Impact of Agricultural Inputs Use on Productivity of Major Crops in Southern Ethiopia

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IMPACT OF AGRICULTURAL INPUTS USE ON PRODUCTIVITY OF MAJOR CROPS IN SOUTHERN ETHIOPIA

Abstract

This invention describes *that the rate of input utilization is decisive for productivity growth of considered crops. The invention enhances the productivity of major crops like maize, teff, wheat, barley and sorghum crops. The sample was based on a panel data of (2011, 2013, and 2015) acquired from the Ethiopian socio-economic survey was used. The invention was scientifically analyzed using the basic fixed effect model and dose-response function under exogenous and endogenous treatment models. In the exogenous and endogenous treatment cases, households applying fertilizer have achieved actual different levels of higher outputs than their counterparts. In endogenous treatment, the household applying fertilizer harvested much higher output than those in the counterfactual condition. Moreover, inputs: fertilizer, seed, labor force, and farm capital utilization have a critical impact on the aggregate outputs of considered crops.*

Keywords: Treatment effects, Dose-response function, Input, Productivity

1. Introduction

Globally, agriculture experienced a shift in a farming system that expresses the transition from zero-input agriculture to intensive input and other post-harvest technologies; from hand, hoe to plow culture; from animal-drawn to tractor-drawn cultivation; and from traditional farming to mechanization. Therefore, a practice of intensive agricultural input use is considered a vital stimulus for raising productivity. However, the level of intensity of inputs and the shift in the farming system differs from country to country. Comparatively, farmers in most developing countries are confronted with the intricacies of accepting and using mechanized inputs to increase productivity growth [1, 2]. Though suggested that improved varieties of inputs, post-harvest technologies, and best agronomic practices can determine the growth of agriculture, there are challenges in applying the inputs and technologies in most developing countries [3-6].

However, adoption is the integration of technologies into farmers' normal agricultural activities over an extended period. The main drivers of adoption are risk management, learning, information, credit availability, taste preferences, agro-ecology, local costs, and benefits. An individual sometimes decides to discontinue using new inputs for personal, institutional, or social reasons. Based on that fact, the classification of adoption is farm level and aggregate adoption. At the individual level, it is defined as the degree of use of new technology in the long-run equilibrium when the farmer has a full-package of the innovative technology and its potential whereas, aggregate adoption is based on adopting the new inputs at the level of the geographical area [7-10].

Therefore, in the context of aggregate adoption behavior, diffusion implies agricultural input aggregate adoption is measured by the aggregate level of specific input or new technology within a given geographical area or within the given population, except for those indivisible inputs [11, 12]. Theoretically, farmers have to choose a combination of input or technology that maximizes their expected production. A package of technologies could provide higher productivity than pieces of technologies used individually. However, pervasive uncertainty about new technology and binding credit constraint can confound this notion of complementarity. The adoption decision-making also involves how many resources or inputs are expected to be in use [13, 14].

There are no exact paths to guide farm intensifications in developing countries. However, depending on resource endowments, a particular group of households can choose the Labor-led intensification path, committing a higher level of labor inputs per unit of land. While others can embark on capital-led intensification involving increased investments in non-labor inputs [15, 13]. More specifically, the fertilizer use effect is higher than other inputs that can lag crop productivity growth. Africa soils experienced inherent difficulties due to nutrient mining by crops, leaching, and inadequate erosion control practices coupled with land-use systems that don't match land suitability [16]. The rates of fertilizer utilization have been much lower in Africa than in other developing countries, and the associated crop yields were also correspondingly lower. The low adoption rate of modern agricultural inputs is one of the main reasons for much of the stagnation in agricultural productivity across SSA countries [17, 18].

Moreover, in agriculture, innovation often takes the form of the utilization of modern inputs and farming practices: seeds, fertilizer, crop protection chemicals, and integrated soil and water management practices to address a wide range of production limiting constraints [19, 20, 10]. Ethiopian agriculture is composed of 12.6 million smallholder farmers and several hundred large-scale farms. The combined annual crop production of these two groups of farms is 31 million tons, with 71% of output comprised of cereals, pulses, and oil crops. The remainder of 29% is the aggregate of vegetables, fruits, and cash crops in Ethiopia (mainly coffee, sugarcane, chat, and enset) [21].

On the other hand, the econometric models examine the causal link between factors productivity with key inputs shared in productivity. This is due to the scanty impacts of input intensity based on a panel data framework at the regional level. Estimate the causal effect of the treatment variable on an outcome through both exogenous and endogenous treatment effects by controlling function models [22-24].

Against all mentioned backdrop, this research analyzed the impact of agricultural input use in productivity of aggregate major crops in Southern Nation, Nationalities, and Peoples Region (SNNPR) Ethiopia. This research is done for three major reasons: first, the study area is one of the biggest regions with more than 30 million population. Next, the study area holds the potential producers of those selected crops on a very fragmented landholding. Then, based on the standards of the national Central Statistic Authority, the selected crops have high coverage and market value in the area.

On top of that, it is challenging to measure the amount of fertilizer already utilized by crops in the area. Thus, the aggregate amount of fertilizer at the household level would be an option at hand for the researchers in the study area. Besides, this research significantly contributes to the existing literature by identifying the level of agriculture input use for productivity in the study area. This study also informs academicians to strengthen the existing model of DRF and productivity analysis based on the empirical evidence from Southern Ethiopia.

Finally, the article is organized as follows: first, reviewing empirical and theoretical literature on the concept of agricultural input use and adoption followed by dose-response models under exogenous and endogenous treatment. Then, the article presented the data sources and method of data collection, as well as the model adopted to analyze the data in the study. Third, the result of the analysis followed by a detailed discussion was presented. Finally, the article concluded by providing plausible recommendations in the last section.

