Total Factor Productivity of Major Crops in Southern Ethiopia: A Dis-Aggregated Analysis of the Growth Components

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Abstract: (1) Background: Even though agriculture is the backbone of the Ethiopian economy, the improvements made regarding crop productivity appeared insufficient and had slow progress. Several studies suggest possible ways to identify the challenges in the productivity of the crop sub-sector. Nevertheless, there are gaps in the empirical literature in both knowledge and methods. The current study intends to identify the factors that affect growth in the productivity of teff, maize, barley, wheat, and sorghum crops. (2) Methods: Cobb-Douglas stochastic production function is estimated using a panel data set of the Living Standard Measurement Survey. To address the objectives of the study, a parametric estimation with a time-varying decay model with deterministic and stochastic components was adopted. (3) Results and Discussion: The effect of inputs on aggregate output was positive and significant at the 1% significance level, implying the presence of economies of scale. Variation in the inefficiency term explained 46.4% of the total variance in the composed error term. The average productivity of major crops was 6.19 per year. This study implied that technical change in the production of major crops increased by 22% with better use of available technology. (4) Conclusions and Policy Implication: The findings pinpoint that farmers should focus on technical change and intensification of improved agricultural inputs.

Keywords: Cobb Douglas production function; technical efficiency; technical change; productivity; teff; maize; barley; wheat; sorghum

1. Introduction

Achieving overall growth in agricultural production and reducing poverty are the major priorities of developing countries. Hence, in developing countries, productivity improvement is all about either increased use of inputs and technologies or enhancing the producer efficiency given a fixed amount of farm inputs and technology [1]. In fact, sources of growth in crop production are significantly different from region to region. For instance, in Asia, crop productivity growth is driven by intensification, whereas in South America, its growth is due to improvement in labor productivity, efficient adoption of new farm technology, and efficiency. In contrast, growth in Africa emerges more from area expansion more than the intensification of cropping systems [2–4].

In Ethiopia, having a population growth rate of 2.45% per annum, agriculture is the dominant economic sector accounting for 43% of its GDP, over 75% employment, and 90% foreign exchange earnings [5]. Despite the most agricultural potential, the country has huge availability of arable land, abundant workforce, and diverse agro-ecological zones, agriculture remains highly vulnerable to the vagaries of nature. Towards this end, there is need for combating the challenges posed by the vagaries of nature and enhance the sector’s contribution to its economy by adopting yield-improving inputs and enhancing...
intensification. Evidence shows that there was 37% inefficiency (inefficiency can occur if a particular product is not possible to produce a given production with at least one input is called technically inefficient) in the product of cereal crops in Ethiopia [6]. However, sources of inefficiencies differ from place to place [7,8].

Globally, over the last two decades (1998/99–2016/17), the growth rate of cereals was 3.45 t/ha compared to 3.01 t/ha in less developed countries (LDCs). Exclusive to China, growth rate would decline to 2.43 t/ha indicating a 29.5% growth rate difference between developed and LDCs [4,9]. The productivity of major crops in Ethiopia has been consistently below the global and even LDC average. In Ethiopia, the national productivity of major crops for 2018 is 2.257 t/ha. Southern Ethiopia has a 1.882 t/ha productivity growth record for the same year, which is by far below the national average [5,10]. Moreover, the average national productivity of cereals such as maize, wheat, teff, barley, and sorghum in 2018 were 2.11, 1.66, 5.8, 2.3, and 1.85 t/ha, respectively. Comparatively, the productivity of these same crops in Southern Ethiopia was below the national average except for maize with 3.42 t/ha for the same period [11,12].

In the 20th century’s technological breakthroughs for high-yielding crop varieties that are highly responsive to agricultural inputs are inorganic fertilizers, insecticides, and improved seeds [13]. Thus, the past and current performances are highly dependent on the intensity of input use. As total factor productivity (TFP) is a concept that describes changes in the efficiency of which inputs have transformed into outputs. In addition to this, TFP can also be determined by analyzing how efficiently inputs have been used in the production process of agriculture. However, as part of TFP, measuring technical efficiency (TE) and technical change (TC) has remained an area of research, especially in LDCs where there is a need for mechanization to upscale productivity [14,15].

