Ethiop. J. Agric. Sci. 32(3) 55-80 (2022)

The Impact of Improved Coffee Technology Adoption and Determinants of Coffee Productivity: A Quantile Regression Approach

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Abstract

Non-morphological and non-physiological factors that affect the productivity of coffee were not critically examined in different coffee-related studies. The objective of this study was to explore such factors that affect the productivity of coffee and estimate the impact of the adoption of improved coffee varieties on yield. It was conducted in major coffee-producing zones of Ethiopia. A total of 694 households made up the sample for the study. The data were analyzed using descriptive statistics and an econometric approach. Socio-demographic and economic factors determining the productivity of coffee were investigated using quantile regression. The propensity score matching (PSM) was used to empirically determine the impact of the adoption of improved coffee varieties on farmers' yield. The result exhibited a positive and significant effect of improved coffee variety on productivity. Adopters can get 25-34% additional yield over non-adopters. An inverse relationship was observed between the size of the area allocated to improved coffee varieties and productivity in the lower quantiles. There was also a local difference both in technology adoption and coffee productivity. The magnitude of the effect of some of the variables in the quantile regression was found significantly different from the OLS estimates suggesting that the latter doesn't reflect the variable effect at different productivity levels. The finding suggests the need to reach out to less addressed areas such as Benishangul Gumuz through aggressive technology promotion efforts, enhance farmers' resource management skills and make training more tailored to farmers falling in different productivity ranges.

Keywords: Adoption, coffee, productivity, PSM, quantile and yield

Introduction

Ethiopia is considered a powerhouse and Africa's largest coffee producer. While over six million farm households are involved in coffee production (CSA, 2020), more than 15 million people rely on the sector for their livelihoods (USDA, 2018). The country is also the center of origin and genetic diversity of Arabica coffee (ECFF, 2015) which is 70% of the total coffee traded in the world (KRBG and

ECFF, 2017). In terms of coffee export, Ethiopia is the world's fifth-largest exporter of Arabica coffee (Moat *et al.*, 2017) and coffee represents 34% of the nation's total export earnings (USDA, 2019).

Four coffee production systems have been identified in the country, namely, forest coffee, semi-forest coffee, garden coffee, and semi-modern plantation (ECFF, 2015). It is estimated that these different production systems make up about 10, 35, 50, and 5% of the total coffee production in the country, respectively.

It is estimated that smallholder farmers contribute above 90% of Ethiopian coffee that is organically produced (EtBuna, 2021). This smallholder coffee production is characterized by being rainfed, low input-having low levels of investment (limited use of fertilizers, pesticides, and herbicides), and consequently, low output-obtaining low yields averaging 0.64 tons per hectare (Tadesse *et al.*, 2020).

Productivity improvement can be attained through increasing efficiency, exploring economies of scale, and/or technological progress. Technological progress happens when new and higher-performing improved technologies including improved varieties are used by farmers. In ensuring technology-induced coffee productivity growth coffee research centers have developed several improved coffee varieties and related production technologies. So far, more than 35 pure lines and six hybrid coffee varieties for different coffee belts of the country were released. The improved coffee varieties released by research offer new opportunities for farmers because of their unique characteristics of high cup quality, higher yield, and huge tolerance to coffee berry disease (CBD) than the traditional cultivars. According to ECTDMA (2016), improved varieties of coffee yield 1.2 to 2.6 tons/ha at research stations and 0.7 to 2.1 tons/ha at farmers' fields. Despite the potential, the national coffee yield remains below 0.7 tons per hectare over the last decade [Figure 1].

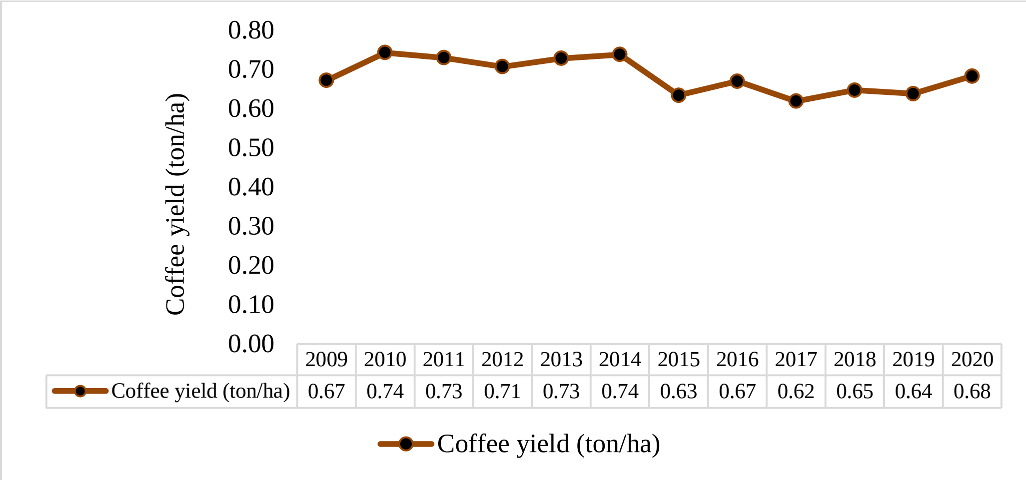


Figure 1: Coffee land productivity in Ethiopia (ton/ha)
Source: CSA, 2009-2020

Using improved coffee varieties alone cannot ensure an increase in productivity, it should be accompanied by good agronomic practices. These improved practices complement the improved varieties to produce optimum sustainable yields. There are recommended agronomic practices including spacing, plantation hole size, appropriate shade trees, plantation spacing, mulching, intercropping, weeding, fertilizer rate, soil and water conservation systems, pruning, disease management, and stumping (EIAR, 2007). Apart from the coffee's morphological and physiological features, other factors can influence the productivity of a farmer. These factors can be divided into three, namely, the quality and quantity of physical inputs employed (capital, land, and labor), socioeconomic characteristics of the farm household, and factors that are external to the farmer such as climatic conditions as well as government and institutional policies (Wiebe *et al.*, 2001). The purpose of this study was to explore the non-morphological and non-physiological factors that affect the productivity of coffee. In addition, the study estimates the impact of using improved coffee varieties on productivity at the household level for major coffee-producing areas in Ethiopia.

Materials and Methods

Study area

The study was conducted in four zones drawn from three regional states of Ethiopia: Jimma zone of Oromia, Metekel zone of Benishangul Gumuz, and Sidama and Gedeo zones of the SNNP regional states [Figure 2].