2. Methodology

2.1.Data sources and collection Methods

Primary data was by employing semi-structured interviews, focus group discussions, and key informant interviews. Regional, three Zonal, and three district Agriculture Development office heads were selected for key informant interviews, purposively. Two focus group discussions from each of the enumeration areas (EAs) were selected and ten households, purposively. The reason was to supplement the quantitative data for analysis. Inclusive questionnaires of household demographic and agricultural information from Ethiopian Socioeconomic Survey (ESS) data sets were used.

In the data cleaning process, a strongly balanced panel of data consisting of 2,187 households was created for SNNPR as the secondary data. The data set included an aggregated number of major crops (barley, maize, teff, wheat, and sorghum) produced and valued in three steps. First, the quantity of product measured in different local units of measurement is converted into a standard measure (kilogram).

Following the findings of [25], conversion factors, prepared by the Central Statistic Authority (CSA) at the village level held. In the second step, the quantity of production in kilograms was converted into monetary values in Ethiopian Birr using average *Kebele* (*Kebele* is the smallest administrative structure next to the district) level unit prices collected during the survey years. Finally, the value of production is generated by multiplying the average unit price at *the Kebele* level by the total quantities produced in kilograms. Land size owned by households measured by local units is converted into standard measure (hectare) using the conversion factors of CSA and aggregated into the household level.

One of the inherent limitations of this study was the use of family labor as a proxy indicator for labor used in crop production. It is due to inconsistency in the duration of labor use data across different years. The labor force included from land preparation up to the harvesting caleder calculated as follows: firstly, we calculated the adult equivalent by sorting the age of each household member by using the standards. Secondly, days in a week, and to annual was found converted. Thirdly, the man-days appeared by multiplying them by their respective category (men, women, and children).

The number of farm-capital was the sum of the number of sickles, hoes, *Mofer* (*Mofer* is one of the farm capital which could be tied with *Kenber* and pulled by the oxen), *Kenber (Kenber* is also the farm capital used to plow land putting on the heads of oxen to be connected with Mofer), water storage pit, water pump, traditional plow, and modern plow converted for cultivation. The use and quantity of ownership are included but differences in quality of the assets owned and their homogeneity are expected to increase the risk of measurement errors in the data. Livestock ownership was measured in Tropical Livestock Units (TEUs) followed by Jahnke (1982). It is also important to note that problems in unit CF and the local measurement unit itself might be a source of measurement error for both production and area cultivated.

2.2. Sampling techniques and sampling size Determination

Central Statistic Authority's Agricultural Sample Survey (AgSS) 74 EAs were selected based on probability proportional to the sizes of the total EAs in SNNPR. A total of 888 households, ten and two households from the sample of 30 AgSS and another household in the other rural EAs are randomly selected, respectively. In all three years (2011, 2013, and 2015), the selected EAs and households per EA for quantitative data remained the same.

2.1.Method of Data analysis and model specification

To identify households' aggregate major crops production by using basic fixed effects specification is as follow:

$y_{it} = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 \ldots + \delta_t + \varepsilon_{it}$ ……………………………………………(1)

$\varepsilon_{it} = \mu_i + V_{it}$ ……………………………………………………………(2)

Where average aggregate considered crops of household i in year t; x is the averages inputs used. Meanwhile is a period dummy to flexibly capture global trends is a household fixed effect and *it* is a random error term.

The other one is dose-response models (DRF) under exogenous and endogenous treatment models (EETM) used with the regression approach. Three reasons why EETMs were selected for this study as follows: first, the treatment variable is continuous. Second, households' reaction is heterogeneous to observable confounders. Finally, the selection of treatment is endogenous. Therefore, the DRF is equal to the average treatment effect **(**ATE**)** given the level of treatment (t) or ATE (t), with t representing the continuous treatment variable. However, the models have a limitation of ignoring estimation of the generalized propensity score and using a Heckman bivariate selection model, which requires additional distributional assumptions [23].

Therefore, we considered two different and exclusive potential outcomes: one referring to the unit i when treated **(Y_1)** and the second referring to the same unit when untreated **(Y_0)**. Define **fertilizer$_i$ (F_0)** as the treatment indicator, taking value 1 for treated and 0 for untreated units, and define $X_i = (X_{1i}, X_{1i}, X_{1i}, X_{1i}, X_{1i}, X_{Ki})$ as a row vector of K exogenous and observable characteristics (confounders) for unit **i** = 1**, . . . , N..** Let N be the total number of units, $\mathbf{N_1}$ be the number of treated units, and $\mathbf{N_0}$ be the number of untreated units, with $\mathbf{N = N_1 + N_0}$. Given the above model notation, we assume a specific population generating process for the two exclusive potential outcomes:

Fertilizer=1: output $= 1: y_1 = \mu_1 + g_1(\mathrm{x}) + h(t) + \varepsilon_1$ ……………………………………(3)

Fertilizer=0: $output = 0: \; y_0 = \mu_0 + g_0(\mathrm{x}) + \varepsilon_0$………………………………………(4)

Where, $g_1(\mathrm{x_i})$ and $g_0(\mathrm{x_i})$ as the unit i's responses to the vector of confounding variables ***x*i** when the unit is treated and untreated, respectively. Assume μ_1 and μ_0 to be two scalars, and assumeε_1 **and** ε_0 to be two random variables having 0 unconditional mean and constant variance. t_i taking values within the continuous range (0, 100) as the continuous treatment indicator, and $h(t_i)$ as a general derivable function of t_i. Where, the h**(t)** function is different from 0 only in the treated status [26].

