithm	Adopters (N)	Non-adopters (N)	ATT	Std.	T
Nearest Neighbour	99	46	11.3***	2.54	4.45
Kernel-based	92	72	10.1***	2.28	4.45

*** Significant 1%

TABLE 6. Impact of improved wheat varieties by level of adoption on productivity in Digelu, Arsi-robe and Hetosa in Ethiopia

Level of adoption/area under improved wheat	ATT Nearest Neighbor	ATT Kernel-based
Less 25 %	10.78***	10.76***
25-50%	25.06***	23.45***
50-75%	9.56	10.34
75-100%	11.01***	10.13***

***Significant 1%

TABLE 7. Impact of improved wheat varieties adoption on household income in Digelu, Arsi-robe and Hetosa in Ethiopia

Matching Algorithm	Adopters (N)	Non-adopters (N)	ATT	Std.	t
Nearest Neighbor	92	44	0.401	0.236	1.697**
Kernel-based	92	72	0.295	0.209	1.411*

**, * Significant at 5 and 10%, respectively

TABLE 8. Level of adoption per area under improved wheat varieties in Digelu, Arsi-robe and Hetosa in Ethiopia

Level of adoption/ area under improved wheat varieties (%)	Nearest Neighbor ATT	Kernel-based ATT
Less 20	0.278	0.379
20 - 40	0.799***	0.724***
40 - 60	0.762***	0.733***
60 - 80	0.827***	0.724***
80 - 100	0.704	0.563

***Significant at 1%; ATT =Average treatment on the treated

found using Kernel-based matching method. However, the effect of technology adoption on household income for farmers who allocated less than 20% and 80 to 100% their total wheat area to improved wheat varieties was not significant, but positive. The impact was significantly higher in household heads who allocated 60-80% of their wheat farm to improved wheat varieties. This means that the income gains from improved wheat varieties was higher for those households who endowed with larger land size. (Mendola, 2007) using propensity score matching Bangladesh found that the effect of rice High Yield Varieties on income increases with higher land sized ownership. Hence, the results showed heterogeneous effects of wheat technology adoption among adopters.

CONCLUSION

The study showed that improved wheat technology adoption on average increased wheat productivity of adopters by about 1 to 1.1 t ha^{-1} than the non-adopters. Furthermore, the average income of adopters was 35 to 50% greater than the non-adopters. It also found that productivity gains from adoption of improved wheat varieties are the highest for those farmers allocated their wheat farms from 25 to 50% to improved wheat varieties and the income gains from improved wheat varieties higher for those households who endowed with larger land size.

The results provide evidence for heterogeneous effects of adoption of improved wheat varieties on farm household's income and productivity of wheat. Hence, the adoption of improved varieties had a positive effect on wheat productivity and farm household income, thereby increasing their likelihood of decreasing poverty levels.

The results also provide evidence that agricultural technology adoption can contribute to improving productivity and raising income of farm households.

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