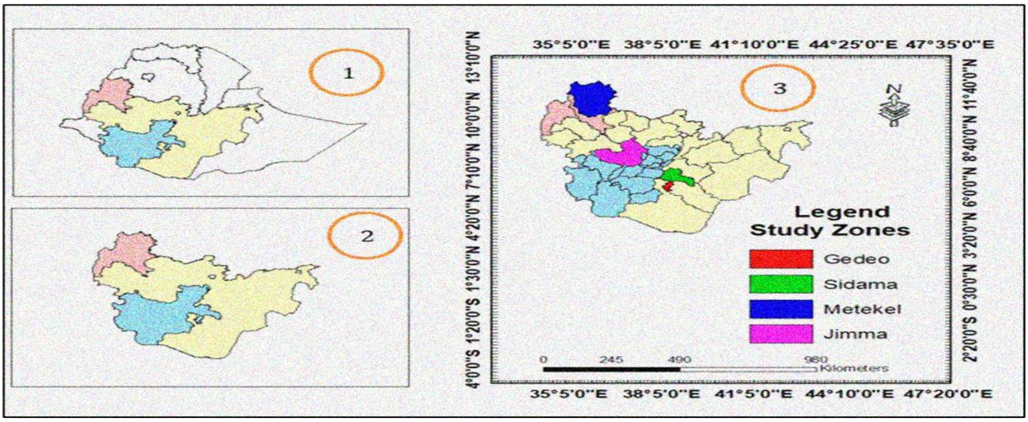


Figure 2: Map of the study area

Sampling and data collection

A stratified sampling technique was employed to select the population for the study which involved both purposive and random sampling techniques. First, zones in the three regions (strata) were purposively selected based on their comparative importance in terms of total production and area covered in coffee, and proximity to coffee research centers to observe the effort of the research centers (Jimma and Wondogenet) in popularizing and dissemination improved coffee varieties, and secondly, districts and *kebeles*[1] were selected randomly. Finally, households were randomly selected from the sampling frame (list of farmers) at the *kebele* level. A total of 694 households made up the sample households selected for the study [Table 1].

Table 1: Study locations and distribution of sample households

Region	Zones	Districts	Number of sample households	Share of the total sample (%)
Oromia	Jimma	Gomma	46	7
		Gera	50	7
		Limu Kosa	71	10
		Manna	38	5
Benishangul Gumuz	Metekel	Wembera	111	16
SNNP	Gedeo	Yirgachefe	98	14
		Kochere	96	14
	Sidama	Bansa Daye	83	12
		Dale	101	15
Total	4	9	694	100

[1] Kebele: peasant association or the smallest administrative unit.

Data were collected through a structured questionnaire administered to sampled farmers. The data were collected both at household and plot levels. Before the actual survey, the questionnaire was pretested in non-sampled villages.

Data analysis methods

The data were analyzed using descriptive statistics and an econometric approach. Adoption of improved coffee varieties was defined as farmers planting an improved variety of coffee which could be hybrid or pure lines. The intensity of adoption of improved coffee technologies was measured among the adopters by the share of coffee land covered by the improved cultivars. Productivity (output per unit area) was calculated using the following formula:

$$Productivity\ of\ coffee\ (kg/ha) = \frac{Coffee\ yield\ (kg)}{Coffee\ land\ size\ (ha)} \ldots\ldots\ldots\ldots (1)$$

Identifying determinants of coffee productivity

Socio-demographic and economic factors determining the productivity of coffee were investigated using quantile regression. Quantile regression is used simply to get information about points in the conditional distribution other than the conditional mean (Koenker and Basset, 1978; Buchinsky, 1994, 1995; Eide and Showalter, 1997). On the other hand, the quantile regression estimator minimizes the weighted sum of absolute residuals rather than the sum of squared residuals, and thus the estimated coefficient vector is not sensitive to outliers. A quantile regression model uses a linear programming representation and simplifies examination; and it is particularly useful when the conditional distribution does not have a standard shape, such as an asymmetric, fat-tailed, or truncated distribution.

The quantile regression approach can, thus, obtain a much more complete view of the effects of explanatory variables on the dependent variable (Kang and Liu, 2014). This approach is different from the conventional piecewise regressions that segment the dependent variable (unconditional distribution), and then run Ordinary Least Squares (OLS) on the subsets. Piecewise regressions are not an appropriate alternative to quantile regression, because of severe sample selection problems (Koenker and Hallock, 2001; Koenker, 2005). Furthermore, piecewise regressions are least-squares based and can be sensitive to the Gaussian assumption or the presence of outliers. The basic quantile regression model specifies the conditional quantile as a linear function of explanatory variables. This can be written as follows:

$$y_i = x_i'\beta_\theta + u_{\theta i} \quad where \quad 0 < \theta < 1 \text{ .... } (2)$$

$$Quant_\theta(x_i) = x_i\beta_\theta$$

where y is the dependent variable, x is a matrix of explanatory variables, u is the error term whose conditional quantile distribution equals zero and $Quant_\theta(x_i)$ denotes the θ^{th} quantile of y conditional on x. The distribution of the error term u is left unspecified. An individual coefficient $\beta_{\theta j}$ associated with the j^{th} independent variable in the vector x_i, called x_{ij}, could be interpreted as how y_i in its θ^{th} conditional quantile reacts to a (ceteris paribus) marginal change in x_{ij}. The quantile regression method allows us to identify the effects of the covariates at different locations in the conditional distribution of the dependent variable.

The θ^{th} regression quantile estimate, $\hat{\beta}_\theta$, is the solution to the following minimization problem

$$\min_\beta \sum_{y_i \geq x_i'\beta} \theta|y_i - x_i'\beta| + \sum_{y_i \geq x_i'\beta}(1-\theta)|y_i - x_i'\beta| \text{ .... } (3)$$

which is solved via linear programming. Standard errors for the vector of parameters are obtainable by using the bootstrap method described in Buchinsky (1995). The quantile regression can provide a more complete description of the underlying conditional distribution compared to other mean-based estimators such as OLS.

Estimating the impact of using improved varieties

The Propensity Score Matching (PSM) was used to empirically determine the impact of the adoption of improved coffee varieties on farmers' yield. It refers to the pairing of treatment and control units with similar values on the propensity score, and possibly other covariates, and the discarding of all unmatched units. It is an alternative method to estimate the effect of receiving treatment when the random assignment of treatments to subjects is not feasible. This method made a comparison between those who had adopted and those who had not adopted and drew conclusions based only on those who have adopted improved coffee varieties. Since it is impossible to know the outcomes for non-adopters of improved coffee varieties when they have adopted, and for adopters when they have not adopted, we turn to propensity score matching (PSM) to determine the average treatment effect on the treated farmers (ATT). In such a case, the average treatment effect (ATE) can be computed as:

$$ATE = E(Y1 \mid D=1) - E(Y0 \mid D=1) \quad \text{.................................... (4)}$$

This is based on the assumption that the output levels of the adopters before their adoption E(Y0|D=1) can reasonably be approximated by the output level of non-adopters during data collection E(Y0|D=0). Otherwise, estimation of ATE using the above equation is not possible since we do not observe E(Y0|D=1) though we do observe E(Y1|D=1) and (E(Y0|D=0). However, technologies are rarely randomly assigned. Instead, technology adoption usually occurs through the self-selection of farmers or, sometimes, through program placement. In the presence of self-selection or program placement, the above procedure may result in a biased estimation of the impacts of improved technologies since the treated group (i.e., the adopters) is less likely to be statistically equivalent to the comparison group (i.e., the non-adopters) in a non-randomized setting.