Given this, we can also define the causal parameters of interest. Indeed, by defining the treatment effect (TE) as TE=(y_1 y_0), we define the causal parameters of interest as the population ATEs conditional on x and t; that is,

$\mathrm{ATE}\ (\mathrm{x}, t) = E\ (y_1 - y_0 | \mathrm{x}, t)$…………………………………………………..………(5)

$\mathrm{ATET}\ (\mathrm{x}, t > 0) = E\ (y_1 - y_0 | \mathrm{x}, t > 0)$……………………………………………......(6)

$\mathrm{ATENT}\ (\mathrm{x}, t = 0) = E\ (y_1 - y_0 | \mathrm{x}, t = 0)$……………………………………….……(7)

As ATE indicates below the overall average treatment effect, **ATET** (the average **TE** on treated), and **ATENT** (the average **TE** on untreated units). By the law of iterated expectation, the population unconditional **ATE**s were obtained as:

$\mathrm{ATE} = E_{(x,t)}\{\mathrm{ATE}(\mathrm{x}, t)$…………………………………………..………………………(8)

ATET = $E_{(x,t>0)}$ {ATE(x, t > 0)}……………………………………………………………………(9)

ATENT = $E_{(x,t=0)}$ {ATE(x, t = 0)}………………………………..…………………………(10)

ATE (t) = {ATEN + (h (t) - $\bar{h}_{(t>0)}$ if t > 0 and when ATENT become t = 0…………………..(11)

1. Estimation under Unconfoundedness

Unconfoundedness states that conditional on the knowledge of the true exogenous confounders X, the conditions for randomization are restored and causal parameters become identifiable.

$E(Y_{ji}/ \mathbf{F_i}, t_i, X_i) = E(Y_{ji} | X_i)$ with j = {0, 1} ……………………………………………… (12)

This form of the conditional mean independence assumption is a sufficient condition for identifying ATEs and the DRF in this context.

$E(Y_{ji}/\mathbf{F_i}, t_i, X_i) = \mu_0 + \mathbf{F_i} \times ATE + X_i\boldsymbol{\theta}_0 + \mathbf{F_i} \times (X_i - \text{mean})\, \boldsymbol{\theta} + \mathbf{F_i} \times [h(t_i) - \bar{h}]$……………..(13)

This is possible because these parameters are functions of consistent estimates. Standard errors for ATET and ATENT can be correctly obtained via bootstrapping [26]. To complete the identification of ATEs and the DRF, we finally assume a polynomial parametric form of degree m for

$h(t)$: $h(t_i)=\lambda_1 t_i + \lambda_2 t^2_i + \lambda_3 t^3_i + \cdot\cdot\cdot + \lambda_k t^k_i$………………………………………………..…(14)

2. Estimation under treatment Endogeniety

To restore consistency semi-structural form of instrumental variables was implemented.

$Y_i = \mu_0 + X_i\boldsymbol{\theta}_0 + \mathbf{F_i} \times ATE + \mathbf{F_i} (X_i - \text{mean})\, \boldsymbol{\theta} + \mathbf{F_i}T_1 i + b\mathbf{F_i}T_2 i + c\mathbf{F_i}T_3 i + \alpha_i$…………………..…..(15)

$\mathbf{F_i} = X_{F,i}\, \boldsymbol{\phi}_F + \epsilon_{F,i}$ ………………………………………………………………………………(16)

$\mathbf{t'}_i = X_{t,i}\, \boldsymbol{\phi}_t + \epsilon_{ti}$ ………………………………………………………………………………(17)

Where, $\mathbf{T}_{1i} = \mathbf{t_i} - \mathbf{E}(\mathbf{t_i})$, $\mathbf{T}_{2i} = \mathbf{t^2_i} - \mathbf{E}(\mathbf{t^2_i})$, and $\mathbf{T}_{3i} = \mathbf{t^3_i} - \mathbf{E}(\mathbf{t^3_i})$; $\mathbf{F_i}$ represents the latent unobservable counterpart variable of $\mathbf{F_i}$; $\mathbf{t_i}$ is fully observed only when $\mathbf{F_i} = 1$ (and $\mathbf{t}_i = \mathbf{t'}_i$) and otherwise, it was supposed to be unobserved (which is equal to 0); $X_{F,i}$ and $X_{1,i}$ are two sets of exogenous repressors; $\epsilon_{output,i}$, $\epsilon_{t,i}$ and α_i are error terms that are supposed to be freely correlated with one another with 0 unconditional mean. On Equation (14) the selection equation defines the regression explaining the net benefit indicator $output_i$. The vector of covariates $X_{F,i}$ are the selection criteria used, for instance, by an agency to set the treated and untreated groups.

In turn, on equation (17) the treatment level equation defines how the level of unit treatment is decided and only considers units that were eligible for treatment. Finally, the vector of covariates $X_{t,i}$ are those exogenous variables were considered as determinants of the treatment level. In equation (13), $X_{F,i}$, $\mathbf{T}_{1i}$, $\mathbf{T}_{2i}$ and $\mathbf{T}_{3i}$ are endogenous, with the latter three being functions of the endogenous **t**. In general, with two endogenous variables, the identification of equation (14–17) required the availability of more than two instrumental variables exogeniety.

Based on the above equations it is possibly done to a Heckman two-step procedure. The Heckman two-step procedure performs a probit of $\mathbf{output_i}$ on X, $\mathbf{F_i}$ in the first step, using only the $\mathbf{N_1}$ selected observations. These all were done to obtain unbiased and consistent estimators. In the second step, it performed an OLS regression of $t'i$ on xt,i, augmented by the Mills' ratio obtained from the probit in the first step, using all the N observations as predictions were also made for the censored data [26, 23]. In order to find productivity, the researchers used estimating production functions using the control function approach. It includes Levinshon-Petrin (LP) estimation methodologies. By default, this production function requires the logarithmic gross of output variable through time. For illustration purposes, consider a simple Cobb–Douglas production function (CDPF) in logs:

$$\text{lnoutput}_{\text{it}} = \alpha_0 + \text{land}_{\text{it}} + \text{seed}_{\text{it}} + \text{fertilzer}_{\text{it}} + \text{oxen}_{\text{it}} + \text{labor}_{\text{it}} + \text{epsilon\_it}$$

Where, $lnoutput_{it}$ *is the logarithm of output,* $land_{it}$, $seed_{it}$, $labor_{it}$, $fertilzer_{it}$ *and* $oxen_{it}$ is the logarithmic inputs that all of which are observed. Then, TFP was obtained through prediction in prodest - production function estimation method [26].