The overwhelming problem of African agriculture, among others, is related to a lack of proper recording of the source of productivity growth. Several studies argued that the principal sources of TFP in agriculture in sub-Saharan Africa (SSA) are TE and the expansion of cultivable land rather than a technology change [16–18]. On the other hand, the unclear recommendations from prior researches demand in-depth analysis in separating the real sources of higher TFP between farms of different sizes in the SSA crop production process [19,20].

Previous studies focused on cross-sectional data and the stochastic frontier approach (SFA) measuring TFP at local levels [8,21–24]. However, there is little examination on the subject by using panel data and SFA at the regional level. This implies that there is a knowledge gap about the dynamics of agricultural TFP growth efficiency and TC in SSA in general and Ethiopia in particular [25–27] and more particularly in Southern Ethiopia. The other knowledge gap worth mentioning is the need for TFP measurement and partial factor productivity considering their dynamism [28–30].

Estimation of TFP growth is likely to comprise the combined effects of TE, TC, economies of scale, variations in producers, and errors in the measurement components of total input and output of the farm [23]. In agricultural economics, to measure TE from some point of the actual output is compared with the ideal output from the production function [31–33]. Reorganization of production, government investment in infrastructure, and external exposure, competitive pressures can enhance TE. Moreover, the best agronomic practices with appropriate policy instruments, the producers’ educational level, skill, and knowledge is the determinant factor that influences agricultural TFP [6,34–36].

On the other hand, there are two approaches to measuring TFP growth: frontier and non-frontier approaches. Each of these approaches can be further divided into parametric and non-parametric techniques. This study used parametric techniques such as econometric estimation of the stochastic, deterministic model, and maximum likelihood estimation. This approach enables to measure and compare productivity growth components through time [37,38].

Against the above backdrop, this research examines the share of TE and TC as the components of TFP in Southern Nation, Nationalities, and Peoples Region (SNNPR) Ethiopia.
This research contributes to filling the observed knowledge gap about the level of TFP in Southern Ethiopia. In addition, it significantly contributes to the existing literature by identifying the share of the source of TE and TC as the components of TFP. In doing so, it informs academicians to strengthen the existing model of TFP analysis based on the empirical evidence from Ethiopia. More importantly, it contributes to practitioners and policymakers in Ethiopia by providing them with relevant information about how to improve the productivity of the major crops considered in the study. The reminder of the article is presented as follows: the second part deals with data sources, method of data collection, and the models adopted for analysis. The second part presents the results of the analysis followed by a nuanced discussion of pertinent issues. Finally, the article concludes by providing actionable recommendations.

2. Methodology

2.1. Research Approach and Design

The study was based on a mixed-method approach to triangulate shreds of evidence from qualitative and quantitative sources. As the authors of [39] mentioned, the mixed methods research approach is a combined element of the qualitative and quantitative research approach. It helps to get a greater degree of understanding than adopting a single one. Triangulating quantitative and qualitative data provides the opportunity for convergence and corroboration of the findings [40]. The study adopted a descriptive and causal research design in a bid to addressing the objective of describing growth rate and accounting for the growth components of crops considered in the study.

2.2. Data Sources and Collection Methods

Primary data was collected by employing semi-structured interviews, focus group discussions (FGDs), and key informant interviews. The regional, three zonal, and three districts of Agriculture and Natural Resources Development office heads were selected purposively to serve as key informants. Two FGDs from each of the Enumeration Areas (EAs) were selected purposively. This was meant to complement the quantitative data obtained from the Ethiopian Socioeconomic Survey (ESS), which contains household demographic and agricultural information collected with the support of the World Bank.

In the data cleaning process, a strongly balanced panel data consisting of 2187 households was created for Southern Nations, Nationalities, and Peoples Region. The data set included major crops (barley, maize, teff, wheat, and sorghum) produced and valued in three steps. First, the quantity product measured in different local units of measurements was converted into a standard measure (kilogram). Following the findings of [41], conversion factors (CF) prepared by the Central Statistic Authority (CSA) used at the village level. 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 was 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 was also converted into standard measure (hectare) using the CF of CSA and aggregated into the household level.