PSM adjusts for selection bias, minimizes the limitation from matching on many observed variables, and estimates counterfactual effects. PSM according to Rosenbaum and Rubin, (1985) is given as:

$$P(X) = \Pr\{D = 1|X\} = E\{D|X\} \quad \text{.................................... (5)}$$

Where, D = {0, 1} is the indicator of exposure to treatment and X is the multidimensional vector of pretreatment characteristics.

The PSM method is a systematic procedure of estimating counter-factual for the unobserved values (E(Y1|D=0) and E(Y0|D=1) to estimate impact estimates with no (or negligible) bias. The validity of the outputs of the PSM method depends on the satisfaction of two basic assumptions namely: the Conditional Independence Assumption (CIA) and the Common Support Condition (CSC) (Becker and Ichino, 2002). CIA (also known as Unconfoundedness Assumption) states that the potential outcomes are independent of the treatment status, given X. Or, in other words, after controlling for X, the treatment assignment is "as good as random". The CIA is crucial for correctly identifying the impact of the program since it ensures that, although treated and untreated groups differ, these differences may be accounted for to reduce selection bias. This allows the untreated units to be used to construct a counterfactual for the treatment group. The common support condition entails the existence of sufficient overlap in the characteristics of the treated and untreated units to find adequate matches (or common support). When these two assumptions are satisfied, the treatment assignment is said to be strongly ignorable.

Estimation of the propensity score is not enough to estimate the ATT of interest. Because propensity score is a continuous variable, the probability of observing two units with exactly the same propensity score is, in principle, zero.

Four commonly used matching algorithms, namely nearest neighbor matching, radius matching, stratification, and kernel-based matching were employed to assess the impact of improved coffee technologies on households' yield.

Radius Matching: In this method, every treated subject is matched with a corresponding control subject that is within a predefined interval of the treatment subject's propensity score. Since each of the treatment subjects must be matched with a control subject for a given interval, only a certain number of comparisons will be available (Thavaneswaran and Lix, 2008).

Nearest neighbor matching method: It matches each farmer from the adopter group with the farmer from the non-adopter group having the closest propensity score. The matching can be done with or without the replacement of observations. The nearest-neighbor matching method faces the risk of bad matches if the closest neighbor is far away. This risk can be reduced by using a radius matching method which imposes a maximum tolerance on the difference in propensity scores. However, some treated units may not be matched if the dimension of the neighborhood is too small to contain control units (Caliendo and Kopeining, 2005).

The kernel-based matching method: It uses a weighted average of all farmers in the adopter group to construct a counterfactual. The major advantage of the kernel-based matching method is that it produces ATT estimates with lower variance since it utilizes greater information; its limitation is that some of the observations used may be poor matches.

Stratified Matching: The propensity scores are classified into intervals based on the range of values. Each interval consists of treatment and control subjects that on average, have equivalent propensity scores. The differences between the outcomes of the treatment and the control group are calculated to obtain the average treatment effect. It is an average of the outcomes of a treatment per block weighted by the distribution of treated subjects across the blocks (Thavaneswaran and Lix, 2008).

Asymptotically, all matching algorithms should yield the same results. However, in practice, there are trade-offs in terms of bias and efficiency involved with each algorithm (Caliendo and Kopeining, 2005).

Results and Discussions

Descriptive results

We categorized the sample household into five quantiles based on productivity and the same is used to describe and compare the socioeconomic and demographic variables of the sampled households. Accordingly, the study result showed a significant difference in the productivity of coffee across the five quantiles; the overall mean was 725.5kg per hectare (Table 2). The lowest total land and coffee land size were seen in Quantile 5 (Q5) and the highest was in Quantile 1 (Q1). It seems that there is an inverse relationship between coffee productivity and coffee land size. Bonferroni test was run to observe the mean difference between coffee land size and productivity levels based on quantiles. The result showed a negative and significant correlation in almost all quantiles (Appendix I). The sample means land size covered in improved coffee was 0.46 hectares with the highest in Q4 and lowest in Q1 which suggests a likely direct relationship between productivity and the amount of area allocated to improved coffee varieties.

On average, farmers are 45.4 years of age. The overall mean family size of the households was 7.1 and the distribution is almost similar across the quantiles (Table 2). On average the sample households keep about five TLU and those in the lower quantiles (Q1-Q3) tend to keep more livestock compared to households in the higher quantiles. For all the variables there is a significant difference across the quantiles [Table 2].

Table 2: Descriptive statistics of variables within the quantile

Variables	Q1 (n=139)	Q2 (n=141)	Q3 (n=139)	Q4 (n=137)	Q5 (n=138)	Total (n=694)	F	P value
Productivity (kg/ha)	280.3 (76.83)	520.8 (79.54)	720.9 (20.39)	928.1 (94.61)	1186.3 (63.67)	725.5 (322.13)	3336.4	0.000***
Total farm size (ha)	3.93 (2.41)	2.81 (1.33)	2.59 (1.79)	2.46 (1.48)	1.93 (0.99)	2.75 (1.79)	27.1	0.000***
Total coffee land (ha)	2.09 (0.99)	1.89 (0.88)	1.49 (0.97)	1.39 (1.04)	1.25 (0.77)	1.67 (0.98)	17.6	0.000***
Improved coffee land (ha)	0.31 (0.58)	0.52 (0.82)	0.32 (0.46)	0.59 (0.61)	0.55 (0.85)	0.46 (0.69)	5.4	0.000***
Age (years)	43.7 (10.12)	47.4 (12.67)	44.1 (11.25)	44.9 (11.38)	46.9 (12.04)	45.4 (11.59)	2.9	0.020**
Education (years)	1.87 (0.98)	1.87 (0.87)	1.94 (0.98)	1.95 (0.83)	2.15 (0.81)	1.96 (0.89)	2.2	0.071*
Family size (number)	7.2 (2.37)	6.6 (2.08)	7.1 (2.22)	7.1 (2.21)	7.3 (2.39)	7.1 (2.26)	2.3	0.056*
TLU (number)	6.8 (6.75)	5.1 (5.86)	5.2 (6.91)	3.9 (5.42)	3.7 (3.75)	4.9 (5.94)	6.0	0.000***

Note: Numbers in the parenthesis are standard deviations

Most of the female households are concentrated in the lower quintiles while male households are fairly distributed across with relatively many falling in the higher quantiles. We have more females in the first two quintiles than in the last two. The reverse is true for male households [Figure 3].