Table 1. Description of Variables and Expected Signs

Variable Description	Expected Sign
Amount of seeds used in (kg)	Positive
Amount of fertilizer consumed in (kg)	Positive
Amount of landholding by the producer farmers in hectares	Positive
Labor force which is equivalent to man-days	Positive
The number of ploughing oxen	Positive
Participation in Extension services program	Positive
Age of the household's head	Negative
Sex of the head of the household (1 = male-headed, 0 otherwise)	Positive
Years of schooling for the head of the household	Positive

Note: Aggregate Output of major crops is the dependent variable.

Source: Illustrated from the above Reviewed literatures.

3. Results and Discussion

3.1. Descriptive statistics of Dose response function

This study analyzed the impact of fertilizer utilization on the TFP of crops grown in Southern Ethiopia: Teff (*Eragrostis tef*) (Teff is the staple and small size local cereal originating from Ethiopia), wheat (*Triticum aestivum*), maize (*Zea mays*), barley (*Hordeum Vulgare*), and sorghum (*Sorghum bicolor*). Inputs and aggregated crop output were transformed into their corresponding logarithmic values in estimating the DRF models. However, there were some variables with the logarithmic value of zero that could become undefined. Consistent with the study of [27] the variables with zero values in the data set were changed to nearly zero (0.0001) values before transforming the data to logarithmic form. Various tests were also done before the analysis.

The probability distribution was allowed to be normal. The treatment variable was fertilizer application on those aggregated crops. Histograms and summary statistics indicated that the treatment variable was distributed normally. The likelihood ratio test (LR test) is performed to compare the goodness of fit of the two models of which, a null model against an alternative model to see the fitness of the two models. The endogeneity test indicated that the H0 is rejected with the value $p<0.001$. Based on the t-test, H0 is rejected due to the mean of both treated and untreated households was significant with a value of $p<0.001$.

The conventional inputs are chosen together with the treatment variable. Therefore, the transformed inputs: land size owned by the households, farm capital, oxen plowing, and labor force (equivalent to the man-days). The aggregate value of considered crop outputs is considered a dependent variable at the household level. In addition to that fertilizer is a continuous treatment variable (dose) in the study.

About, 37% variation in the outputs of considered major crops within the household is captured by the model (i.e., it indicates how well the explanatory variables account for changes in outputs within each household over time). 60% of the variance is due to differences across panels. The corr (u_i, Xb) = -0.5397, means the correlation between u_i and fitted values of explanatory variables is -0.5397. As land covered by the considered crops varies across time by one unit, its outputs increases by 0.28 units. Moreover, a 10% increase of oxen to plowing, seed, and labor force appears to increase outputs of considered major crops by 0.4%, 0.3%, and 0.2%, respectively. In other words, it is possible to argue that intensification is imperative in increasing the production of those crops (Table 2).

Table 2. Estimates of Fixed Effect Model (n=1,954)

Variables	Coefficients	Robust Std.Err.	t-test	P>|t|
Constant	-100.86 **	41.92	-2.43	0.015
Logarithm of area cultivated	0 .28***	0.06	4.81	0.000
Logarithm of ploughing oxen)	0 .04 ***	0 .01	5.23	0.000
Logarithm of seed used in Kg	0 .03 ***	0 .01	4.24	0.000
Logarithm of labor force in man-days	0 .02***	0 .01	2.91	0.004
Male headed households	0.46*	0 .20	2.30	0.021
Households participated in extension program	0.94***	0 .09	10.21	0.000
Households credit access used	0 .39***	0 .09	4.31	0.000

Households distance in (KMs) to nearest the market	-0.02**	0.01	-3.16	0.002
year	0.05*	0.02	2.59	0.010
Sigma_u	1.31			
Sigma_e	1.08			
Rho	0 .60			
corr(u_i, Xb) = -0.5397				
R-sq: within = 0.3720				

Legend: ***Significant at * p<0.05; ** p<0.01; *** p<0.001

Source: Authors' Computation.

Consistent with the authors of [28] stated that households who used fertilizer packages have a surplus of 109% increment of considered crop output than their counterparts. Households who applied oxen to plow, seed, and labor force, fertilize in the production process achieved a much higher surplus than their complements (Table 3).

Table 3. Summary of Observable Covariates

Variables	Mean Diff	Std.Err.	[95% Conf. Interval]	
Logarithm of aggregate output of major crops produced (treated)	1.09***	0.07	-1.23	-0.96
Logarithm of land cultivated in hectare (treated)	0.65***	0.05	-0.75	-0.56
Logarithm of labor force (treated)	1.07***	0.24	-1.54	-0.59
Logarithm of seed used in Kg (treated)	3.62***	0.26	-4.13	-3.09
Logarithm of ploughing oxen (treated)	4.81***	0.24	-5.27	-4.34

Legend: ***Significant at $p<0.01$

Source: Authors' Computation.

Households who participated in the extension program indicated a significant difference from their counterpart. The male-headed houses that applied fertilizer become benefited 66% more than the female-headed. Similarly, those households who used chemical for crop protection and applied fertilizer has gained a 22% surplus over the non-users of fertilizer. Thereby, 35% proportion of those households who did not use fertilizer during the survey years had access to irrigation, and 65% proportion of households who used fertilizers had access to irrigation (Table 4).