One of the inherent limitations of this study is the use of family labor as a proxy indicator for labor used in considered crop production. This 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 period calculated as follows: firstly, we calculated the adult equivalent unit by sorting the age of each household member by using the standards. Secondly, days in a week, a month and a year were converted. Thirdly, the man-days were calculated by multiplying them by their respective category (men, women, and children). Farm capital was measured as 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 a farm implement used to plow land by putting around the neck region of
oxen to be connected with Mofer; it is a yoke), water storage pit, water pump, traditional plow, and modern plow were converted. Differences in quality and heterogeneity in the types of the assets owned are expected to increase measurement errors. Livestock ownership was measured in Tropical Livestock Units (TLUs) following prior works [27]. 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.

2.3. Sampling Techniques and Sampling Size Determination

From 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 were randomly selected, respectively. In all three years (2011, 2013, & 2015), the selected EAs and households per EA for quantitative data remained the same.

2.4. Method of Data Analysis and Model Specification

The efficiency of households was estimated using the time-varying inefficiency decay model with deterministic and stochastic components of parametric functions. Estimation assumed unobserved individual error as random and a deterministic function of time dummies [37,40,42–45]. These models were selected over the other panel data models of the production function as it drops the entire incidental parameters problem in the analysis. In addition, the specification of inefficiency is easy to derive from the likelihood function [40]. Thus, the study employed specific SF parametric approaches of SPF and deterministic models to measure TE and TC with the above-mentioned crops. There are reasons for using this model. First, the model can fix inefficiency for a given individual. Second, it is able to change over time and across individuals. The parametric deterministic production frontier is presented as follows:

\[ y_{it} = f(X_{it}; \theta) \cdot \exp(-u) \]  

where \( y_{it} \) is the scalar output of a producer, \( f(X_{it}; \theta) \) is the deterministic part of SPF with technology parameter vector \( \theta \) to be estimated, \( X = (X_1, \ldots, X_n) \geq 0 \) is an input vector, \( t \) is a time trend serving as a proxy for TC, and \( u \geq 0 \) represents output-oriented technical inefficiency. From this production frontier, the rate of TC is measured as follows:

\[ \Delta TC = \frac{\partial \ln f(X_{it}; \theta)}{\partial t} \]  

Then, \( \Delta TC \) would have three chances: being a value greater than, less than or equal to zero as TC shifts the production frontier up, leaves it unchanged, or shifts it down, respectively. Similarly, the rate of change of TE \( \Delta TE \) is also measured as:

\[ \Delta TE = -\frac{\partial u}{\partial t} \]  

where \( \Delta TE \) is TE, the inefficiency term \( \partial u \) is always between 0 and 1, where \( \partial u \) is equal to zero, then production is on the frontier and \( \Delta TE = 1 \), therefore a farmer is technically efficient. When \( \partial u \) is greater than zero, the farmer is technically inefficient (\( \Delta TE < 1 \)), since production is below the frontier. In other words \( \Delta TE \) would have a value greater than, less than or equal to zero as technical inefficiency declines, remains unchanged, or increases through time, respectively [43].

\[ \ln output_{it} = \beta_0 + \beta_1 \ln land_{it} + \beta_2 \ln oxen_{it} + \beta_3 \ln seed_{it} + \cdots + \beta_n \ln labor_{it} + \beta_n \ln fertilizer_{it} + \epsilon_{it} \]  

where \( i = 1 \ldots, I \) and \( t = 1 \ldots, T \) and \( \epsilon_{it} = V_{it} - U_{it} \)
where \( \varepsilon_{it} \) is the composed error terms \( V_{it} and U_{it} \). \( V_{it} \) is a non-negative random variable (inefficiency) term, which is assumed to be independently and identically distributed as half normal distribution above zero of the \( N\left(\mu, \sigma_u^2\right) \) distribution. Error terms \( U_{it} and V_{it} \) are respectively, the idiosyncratic and inefficiency components of the “composed error term”, \( \varepsilon_{it} \) of producer \( i \) at time period \( t \) \([38,44]\).

\[
u_{it} = \gamma u_i = \{\exp[-\gamma(t - T)]\}u_{it} and TE_{it} = E\left[\exp\left(-\frac{U_{it}}{\varepsilon_{it}}\right)\right]
\] (6)

where \( \gamma \) is the unknown scalar parameter, and \( T \) is the last period for which observations for the \( i \)th households were obtained. This model assumes that \( u_{it} \) decreases, remains constant or increases, as \( \gamma > 0, \gamma = 0 \) or \( \gamma < 0 \), respectively. Setting \( \gamma = 0 \) provides the time invariant model. On the other hand, \( \gamma > 0 \) implies households tend to improve their efficiency over time and vice versa. \( V_{it} \) is assumed to be independently and identically distributed. Thus, based on these assumptions, the probability density function of the composite error term \( \varepsilon_{it} \) and its log-likelihood function are derived for the model using maximum likelihood estimation technique. The predicted value of TE for producer \( i \) in period \( t \) is the conditional expectation of the inefficiency component in the error term.