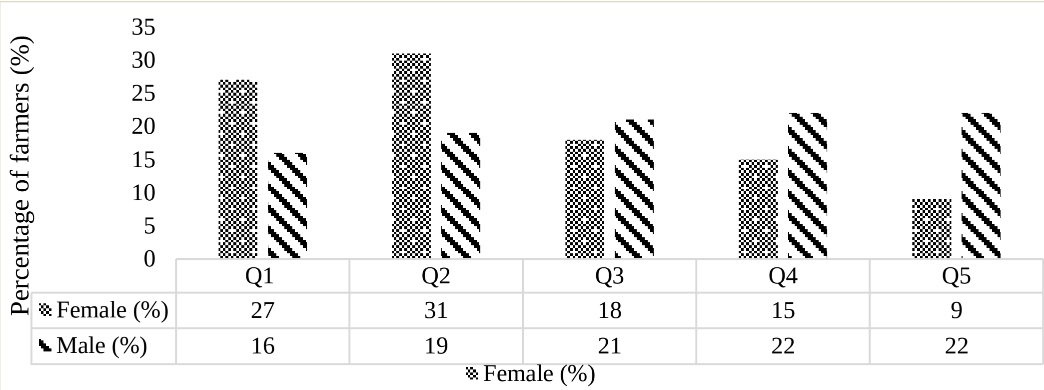


Figure 3: Quantile distribution of farmers by gender (%) [Pearson chi^2 (4) = 5.05 P = 0.282]

The productivity of crops is enhanced by the use of agricultural technologies. The goal of coffee research is also to enhance the yield of coffee per unit of land through the generation and promotion of improved coffee technologies including varieties and improved coffee production practices.

The rate of adoption of improved coffee cultivars was an important criterion to evaluate the level of technology diffusion. Since the study was a plot-level survey, the adoption rate was observed both at the plot and household levels. The mean adoption rate of improved coffee varieties was 45% and 57% at plot and household levels, respectively. Comparatively, the adoption rate was high in the Gedeo zone and Sidama National Regional State. In these two areas, garden coffee is the dominant type and the likelihood to uproot the old and plant new coffee in the garden is high. However, in zones such as Jimma, forest coffee dominates, and farmers tend to resist uprooting the old coffee. The lowest adoption rate was recorded in the Metekel zone where there was no direct intervention regarding improved coffee popularization [Figure 4].

Generally, coffee is a perennial crop and its extension system needs special care, patience, and devotion. The difference in adoption rate among study areas could be related to the coffee production system (garden, forest, and plantation), the emphasis given to coffee extension, and the coverage of the Coffee Improvement Project (CIP) (EIAR, 2007). CIP has been implemented with financial support from the European Union (EU) since 1977. The agreement was signed between the EU and the Ethiopian government and the implementation was carried out in different phases. The objective of the project was to introduce better coffee management practices with intensive extension, constructing rural roads and cooperative stores, conducting intensive coffee research, and providing coffee-related farm inputs on a credit basis. With the help of CIP, several hectares of land were planted or replanted with coffee berry disease-resistant varieties, many kilometers of access road were constructed, thousands of hectares of old coffee trees were rejuvenated and generally, coffee production and productivity had increased significantly. The contribution of CIP was significant in the coffee development history of Ethiopia (EIAR, 2007).

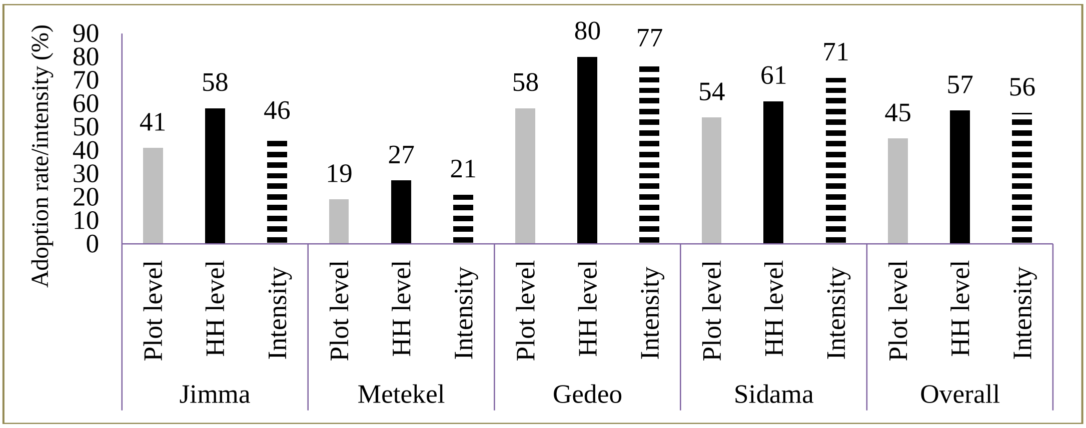
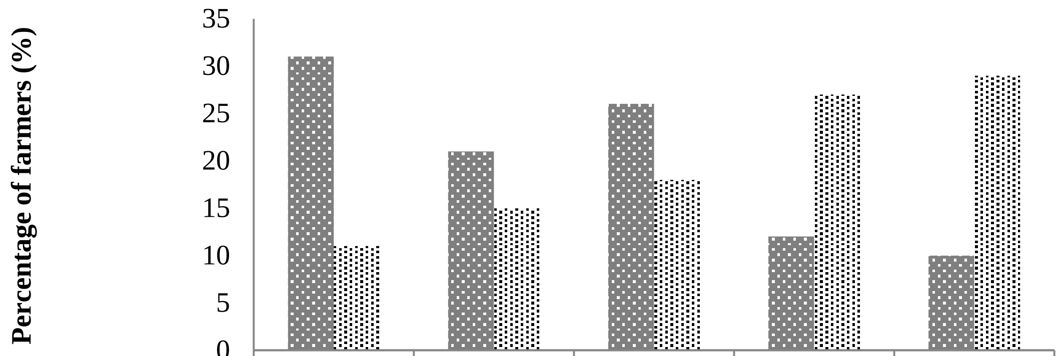


Figure 4: Rate and intensity of adoption (%) of improved coffee variety along study zones

The mean adoption intensity was 56% and relatively adopters from the Gedeo zone covered the highest proportion of their land with the improved cultivars. The lowest proportion of improved coffee was seen in the Metekel zone where also the lowest adoption rate was observed [Figure 4].