Table 4. Summary of Two-sample test of proportions with Treatment

Variables	**Mean Diff.**	**Treated**	**Untreated**	**Std. Err.**
Households who participated in the extension program	0.27***	0.63	0.37	0.03
Male headed households	0.66***	0.83	0.17	0.03
Households who used credit service	0.09***	0.55	0.45	0.03
Households who used chemicals for the prevention of crops from damage	0.22***	0.61	0.39	0.03
Households' with irrigated land	0.29***	0.65	0.35	0.03

Legend: ***Significant at $p<0.01$

Source: Authors' Computation.

2.1. Estimation of Dose-response function under exogenous treatment

The total value of output and fertilizer was scrutinized as the outcome, and treatment variables, respectively. The controls from the explanatory variables: age, the gender of the household heads, participation in the erosion prevention and extension program, access to irrigation, numbers of farm capital owned, landholdings, oxen for plowing, and labor force used in the production of considered crops in the area. The treatment effect (fertilizer application) on aggregate output indicated that fertilized land is estimated to have a 15% higher yield than its counterparts. Among the households who fertilized their land, a 10% increment in male-headed could positively affect the output of major crops by 1.3% in the area (Table 5).

Consistent with the findings of [22, 29, 34], the ages of household heads who applied fertilizer were affirmed to have a positive effect and increments by one more year, which implies the slight increments in the productivity of major crops by 0.01 units. A 10% increment in the involvement of the extension system of households who applied fertilizer brought a 5.7% increment in the productivity of considered crops. A 10% increment in the size of irrigated land of households that applied fertilizer is also estimated to improve the productivity of considered crops by 1.04%. A 10% increment in the farming capital of fertilizer-applying households could increase 0.5% of the mentioned crop output, indicating the crop's productivity depends on the utility level of fertilizer (Table 5).

Table 5. Estimation of Dose-Response Function as Exogenous Treatment Case

Logoutput	Coeff.	Std. Err.	t-test	[95% Conf. Interval]	
Treatment	0.15***	0.09	2.81	0.07	0.41
Household head’s gender	0.13***	0.07	2.42	0.03	0.30

Household's that have irrigation access	1.04***	0.06	16.94	0.93	1.18
Extension program participated	0.57***	0.17	3.30	0.23	0.91
Logarithmic Value of farm capita in number	0.05***	0.01	5.05	0.04	0.09
Logarithmic Value of oxen	0.03***	0.01	5.47	0.02	0.04
_ws_age of the household heads	0.01***	0.003	3.52	0.004	0.01
_ws_extension	-0.98***	0.19	5.24	-1.34	-0.60
_ws_erosion prevention	0.28***	0.08	3.69	0.13	0.43
Tw_1	0.1***	0.03	3.05	0.04	0.17
Tw_2	-0.01***	0.001	-3.52	-0.008	-0.002
Tw_3	0 .00004***	0.00001	3.49	0.00002	0.00006
__cons	6.1***	0.35	17.52	5.42	6.78

Legend: ***Significant at $p<0.01$; Coeff. = Coefficients

Source: Authors' estimation.

The DRF indicates the relationship is weakly increasing and quite precisely estimated for both higher and lower values of fertilizer in the study area. Therefore, DRF is more strongly decreasing some values of outputs estimation becomes increasing for higher levels of dose or fertilizer to improve the productivity of considered crops. In other words, the minimum dose of fertilizer application was found around a dose of 70 where the DRF correctly exhibits a flex point, indicating that production of higher output demands at least 70% application of fertilizer. Thus, as the dose of using fertilizer increases, the proportion of output produced could increase (Figure 1).

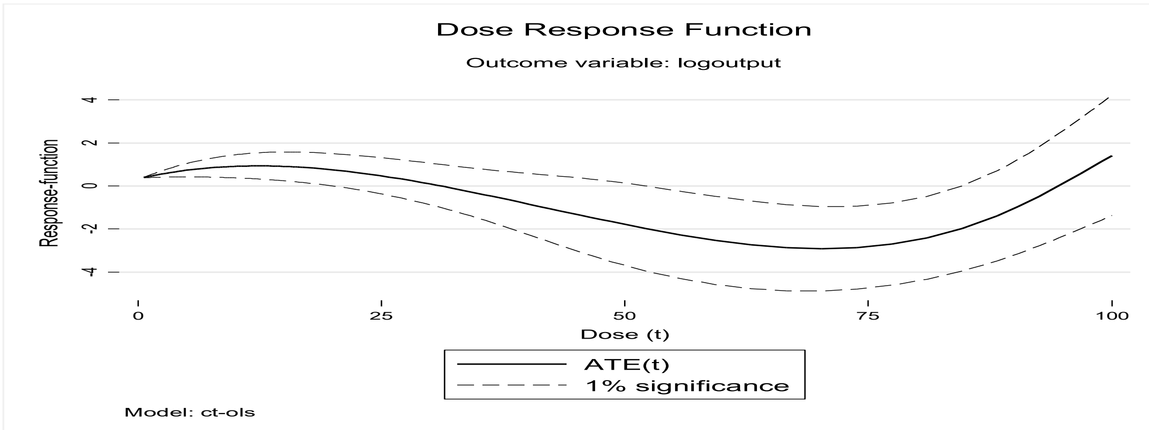


Fig 1. Dose-Response Function of Fertilizer on Aggregate Outputs of Major Crops; Exogenous Treatment Case

However, the derivative of DRF with its confidence interval improved the dose level that can enhance productivity. As the parabola of derivative DRF is a cubic function of the previous DRF, the minimum dose becomes between 40-50, where the DRF correctly exhibits a flex point. The derivative dose-response showed that the decreasing and later increasing tendencies were initially downward sloping and later upward sloping trends of fertilizer application, indicating both negative and positive impacts on the productivity of considered major crops (Figure 2).