To find TFP, we estimated production function using the control function approach. Method of estimation was Levinshon-Petrin (LP) approach. It requires the logarithmic gross of output variable through time. For illustration purposes, consider a simple Cobb–Douglas production function (CDPF) in logs as follows:

\[
\ln output_{it} = a_0 + land_{it} + seed_{it} + fertilizer_{it} + oxen_{it} + labour_{it} + \varepsilon_{it}
\] (7)

where \( \ln output_{it} \) was the log of output, \( land_{it}, seed_{it}, labour_{it}, fertilizer_{it} \) and \( oxen_{it} \) were the logarithmic inputs that all of were observed. Then, TFP was estimated by predicting the production function estimation method. The variables included in the model and their expected signs are presented in Table 1.

**Table 1. Description of Variables and Expected Signs.**

| Variable Description | Expected Sign |
|----------------------|---------------|
| Amount of seeds used in (kg) | Positive |
| Real Output in value (of Teff; Maize; Barley; Wheat, and sorghum) | 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 plowing oxen | Positive |
| Households’ Participation in extension program | Positive |
| Credit services used | Positive |
| Prevention measures of crop by chemical | Positive |
| Households’ participated in crop rotation | Positive |
| Households’ participated in erosion prevention | 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 |

Aggregate output of major crops is the dependent variable. Sources: Compiled from the Literatures.

3. Result and Discussion

3.1. Growth Rate of Input Use and Output of Major Crops in Southern Ethiopia

The major crops grown in SNNPR are Teff (Teff is the staple-small size local cereal originated from Ethiopia) (Eragrostis), wheat (Triticum), maize (Zea Mays), barley (Hordeum Vulgare), and sorghum (Sorghum Bicolor) \([5]\). The bulk of production was increased due to increments in the factors of production, except for sorghum, i.e., sorghum showed a negative growth rate in Southern Ethiopia during the survey years. Variation of the output
to the variation in the utilization of inputs is attributed. More specifically, 2011/12 as the base year, the average growth rate (AGR) of maize production showed a slight increment from 9.79% in 2013/14 to 11.17% in 2015/16 (Table 2). This is consistent with the claim by [43] and contradictory with the findings of [27] over the last five decades. Therefore, it is possible to argue that households have participated relatively in better agronomic practices to enhance maize crop production than other crops under consideration in the study area.

Table 2. Average Growth rate of Volume of Production of Major Crops.

| Major Crops | Average Growth Rate of Major Crops in % |
|-------------|----------------------------------------|
|             | 2013/14 | 2015/16 |
| Barley      | 53.61   | 37.41   |
| Maize       | 9.79    | 11.17   |
| Sorghum     | −26.24  | −31.97  |
| Teff        | 41.28   | 30.23   |
| Wheat       | 29.79   | 25.08   |

Source: Authors’ estimation.

Though there is a significant improvement in participation in the extension program, crop rotation activities, use of irrigation facilities, and access to credit service, there was a slight decline in fertilizer consumption during 2013/14 as compared to that of 2011/12. Though 45% of households participated in the extension program and 57% of households irrigated their land in 2013/14, this data might be exaggerated based on the number of aggregate outputs during 2013/14. There was also a slight decline in the fertilizer consumption in the 2013/14 survey year as compared to that of 2011/12 (71.56 kg to 61.65 kg) (Table 3). As FGDs and interviewees indicate, fluctuation in the needs of fertilizer was mainly due to the repayment problems and the mismatch between the demands of smallholder households and the supply of fertilizer by the regional government in the study area.