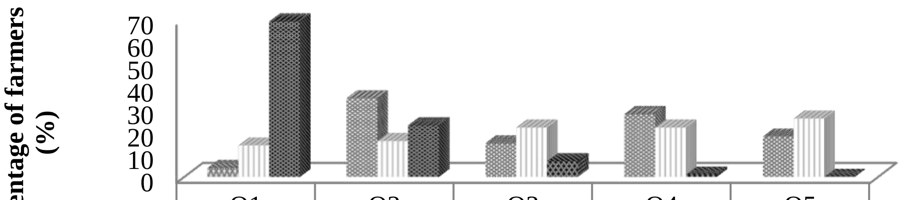
Looking into the adoption distribution across the quantiles, the survey result showed that most adopters (29%) are in Q5 and the majority of non-adopters (31%) are in Q1 [Figure 5]. A similar pattern is observed in productivity level [see Table 3] suggesting a possible link with the adoption of improved coffee varieties.



	Q1	Q2	Q3	Q4	Q5
Non-adopters (%)	31	21	26	12	10
Adopters (%)	11	15	18	27	29

Figure 5: Quantile distribution of farmers by adoption status (%) [Pearson chi^2 (4) = 89.39 P = 0.000]

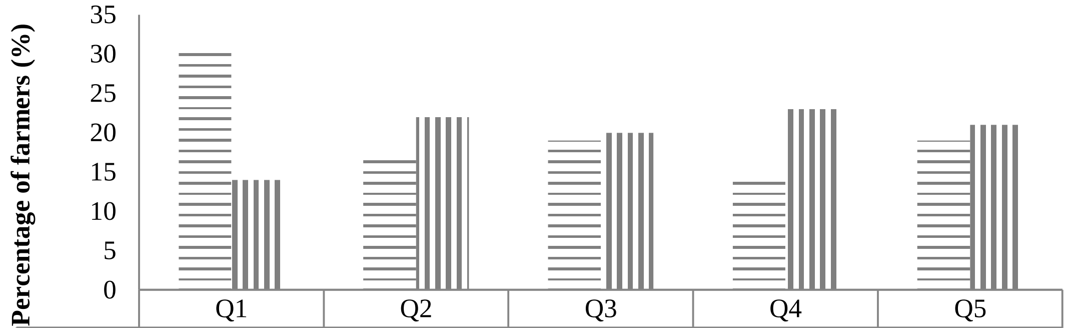
Coffee, in Ethiopia, is produced in different regions. Oromia and SNNP are the major coffee-producing regions of the country. Benishangul Gumuz is an emerging region, in this case. The result showed that there is a significant difference in coffee productivity among the regions, and the regional distribution of the sample households by quintile also supports the difference across the regions. The productivity of the majority of sample farmers from Oromia falls under Q2 and Q4 while the majority (26%) from the SNNP region were in Q5 where the highest productivity level is observed. However, the majority of sample farmers (69%) from the Benishangul Gumuz region were stacked in the low productivity range, that is Q1 [Figure 6]. Compared to Benishangul Gumuz, coffee research and development is well established in Oromia and SNNP regional states.



	Q1	Q2	Q3	Q4	Q5
Oromia (%)	4	35	15	28	18
SNNP (%)	14	16	22	22	26
BSG (%)	69	23	7	1	0

Figure 6: Quantile distribution of farmers by region (%) [Pearson chi2 (8) = 262.92 P = 0.000]

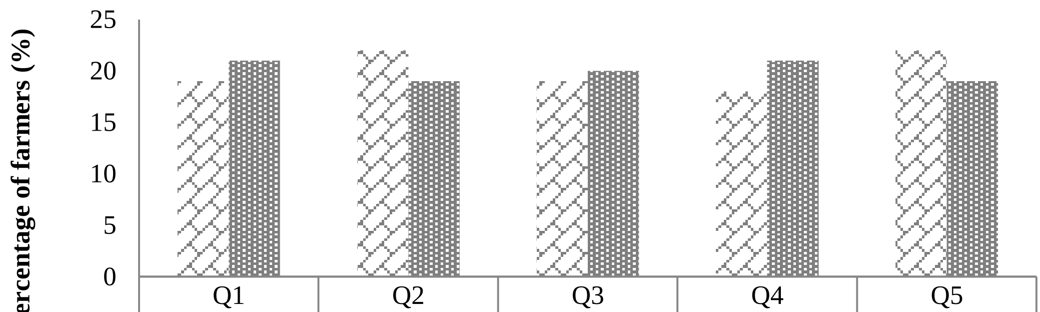
Training is one of the sources of agricultural information in Ethiopia. Farmers' access to training on agricultural production practices is expected to have a positive effect on productivity. About 61% of sample farmers in the study areas have access to training related to coffee production and management. About 64% of the sample farmers who got training were found in Q3 or above, on contrary, 76% of the sample farmers who did not get such training were in Q3 and below suggesting the possible contribution of training, among other factors, for productivity [Figure 7].



	Q1	Q2	Q3	Q4	Q5
No (%)	31	17	19	14	19
Yes (%)	14	22	20	23	21

Figure 7: Quantile distribution of farmers by participation in training [Pearson chi2 (4) = 29.33 P = 0.000]

Mass media such as radio is another source of agricultural information. More than 57% of farmers have access to radio in the study area. The result of the study revealed no meaningful difference across quantiles in terms of radio ownership. The proportion of farmers having a radio was almost similar across the quantiles [Figure 8].



	Q1	Q2	Q3	Q4	Q5
No (%)	19	22	19	18	22
Yes (%)	21	19	20	21	19

Figure 8: Quantile distribution of farmers by radio ownership (%) [Pearson chi2 (4) = 2.01 P = 0.735]

Factors affecting coffee productivity

We analyzed coffee productivity, the dependent variable, at five representative quantiles: 0.10, 0.25, 0.50, 0.75, and 0.90 which we will denote by Q0.10, Q0.25, Q0.50, Q0.75, and Q0.90. The result of the quantile and OLS regressions are presented in Table 3, and the findings show that compared to the reference category SNNP coffee productivity was lower at the Benishangul Gumuz (BSG) as well as Oromia regional states at all quantiles. When we compare the two regression estimates, while the OLS indicates that farmers in Oromia on average get nearly 100 kg/ha less yield compared to SNNP, the corresponding estimated reduction at Q0.10 is larger than twice the OLS estimate, and the two estimates are significantly different. Likewise, the OLS estimated yield reduction (-286kg/ha) for farmers in BSG (compared to those in SNNP) is significant and nearly two times larger than the estimate at Q0.10 (-156kg/ha) and about two times smaller than the estimate at Q0.90 (520kg/ha). The differences between the estimates in the OLS and at the two quantiles are statistically different. Compared to a farmer in SNNP, those in BSG have much lower productivity at the higher quantiles. The reverse is true for farmers in Oromia, that is, in reference to farmers in SNNP, farmers in Oromia have an estimated yield reduction at Q0.10 which is more than twice the estimated yield reduction in the OLS. This suggests that compared to the SNNP, the effect (reduction in yield) is more pronounced at the lower quantile (lower productivity level) for Oromia farmers, and at the higher quantiles (higher productivity level) for BSG farmers. The result implies that the productivity of coffee at SNNP is higher than the productivity at Oromia and BSG at most/all quantiles (productivity levels). The reason could be that the coffee production system in the SNNP region is mainly categorized as garden coffee. Comparatively, garden coffee enjoys high management and close follow-ups due to proximity and operational size which is often small. Compared to SNNP, the relative reduction in yield at BSG (except at Q0.10) is larger than that of farmers in Oromia. Lower productivity in Benishangul Gumuz (BSG) region is likely associated with poor adoption of improved coffee varieties and related coffee technologies which in turn is associated with lower investment in coffee technology promotion in the area. However, the region is currently considered an emerging coffee-producing area.