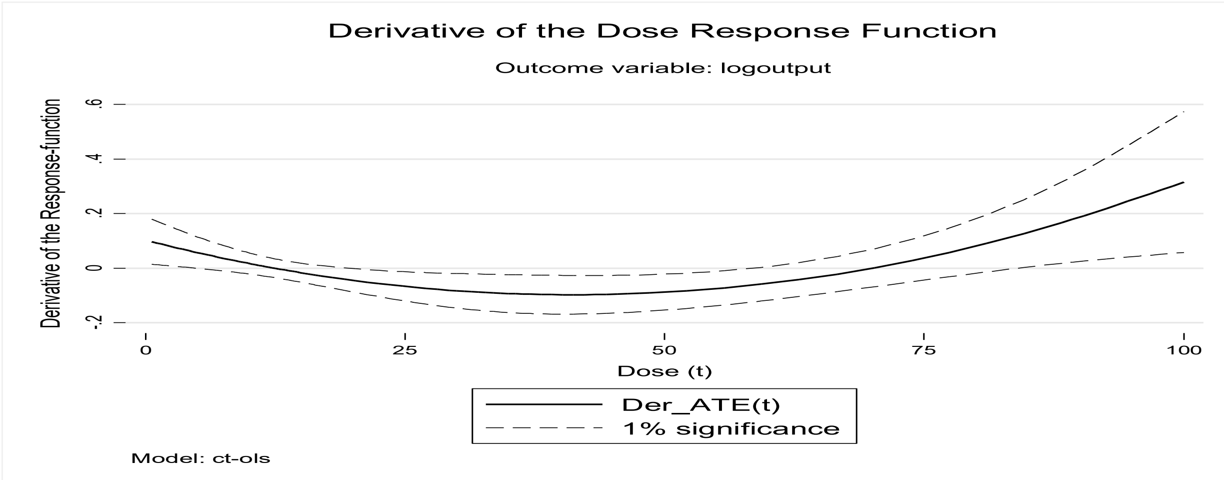


Fig 2. Derivative of the Dose-Response of Function of Fertilizer on Aggregate Outputs of Major Crops; Exogenous Treatment Case

Estimated DRF in Figure 1 and its derivatives in Figure 2 indicated that the households who applied fertilizer to their considered major crops at higher doses can increase their productivity. Comparatively, the minimum requirement of fertilizer that is expected to increase the productivity of considered crops was 70 in DRF of Figure 1. However, 40-50 in derivatives DRF of Figure 2 shows fertilizer applying households using at least 40-50 of a dose can produce higher outputs.

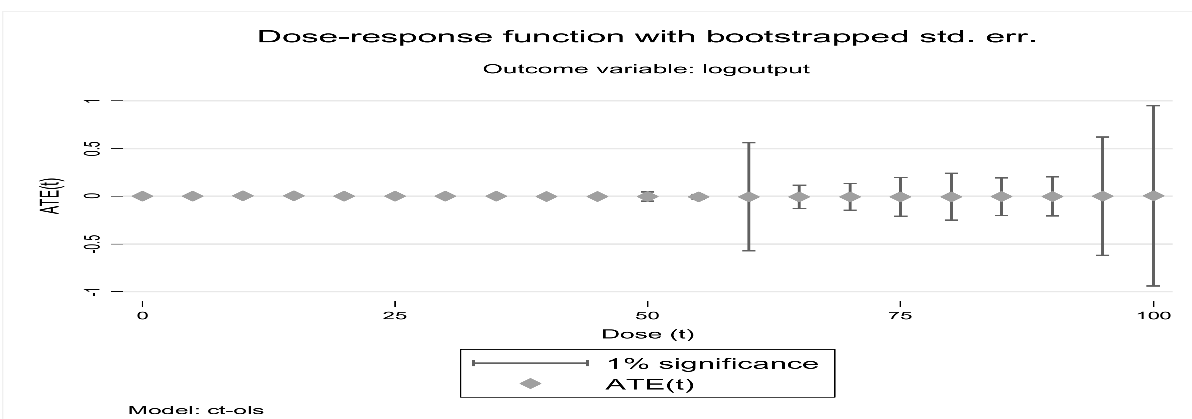


Fig 3. Dose-Response of Function of Fertilizer on Aggregate Outputs of Major Crops; Exogenous Treatment Case with Bootstrapped Standard Errors.

In estimating the DRF under endogenous treatment, 782 censored and 1,173 uncensored observations were considered for the analysis. About 61% of the variability in the productivity among the households who applied fertilizer was due to differences across the survey years. The explanatory variables considered in the analysis had positive effect on the aggregate output of major crops. In addition, a 10% increment in the male-headed household that applied fertilizer experienced a 0.4% output rise for the major crops (Table 6).

The coefficient of second-stage variables (3.55) was much larger than that of the first-stage estimate (2.57). The variances of the variables in the first stage (1.27) are higher than the variance of the variables in the second stage (0.19), indicated that the higher variance of the variables is the best reason for the coefficient's lower value (Table 6). Consistent with the previous studies of [30, 19, 35, 32], a 10% increment of irrigated land by the households who applied fertilizer brings nearly a 2.5% increase in the aggregate output of major crops. Households with farm capitals who apply fertilizer can get 6% higher production of considered crops than their counterparts (Table 6).