Table 3. Mean Values and Average Growth rate of Households Input–Output Data used in Stochastic Production Function.

| Variables                                | 2011  | 2013  | 2015  | AGR in % |
|------------------------------------------|-------|-------|-------|----------|
| Households’ irrigation use (Yes = 1)     | 0.13  | 0.57  | 0.16  | −44.83   |
| Participation in extension program (Yes = 1) | 0.27  | 0.45  | 0.45  | 15.38    |
| Credit service used (yes = 1)            | 0.29  | 0.37  | 0.36  | 5.88     |
| Prevention measures of crop by chemical (yes = 1) | 0.39  | 0.51  | 0.53  | 10.42    |
| Households’ participated in crop rotation (yes = 1) | 0.37  | 0.40  | 0.43  | 7.5      |
| Households’ participated in erosion prevention (yes = 1) | 0.38  | 0.44  | 0.47  | 9.3      |
| Amount of fertilizer used (in Kg)         | 71.56 | 61.64 | 66.8  | −0.52    |
| Households’ seed used (in Kg)             | 2.90  | 14.99 | 19.69 | 57.14    |
| Number of farm capital                    | 4.31  | 4.92  | 5.04  | 5.88     |
| Labor force (man-days)                    | 319.6 | 388.6 | 412.4 | 10.4     |
| Area cultivated (in hectare)              | 0.92  | 1.07  | 0.95  | −3.06    |
| Number of plowing oxen                    | 0.82  | 1.15  | 1.14  | 9.62     |
| Real value of output produced (in Kg)     | 1035  | 1092  | 1241  | 10.51    |

Source: Authors’ calculation.

About 15.22% increment of land coverage from 2011/12 to 2013/14 declined by 10.38% in 2015/16. Therefore, it is possible to argue that increment in the volume of production of crops considered mainly comes from area expansion (Table 3). It contradicts the findings’ of similar studies [24]. However, it is consistent with the findings of another study [29].

3.2. Estimation Result of the Cobb-Douglas Production Function

Inputs and aggregated output of crops considered were transformed into their corresponding logarithmic values in estimating the Cobb Douglas production function. How-
ever, some variables with a logarithmic value of zero could become undefined in the raw data. Following suggestions [8], variables with zero values in the data set were changed to nearly zero (0.0001) before transforming them into their logarithmic form. Various tests of the parameters estimates of the production frontier were presumed. The validity of models was also checked before the analysis.

All explanatory variables were jointly significant in explaining the dependent variable (the $H_0$: $\beta_1 = \beta_2 = \beta_3 \ldots \beta_6 = 0$ is rejected at $p < 0.001$). Wald tests performed for parametric testing of the null hypothesis ($H_0$) of no inefficiency is rejected at $p < 0.001$. (Table 4). Then, inefficiency effects were present in the model. When it takes values between 0 and 1, the $H_0$ might be rejected. Alternatively, this is to test whether the stochastic frontier production function is more appropriate than the conventional one. If the $H_0$ is not rejected, the stochastic frontier production function would have the same value as the conventional one. Based on the estimation results presented in Table 4, the $H_0$ for the test of no inefficiency is rejected showing the presence of inefficiency in the production of major crops in the study area. In the same table, it was confirmed that there is half normal distribution. The $H_0$ for the test of no half normal distribution is rejected at $p < 0.001$.

Table 4. Generalized Likelihood ratio Tests for the Parameters of Stochastic Production Frontier and Technical Efficiency Factors.

| Hypotheses                             | LL $H_0$ | LL $H_1$ | Test Statistics | Critical Value | Decision |
|----------------------------------------|----------|----------|-----------------|----------------|----------|
| $H_0$: $\beta_1 = \beta_2 = \beta_3 \ldots \beta_6 = 0$ | -3421.55 | -3411.38 | 20.51           | 20.34          | Reject $H_0$ |
| $\mu$ is not half normal distribution ($H_0$: $\mu = 0$) | -3421.01 | -3403.62 | 34.78           | 22.46          | Reject $H_0$ |
| No inefficiency ($H_0$: $\gamma = 0$) | -3436.92 | -3403.62 | 66.6            | 13.82          | Reject $H_0$ |

LL stands for log-likelihood. Source: Authors’ estimation.

The stochastic frontier model and the log-likelihood test done continuous iteration achieved the maximized iteration, which used to calculate the log-likelihood statistics (Table 4). The likelihood-ratio test statistic $\lambda = -2[\log [\text{Likelihood (H}_0>] - \log [\text{Likelihood (H}_1>)]$ has approximately a chi-square distribution ($\chi^2$), distribution with q equal to the number of parameters assumed to be zero in the $H_0$; it is compared with the critical values of ($\chi^2$) and decided between the two models [31]. According to Akaike’s information criterion (AIC) and Bayesian information criterion (BIC) presented in (1974), a model with the maximum likelihood estimates (MLE) of the parameters which give the minimum of AIC to be accepted.