As expected, the adoption of improved coffee was found to have a significant and positive effect on coffee productivity at all the quantiles. The quantile regression result is also in line with Ordinary Least Squares (OLS). However, the result of OLS does not show the variable effect of the use of improved coffee variety on coffee productivity at different productivity levels. The OLS estimate underestimates the gains of adoption when compared with some of the quantiles. For instance, the estimate at Q0.50 (median) is significantly larger than the OLS estimate suggesting at Q0.50 adopters tend to benefit nearly twice more additional yield due to the use of improved variety than what is estimated by the OLS. The importance of improved seed varieties for improving crop productivity in developing countries has been reported by several earlier studies (World Bank, 2007; González *et al.* 2009; Awotide *et al.* 2012; Adofu *et al.* 2014; Nyangena and Maurice, 2014).

The effect of training on coffee productivity was negative for the first three quantiles and became positive for the last two though non-significant for most of the quantiles. While the negative relationship is unexpected given that most studies reported a direct influence of access to extension and training on agricultural productivity (Bravo-Ureta and Evenson, 1994; Evenson and Mwabu, 1998; Khanal *et al.* 2019), the result generally suggests that apart from the access, the quality of the training need to be examined. Probably the training is not tailored or mere repetition without bringing additional value to an already existing stock of knowledge. The negative effect is significant for households in Q0.25 and the magnitude of the difference between this quantile and the OLS coefficient is also statistically significant. While the OLS undermines the variability among farmers of different productivity levels, the quantile regression identifies where the effect is meaningful. Farmers in the lower quantiles are the least educated and the same content and approach of training may not serve a similar purpose as farmers in the higher quantiles.

The inverse relationship observed between total farm size and coffee productivity (although not statistically significant) reflects the farm size-productivity paradox. This suggests that excess land ownership drives diversification and forces a thin spread of available resources (input and other costs) across different types of crops which may penalize the performance of all commodities cultivated and coffee may not be an exception, in this case.

Table 3: Determinants of coffee productivity, quantile regression output

Explanatory variables		**Coefficients of Quantile Regression**					
		Q 0.10	Q 0.25	Q 0.50	Q 0.75	Q 0.90	OLS
Location Dummy [Ref. = SNNP]	Oromia	-234.06*** ± (42.29)	-98.39** (49.66)	-4.08 (41.51)	-40.85 (60.05)	-74.21*** (22.30)	-99.42*** (32.18)
	BSG	-156.18*** ± (51.76)	-178.50*** (60.79)	-288.46*** (50.81)	-370.25*** (73.50)	-519.83*** ± (27.29)	-285.97*** (39.39)
Dummy of adoption [Yes]		105.26*** (38.81)	155.09*** (45.58)	200.23*** ± (38.09)	187.50*** (55.12)	25.53** (20.47)	114.32*** (29.54)
Sex of the household head (Male=1, Female=0)		22.39 (68.57)	36.55 (80.53)	55.26 (67.30)	80.87 (97.37)	17.58 (36.16)	53.18 (52.18)
Age of the household head in completed years		1.04 (1.28)	0.02 (1.49)	-0.12 (1.25)	0.46 (1.81)	0.004 (0.67)	0.47 (0.97)
Family size in numbers		-2.40 (6.58)	0.92 (7.73)	3.36 (6.46)	-0.68 (9.34)	1.08 (3.47)	0.47 (5.01)
Education level of the household head in completed years		11.56 (16.68)	3.14 (19.59)	3.34 (16.37)	-5.75 (23.69)	-1.09 (8.79)	7.38 (12.69)
Dummy of radio ownership [Yes]		40.36 (32.09)	51.35 (37.69)	18.29 (31.51)	23.07 (45.58)	2.19 (16.93)	16.79 (24.43)
Dummy of access to training on coffee [Yes]		-36.72 (32.21)	-70.06*± (37.83)	-19.61 (31.61)	36.52 (45.74)	2.27 (16.99)	3.81 (24.51)
Coffee land size (hectares)		-46.72** (20.05)	-66.52*** (23.54)	-48.41** (19.68)	-79.14*** (28.47)	-1.52 (10.57)	-72.03*** (15.26)
Area covered in improved coffee (hectares)		-23.59 (26.42)	-42.24 (31.03)	-60.39** (25.93)	2.92 (37.52)	16.25 (13.93)	-23.03 (20.11)
Tropical Livestock Unit (TLU) in numbers		2.53 (2.87)	-0.38 (3.38)	2.67 (2.82)	5.24 (4.08)	-0.03 (1.52)	2.82 (2.19)
Constant		377.81*** (113.69)	531.95*** (133.52)	646.34*** (111.59)	934.53*** (161.45)	1224.47*** (59.96)	757.67*** (86.52)

**** p<0.01, ** p<0.05, * p<0.1; Numbers in the parenthesis are standard errors*
± indicates the coefficient at the quantile is significantly different from that of the OLS, this is shown based on the confidence intervals in Appendix IV.

Coffee productivity was inversely related to improved coffee land size from Q0.10-Q0.50. However, the sign changes at Q0.75 and Q0.90. Farmers in the lower quintiles tend to keep more livestock than those in the higher ones implying that coffee land even covered with improved technologies might suffer from a lack of enough attention (see Table 2). Besides, proportionally, more land is devoted to improved coffee in the higher quantiles than the lower ones implying that those in the lower quantiles are involved in mixed farming (crop-livestock) which competes for their attention and resources.

Literature has shown both positive and negative influences of farm size on the productivity of crops. Studies conducted by Fan and Chan-Kang (2005), Goni *et al*. (2007), Sienso *et al*. (2013), and Bempomaa and Acquah (2014) have reported significant positive impacts of land size cultivated on the productivity of different crops. However, Pender *et al.* (2004), Adesoji and Farinde (2006), Masterson (2007), Okoye *et al.* (2008), Stifel and Minten (2008), Minai *et al.* (2014), and Gezahagn (2019) reported that there is a negative relationship between area under crop production and productivity. Farmer's resources are scarce and may not be able to meet the requirements of the large farmlands that they cultivate. This generally indicates the need for enhancing farmers' resource management capacity and economic decision-making for efficient use of available resources thereby maximizing the return from all commodities produced through the Pareto optimum. The OLS result also exhibited a negative and significant relationship between coffee land size and coffee productivity, but there was no significant difference between the estimates of the OLS and the reported quantile regression result.