Table 6. Two-step Estimation of Heckman Selection Model

Variables	**Coeff.**	**Std. Err.**	**z-test**	**[95% Conf. Interval]**	
fertlizer2					
Male headed households	-0.28*	0.38	0.74	-0.46	1.02
Access for irrigation (yes=1)	-0.45*	0.34	-1.32	-1.12	0.22
Participation in extension program	-2.19**	1.20	-1.81	-4.56	0.18

Logarithmic value of oxen	0.02*	0.05	0.43	-0.07	0.12
Logarithmic value of farm capital	0.11	0.13	0.86	-0.14	0.36
Logarithmic value of land size in ha	0.56*	0.16	3.48	0.25	0.88
Credit access (yes=1)	0.61*	0.32	1.94	-0.01	1.23
_cons	2.57**	1.28	2.01	0.07	5.07
Treatment					
Male headed households	0.04*	0.09	0.44	0.03	0.20
Access for irrigation (yes=1)	0.25***	0.09	2.94	0.41	0.80
Participation in extension program	1.73***	0.09	19.94	1.90	2.56
Logarithmic value of oxen	0.05***	0.01	8.21	0.04	0.06
Logarithmic value farm capital	0.06***	0.02	3.53	0.03	0.09
Logarithmic value of seed	0.003***	0.01	4.69	0.002	0.04
_cons	3.55***	0.19	18.44	3.18	3.93
Mills					
Lambda	3.06	1.46	2.10	0.20	5.92
Rho	0.61				
Sigma	5.06				

***Significant in <1%; **Significant in <5%; *Significant in <10%; Coeff. = Coefficient

Source: Authors' estimation.

Consistent with findings [29, 33, 34], the logarithmic values of landholding, seed, and households that used credit services are considered instrumental variables for 2sls estimation. The estimation result of the impact of applying fertilizer by using an instrumental variable revealed that households who applied fertilizer are estimated to harvest 111% higher output than their counterparts. The age of household heads is also statistically significant at the 10 percent level, implying that as the age of the household head increases by one more year, the outputs of aggregated major crops exhibit a slight increment by 0.009 units. About, a 10% increment of irrigated land for the fertilizers applied to households could increase by 10.4 % of outputs (Table 7).

Table 7. Instrumental Variables by Two Stage Least Square (2SLS) Regression

Logoutput	Coeff.	Std. Err.	t	[95% Conf. Interval]	
Treatment	1.11*	0 .66	1.69	-0.18	2.39
_ws_age	0.01*	0 .004	2.10	.0006	0.02
_ws_extension	-4.21***	1.17	-3.61	-6.50	-1.93
Tw_1	0.371*	0.16	2.28	0.05	0.69
Tw_2	0.003*	0 .02	017	-0.03	0. .04
Tw_3	-0.0001*	0 .0002	-0.29	-0.0005	0.0003
Male headed households	-0.12*	0 .18	-0.68	-0.48	0.24
Access for irrigation (yes=1)	1.04***	0 .13	8.11	0.79	1.29
Households participated in extension (yes=1)	2.21*	0.97	2.28	0.31	4.11
Logarithmic value of oxen	-0.02*	0.01	1.56	-0.005	0.05
Logarithmic value of farm capital	0.03*	0 .02	1.44	-0.010	0.07
_cons	0.58*	2.10	0.28	-3.54	4.71

Instrumented: treatment _ws_age _ws_extension Tw_1 Tw_2 Tw_3
Instruments: sex dmmirrig extension logoxen logfarm_capita probw _ps_age _ps_extension T_hatp_1 T_hatp_2 T_hatp_3

Note: Coeff.= Coefficient

Source: Authors' estimation.

In the endogenous treatment, DRF indicated that the relationship was slightly increasing for the values of dose. DRF was slightly increasing some values of treatment estimation for higher levels of the dose in the mentioned crops. Therefore, the maximum dose of fertilizer application was around a dose of (90-100) where the DRF correctly exhibits a flex point, indicating that improvement in the expected productivity (Figure 4).

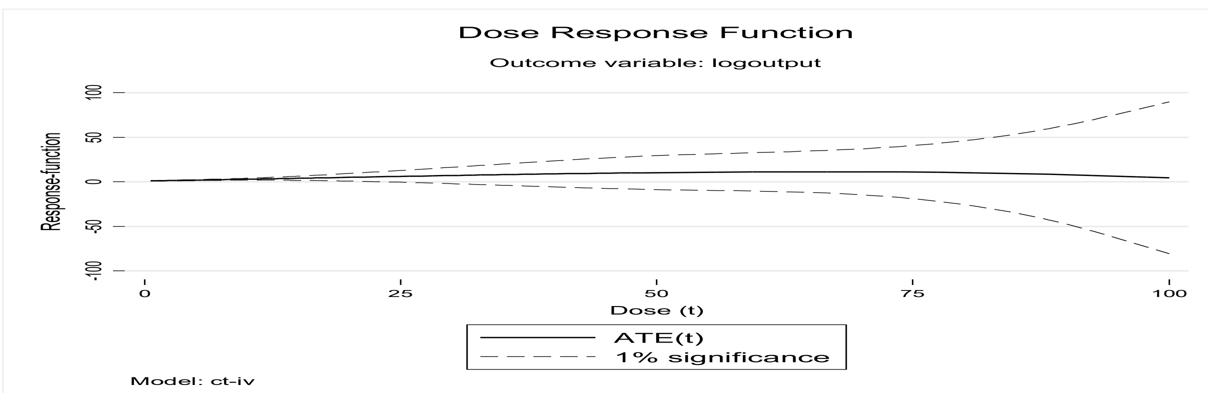


Fig 4. Dose-Response of Function of Fertilizer on Aggregate Outputs of Major Crops; Endogenous Treatment Case

In endogenous treatment, the dose-responses and derivative demonstrations have similar tendencies for the outputs of considered crops. However, the minimum dose for the increasing trends of fertilizer in the dose-response and derivative was varying so far. This result was dissimilar to the one obtained using the exogenous treatment. As indicated earlier by [31], on average, 54.8%

of households can consume fertilizer in 2011/12 to enhance their production of considered crops. The average number of households who have been utilizing fertilizer increased from 63.4% to 64.9% (2013-2016) (Figure 5).