Parametric estimation of the Cobb-Douglas production function predicted that the coefficients of ploughing oxen, land size, the labour force, and fertilizer consumed, and seed used is statistically significant in affecting the volume of production of major crops. Thus, a 10% increase in the labour force and area covered by the considered crops is estimated to improve aggregate output by 0.336% and 0.648%, respectively. Those households who applied fertilizer can enhance their productivity by 0.487% than the counterpart. Thus, improvement in the utilization of labour force, fertilizer, and land for the crops considered in this study could have additional production and productivity impact in the study area. Similarly, a 10% increase in the use of improved seeds and ploughing oxen are estimated to increase the aggregate output of major crops by 0.334% and 0.623%, respectively during the survey years. It implies that as a greater number of oxen is used for land preparation until the land become softer, it could improve the level of production of those major crops in the study area (Table 5). This result is consistent with previous findings [6,25,44].
Table 5. OLS Estimates of Cobb-Douglas Production Function (n = 1957).

| Variables                          | Coefficients | Std. Err. | z-Test | p > |z|  |
|-----------------------------------|--------------|-----------|--------|-----|---|---|
| Constant                          | 7.6667 ***   | 0.061     | 125.59 | 0.000 |   |
| Logarithm of area cultivated      | 0.0648 ***   | 0.03      | 2.18   | 0.000 |   |
| Logarithm of plowing oxen         | 0.0623 ***   | 0.01      | 9.61   | 0.000 |   |
| Logarithm of fertilizer used in Kg| 0.0487 ***   | 0.01      | 10.38  | 0.000 |   |
| Logarithm of seed used in Kg      | 0.00334 ***  | 0.01      | 6.17   | 0.000 |   |
| Logarithm of labor force in man-days | 0.0036 *** | 0.01      | 5.77   | 0.000 |   |
| /lnsig2v                          | 0.49         | 0.48      | -7.89  | 0.000 |   |
| /lnsig2u                          | 0.04         | 0.02      | 28.05  | 0.000 |   |
| sigma_v                           | 0.97         | 0.15      |        | 0.000 |   |
| sigma_u                           | -0.14        | 0.32      |        | 0.000 |   |
| sigma2                            | 2.64         | 0.38      |        | 0.000 |   |
| Lambda                            | 0.46         | 0.08      |        | 0.000 |   |

*** Significant at p < 0.01. Source: Authors’ own Computation.

3.3. Estimation of Stochastic Frontier Model

The maximum likelihood estimation of parametric time-varying inefficiency Cobb-Douglas stochastic frontier production function is discussed in Table 6. Wald test indicates that all the explanatory variables used in the model significantly explained the dependent variable. The value of eta (η) significantly indicates that TE improved over time by a rate of 0.04 (the level of inefficiency decays toward the base level during the survey years in the study area declined by a factor of 0.04). This result is consistent with the findings of [46].

Table 6. Results from the Stochastic Frontier Model.

| Variables                          | Coefficients | Marginal Effects | Std. Err. | z-Test |
|-----------------------------------|--------------|-----------------|-----------|--------|
| Constant                          | 7.0938 ***   | 0.13            | 53.50     |        |
| Logarithm of area cultivated (hectare) | 0.1176 ***   | 0.12            | 0.04      | 3.27   |
| Logarithm of plowing oxen         | 0.0614 ***   | 0.06            | 0.01      | 8.91   |
| Logarithm of fertilizer used in Kg| 0.0411 ***   | 0.04            | 0.01      | 8.11   |
| Logarithm of seed used in Kg      | 0.00335 ***  | 0.03            | 0.01      | 5.40   |
| Logarithm of labor force in man days | 0.0374 **    | 0.04            | 0.01      | 5.72   |
| /mu (μ)                           | 0.49 **      | 0.48            | 1.01      |        |
| eta (η)                           | 0.04 **      | 0.02            | 2.51      |        |
| /lnsigma2                         | 0.97 ***     | 0.15            | 6.65      | -0.45  |
| /ilgtgamma                        | -0.14 **     | 0.32            | -0.45     |        |
| Sigma2 (σ²_u + σ²_v)              | 2.64         | 0.39            |          |        |
| Gamma (γ)                         | 0.46         | 0.08            |          |        |
| sigma_u2 (σ²_u)                   | 1.23         | 0.38            |          |        |
| sigma_v2 (σ²_v)                   | 1.41         | 0.06            |          |        |

Log likelihood = –3394.0797; Wald chi2 (5) = 1020.70; Prob ≥ chibar2 = 0.000; *** p < 0.01 and ** p < 0.05 Source: Authors’ estimation from the SFA model.