Impact of adoption of improved coffee varieties on yield

The result of propensity score matching showed a significant contribution of the adoption of improved coffee varieties on coffee yield. ATT result of the yield in all four matching algorithms ranges between 0.253 and 0.341 which implies that adoption of the improved coffee variety offered a yield advantage of 25-34% for adopters over non-adopters. The result of the study was significant at a 1% significance level [Table 5].

Table 5: Estimation of ATT for coffee yield

Type of matching	Treated	Control	ATT	SE	t
Nearest Neighbor Matching Method	395	133	0.253	0.085	2.990***
Radius Matching Method	395	294	0.341	0.083	5.511***
Kernel Matching Method	395	294	0.316	0.061	5.210***
Stratification Method	395	294	0.308	0.066	4.653***

Output variable = log of clean coffee yield kg/ha
S.E = Bootstrapped standard errors with 50 replications
**** Indicate significance level at 1%*

Testing the balance of propensity score and covariates

The main purpose of propensity score estimation is not to obtain a precise prediction of selection into treatment, but rather to balance the distributions of relevant variables in both groups. The balancing powers of the estimations are established by considering different test methods such as the reduction in the mean standardized bias between the matched and unmatched groups, and equality of means using the t-test and chi-square test for joint significance of the variables.

The standardized bias difference between treatment and control samples is used as a convenient way to quantify the bias between treatment and control samples. In all the cases, it is obvious that sample differences in the raw data (unmatched data) significantly exceed those in the samples of matched cases. The low Pseudo-R2 and the insignificant likelihood ratio tests support the hypothesis that both groups have the same distribution in covariates X after matching. In addition, the indicators of matching quality show a substantial reduction in absolute bias for all the outcome variables. As indicated in Table 6, the mean bias in the covariates after matching lies below the 20% level of bias reduction suggested by Rosenbaum and Rubin (1985).

These results clearly show that the matching procedure can balance the characteristics in the treated and the matched comparison groups. Therefore, the results used to evaluate the effect of the adoption of improved coffee varieties among groups of farmers having similar observed characteristics are reasonable. The comparison was therefore made between observed outcomes for adopters with those of a comparison group of non-adopters sharing common support. The balancing information for propensity scores before and after matching is presented in Table 6.

Table 6: PSM quality indicators before and after matching

Indicators	Before matching	After matching
Pseudo-R^2	0.085	0.01
LR chi^2	68.50	13.74
$P>chi^2$	0.00***	0.39
Mean absolute bias	16.2	5.00
Mead absolute bias	12.3	3.40
*** *Indicate significance at less than 1% probability level*		

Source*: Survey result*

Conclusions and Policy Implications

The evidence presented in this study showed that the use of improved coffee varieties by farm households has contributed positively to coffee productivity. Sample farmers from the SNNP regions had the highest rate of adoption of improved coffee varieties and garden coffee is the dominant production system while the lowest adoption rate was observed in BSG regional states where coffee production-related interventions are relatively minimal compared to the production areas in the SNNP and Oromia regional state. Correspondingly, sample farmers falling in the low productivity quantiles were from BSG and those in the high productivity quantiles were from SNNP, and Oromia fell in between. Ensuring and widening the gains from the use of improved varieties by coffee farmers require aggressive promotion efforts in all areas of coffee production including in BSG where both the adoption rate and the productivity are very low. Moreover, important lessons associated with the garden coffee production system in SNNP need to be explored for scaling up across coffee production areas.

There is a significant productivity difference across the five quantiles. Although productivity is low in the lower quantiles, farmers in those quantiles tend to own larger total as well as coffee land size and livestock. Farmers in the lower quantiles are relatively less educated and use improved coffee varieties on a smaller proportion of their land compared to those in the higher quantiles.

The quantile regression indicated that compared to the SNNP, the effect (reduction in yield) is more pronounced at the lower quantile (lower productivity level) for Oromia farmers, and at the higher quantiles (higher productivity level) for BSG farmers. Moreover, the gain from the adoption of improved coffee varieties is more significantly pronounced at the median quantile (Q0.50) which is nearly twice larger than the estimate in the OLS regression model. The negative relationship between training access and productivity at lower quantiles suggests that a one-size-fits training approach is not a sufficient condition for increasing coffee productivity. Instead, the content and approach followed for farmers at lower productivity quantiles need to be tailor-made given that most of these farmers are less educated.

Likewise, the amount of land devoted to improved coffee varieties has negative effects on productivity at lower quantiles. Farmers who are involved in mixed farming (mostly in the lower quintile) tend to diffuse their resources and suffer from lower productivity despite the amount of land allocated to improved coffee varieties. There should be an effort to help farmers improve their resource management skills as well as production decision capacity to help them get a better return from additional investment as well as from diversified production systems.

While the scope with which the findings from this study should be generalized needs to be understood with a caveat as it has covered only selected coffee-producing areas (excluding important production areas such as those in the eastern part of the country), subsequent studies need to address such gaps by including missed areas. Moreover, apart from improved varieties practices associated with coffee management practices as in the garden coffee is expected to have a contribution to productivity. Therefore, follow-up studies would complement this one if important coffee production technologies in addition to varieties are included in the analysis.

Acknowledgments

The authors appreciate the Ethiopian Institute of Agricultural Research (EIAR) for financing the study. We also acknowledge the enumerators and supervisors from Jimma, Wondogenet, and Pawe research centers who have been involved in data collection as well as management, and not the least, farm households who patiently responded to our survey questionnaire.

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Appendixes

Appendix I: Mean comparison of coffee land size across five quantiles of productivity (Bonferroni)

Row mean-column mean	Q1	Q2	Q3	Q4
Q2	-0.206 (0.650)			
Q3	-0.608* (0.000)	-0.402* (0.003)		
Q4	-0.467* (0.000)	-0.260 (0.205)	0.142 (0.999)	
Q5	-0.846* (0.000)	-0.639* (0.000)	-0.238 (0.345)	-0.379* (0.008)

Note: Numbers in parenthesis are p values and * indicates statistical significance at a 1% level of significance

Appendix II: Estimation of propensity score: Logit model

Variables	Coefficient	Standard error	t	P-value
HHH sex [Male]	0.334	0.396	0.84	0.400
HHH education	0.185	0.097	1.91	0.056*
HHH age	0.004	0.007	0.54	0.590
Membership in local organizations	0.410	0.177	2.31	0.021**
Radio ownership	0.031	0.184	0.17	0.868
Mobile phone ownership	0.033	0.200	0.17	0.869
Training on coffee	0.225	0.179	1.26	0.209
Visit coffee demos	0.728	0.172	4.22	0.000***
Ln (total land in ha)	1.362	0.355	3.83	0.000***
Ln (coffee land in ha)	1.292	0.338	3.82	0.000***
Oxen ownership	-0.077	0.240	-0.32	0.747
TLU	0.048	0.019	2.57	0.010**
Commercialization index	0.001	0.004	0.23	0.821
Constant	0.677	0.628	1.08	0.281
Pseudo r-squared = 0.091 LR chi-square = 85.607***				