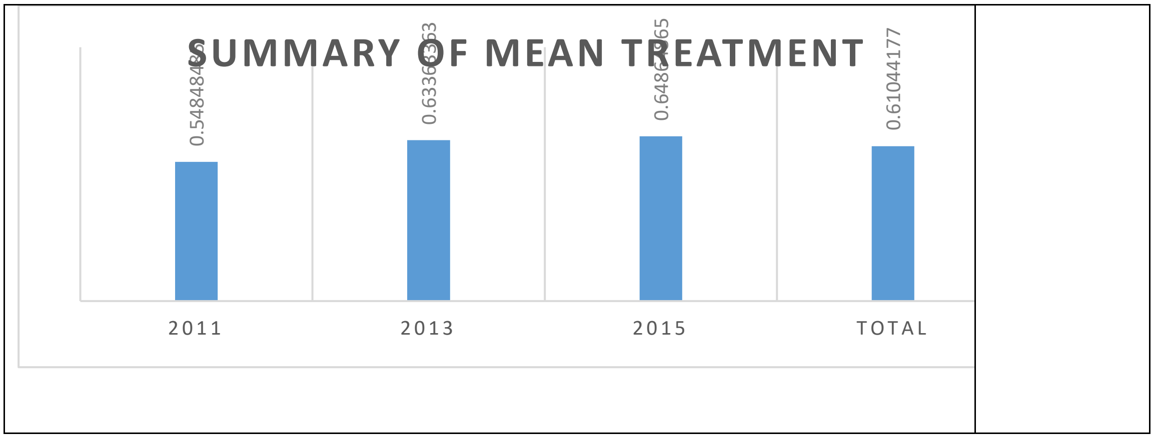
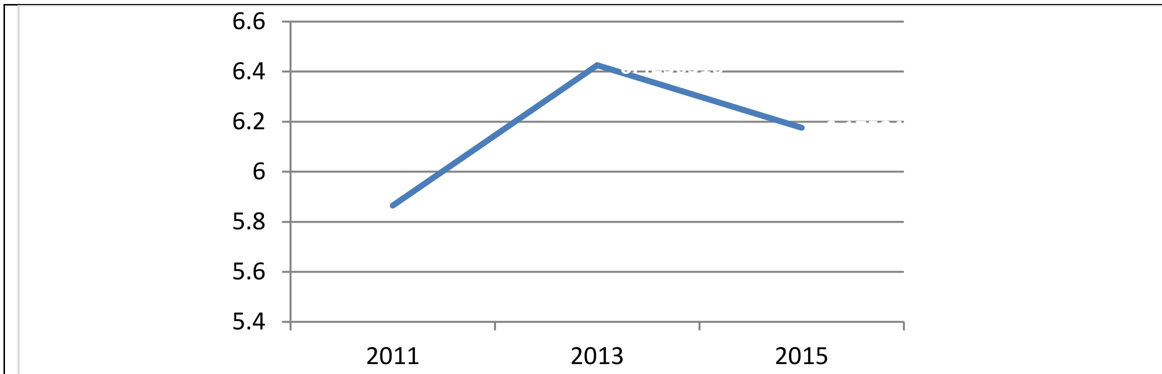


Fig 5. Summary of Treatment

3.2.Treatment effect on total factor productivity of major crops

Following theoretical acknowledgment of [13, 20], in this study, the average TFP obtained was 6.16 during the survey years indicating that; the productivity of considered major crops exhibited a clear upward trend between 2011/12 to 2013/14 and bent down from 2013-2015 in the area. Though aggregated outputs of crops increased from 2011/12-2013/14, there was a slight decline in TFP in 2015/16. In both exogenous and endogenous treatments, the outputs of crops treated households were positive and highly significant (Figure 6).



Average

TFP

Fig 6. Summary of total factor productivity during the survey years

Labor productivity which is the ratio of real value of production in birr to the productive member of the family labor in adult equivalents increased significantly in the survey years. On top of that, average land productivity in birr per hectare increased from 858.93 birr in 2011 to 1855.89 birr in 2013 and slightly increased to 1872.35 birr in 2015. This happens mainly because of extreme observations in the data. The land-labor ratio indicated that the relative scarcity of land in the study area.

Table 8. Land and labor productivity from 2011–2015 (in Birr)

Year	Mean Land-productivity	Mean Labor-productivity	Land–labor ratio
2011	858.93	2.72	0.0142
2013	1855.89	5.33	0.0219
2015	1872.35	16.66	0.0094

Source: Own Illustration (2022).

Household's members under productive age between (15 to 65) years are used to proxy labor use for the households.

4. Conclusion and Policy Implication

In the case of endogenous treatment, the households have got much larger outputs than in exogenous treatment. When the extension service participant increases by one unit in the exogenous and endogenous treatment cases, the farm household outputs of considered crops enhanced significantly by 0.57unit and 1.73 units, respectively. Intensification is the ideal source of productivity growth. Thus, land size, fertilizer use, extension service, and farm capital are the main determinants of the productivity of expected crops.

Moreover, inputs: land covered by those crops, oxen; seed, and labor force in man-days can positively affect the level of production across time. Households with irrigated land irrigated and applied fertilizer have a significant proportional effect on the level of considered crop production. Generally, households who treat fertilizer for the output growth have gotten a 109% surplus of those considered crop production. Agricultural input intensified in the production of those considered crops has a pivotal role in enhancing the productivity of the crops.

Disclosure statement

No conflict of interest was reported by the author(s).

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