**** p<0.01, ** p<0.05, * p<0.1*

Appendix III: Propensity score and covariate balance

Variable	Sample	Mean		Percent reduction		t-test	
		Treatment	Control	% Bias	Bias	t	P value
Propensity score	Unmatched	0.6224	0.5073	73.4		9.07	**0.000**
	Matched	0.6224	0.6229	-0.3	99.6	-0.05	0.959
HH sex	Unmatched	0.9489	0.9480	0.4		0.05	0.962
	Matched	0.9489	0.9543	-2.4	-516.0	-0.34	0.733
HHH education	Unmatched	2.0403	1.8398	22.4		2.74	**0.006**
	Matched	2.0403	1.9570	9.3	58.4	1.32	0.186
HHH age	Unmatched	45.720	45.225	4.3		0.51	0.613
	Matched	45.720	45.199	4.5	-5.3	0.61	0.545
Membership in local organizations	Unmatched	0.2903	0.3982	-22.8		-2.75	**0.006**
	Matched	0.2903	0.3897	-21.0	7.9	-0.88	0.542
Radio ownership	Unmatched	0.6935	0.6969	-0.7		-0.09	0.929
	Matched	0.6935	0.6182	16.3	-2100.0	0.16	0.312
Mobile phone ownership	Unmatched	0.7338	0.7489	-3.4		-0.41	0.683
	Matched	0.7338	0.7580	-5.5	-60.8	-0.76	0.449
Training on coffee	Unmatched	0.7150	0.5930	25.8		3.11	**0.002**
	Matched	0.7150	0.7607	-9.7	62.5	-1.42	0.157
Visit coffee demo sites	Unmatched	0.5322	0.2813	52.7		6.22	**0.000**
	Matched	0.5322	0.5483	-3.4	93.6	-0.44	0.659
Ln (total land in ha)	Unmatched	0.7033	1.0035	-44.4		-5.35	**0.000**
	Matched	0.7033	0.6476	8.2	81.4	1.14	0.255
Ln (coffee land in ha)	Unmatched	0.2593	0.4855	-33.3		-3.94	**0.000**
	Matched	0.2593	0.2234	5.3	84.1	0.70	0.486
Oxen ownership	Unmatched	0.2822	0.4242	-30.0		-3.62	**0.000**
	Matched	0.2822	0.2930	-2.3	92.4	-0.32	0.746
TLU	Unmatched	3.9313	6.2277	-40.6		-5.00	**0.000**
	Matched	3.9313	3.9775	-0.8	98.0	-0.14	0.887
Commercialization index	Unmatched	37.616	41.071	-12.3		-1.47	0.141
	Matched	37.616	38.976	-4.8	60.6	-0.69	0.489

Note: Figures in bold are significant variables

Appendix IV: Output of the quantile and OLS regression with confidence intervals

	Q 0.10		Q 0.25		Q 0.50		Q 0.75		Q 0.90		OLS	
Variables	Coeff.	95% Conf Interval	Coeff.	95% Conf Interval	Coeff.	95% Conf Interval	Coeff.	95% Conf Interval	Coeff.	95% Conf Interval	Coeff.	95% Conf Interval
Oromia (ref=SNNP)	-234.06***	-317.1, -151.02	-98.39**	-195.8, -0.87	-4.08	-85.58, 77.42	-40.85	-158.76, 77.05	-74.21***	-117.99, -30.42	-99.42***	-162.59, -36.23
BSG (ref=SNNP)	-156.18***	-257.8, -54.54	-178.50***	-297.8, -59.1	-288.46***	-388.2, -188.7	-370.25***	-514.56, -225.93	-519.83***	-573.42, -466.23	-285.97***	-363.30, -208.64
Dummy of adoption [Yes]	105.26***	29.05, 181.5	155.09***	65.59, 244.58	200.23***	125.43, 275.03	187.50***	79.28, 295.72	25.53**	-14.66, 65.72	114.32***	83.33, 199.31
Sex of the household head (Male=1, Female=0)	22.39	-112.2, 157.0	36.55	-121.5, 194.6	55.26	-76. 88, 187.40	80.87	-110.31, 272.05	17.58	-53.42, 88.58	53.18	-49.26, 155.63
Age of the household head in completed years	1.04	-1.46, 3.53	0.02	-2.92, 2.95	-0.12	-2.57, 2.34	0.46	-3.09, 4.01	0.004	-1.32, 1.33	0.47	-1.430, 2.38
Family size in numbers	-2.40	-15.32, 10.51	0.92	-14.25, 16.09	3.36	-9.32, 16.03	-0.68	-19.02, 17.67	1.08	-5.73, 7.89	0.47	-9.36, 10.29
Education level of the household head in completed years	11.56	-21.12, 44.30	3.14	-35.3, 41.6	3.34	-28.81, 35.49	-5.75	-52.26, 40.76	-1.09	-18.36, 16.19	7.38	-17.55, 32.30
Dummy of radio ownership [Yes]	40.36	-22.65, 103.38	51.35	-22.67, 125.36	18.29	-43.56, 80.15	23.07	-66.42, 112.57	2.19	-31. 04, 35.43	16.79	-31.17, 64.75
Dummy of access to training on coffee [Yes]	-36.72	-99.51, 25.95	-70.06*	-144.9, 4.93	-19.61	-81.9, 42.68	36.52	-13.99, 86.99	2.27	-31.12, 35.65	3.81	-44.31, 51.93
Coffee land size (hectares)	-46.72**	-86.08, -7.36	-66.52***	-112.7, -20.2	-48.41**	-87.05, -9.77	-79.14***	-135.04, -23.24	-1.52	-22.28, 19.24	-72.03***	-101.99, -42.08
Area covered in improved coffee (hectares)	-23.59	-75.47, 28.28	-42.24	-103.1, 18.6	-60.39**	-111.3, -9.46	2.92	-70.75, 76.59	16.25	-11.21, 43.69	-23.03	-62.50, 16.45
Tropical Livestock Unit (TLU) in numbers	2.53	-3.11, 8.17	-0.38	-7.00, 6.25	2.67	-2.87, 8.23	5.24	-2.77, 13.26	-0.03	-3.01, 2.95	2.82	-1.47, 7.12
Constant	377.81***	154.57, 601.04	531.95***	269.7, 794.1	646.34***	427.22, 865.46	934.53***	617.52, 1251.53	1224.47***	1106.74, 1342.20	757.67***	587.79, 927.54