Consistent with findings of other studies [1,47–49], all of the explanatory variables maintained the expected sign and are highly significant. Variation in the inefficiency term explained 46.4% of the total variance in the composed error term. In other words, 46.4% of the variation in the outputs of the major crops considered in this study among the households was explained by technical inefficiency. Thus, value of output to the amount of cultivated land, number of plowing oxen, labor force, amount of fertilizer, and seed rates used were statistically significant at a 1% level of significance. A 10% increment in the number of plowing oxen, labor force, land size, and fertilizer consumption is estimated to improve the aggregate output of crops by more than 0.61%, 0.37%, 1.18%, 0.41%, respectively. Although the sign of the coefficient of seed is positive, its elasticity compared to other explanatory variables is less responsive to the output (Table 6). The findings of are consistent with prior studies [24].
In general, the elasticity of the marginal effects of all inputs used indicated an increment in the aggregate outputs of crops considered, depicted by the improvement in the inputs used in the production process. However, the sum of the value of transformed parameters used for estimation in logarithmic form is 0.29, indicating diminishing marginal returns to scale in the production processes during the survey years. In other words, a 1% simultaneous increase in the input followed by a less than 1% increase in the aggregate output of major crops.

As [46] stated, the behavior of the production function of the crops considered exhibited diminishing returns to scale is associated with limited TC utilization. The average TE during the survey years increased from 38.97%, 41.07%, and 43.35% in three consecutive rounds. However, about 46.86% of the households are under the category of the minimum range of TE. The maximum number of the household that have relatively better TE are 4.55% during the survey years (Table 7).

Table 7. Frequency Distribution of Technical Efficiency of major Crops in the study area.

| Frequency Group | Observation | Percent | Min  | Max  |
|----------------|-------------|---------|------|------|
| 0.030–0.399    | 917         | 46.86%  | 0.036| 0.399|
| 0.400–0.499    | 324         | 16.56%  | 0.400| 0.499|
| 0.500–0.599    | 368         | 18.80%  | 0.500| 0.599|
| 0.600–0.699    | 259         | 13.23%  | 0.600| 0.699|
| 0.700–0.791    | 89          | 4.55%   | 0.700| 0.791|
| Mean TE = 41.22%| 1957        | 100     | 0.036| 0.791|

Source: Authors’ estimation from the SFA model.

Moreover, the model predicted that the mean level of TE for crops is 41.22%. Ceteris paribus implying that given the level of input and the existing technology, there is room to boost the production of crops in the SNNPR by 58.78%. In other words, only 41.22% of the potential outputs were realized by the producers in the area. About 18.8% of the households are found nearly at the middle of (50–60%) the TE level (Table 7). These results are consistent with other findings in Ethiopia [6].

In this study, the mean TC of aggregated crops was 22.41% indicated that the level of sensitivity for technological change or innovation in the study area. The average TC of 2011/12 is 28.4% declined to 21% and 18.3% in 2013/14 and 2015/16 respectively. In other words, households are less sensitive to the newly invented production technologies during the survey years. Thus, the uptake of technological practices in the production of considered crops through intensification decreased in the study area. Therefore, it is possible to argue that introducing and utilizing new techniques or technologies of indicated inputs can improve the total production of considered crops in the study area.

In addition to that, the average TFP value is 6.19 during the survey years. In other words, the growth of those considered crops in real output was over 6.19 for the total inputs used in the production process. However, a very slight decline in TFP in 2015/16 exhibited a clear upward trend in the period 2011/12–2013/14. Though the upward shift of TFP bent down in the latter two rounds, the overall growth of productivity is positive during the survey years (Table 8).

Table 8. Summary of mean Technical Change and Total Factor Productivity for major Crops in Southern Ethiopia.
3.4. Determinants of Technical Efficiency of Major Crops in Southern Ethiopia

Consistent with [47,48,50], participating in the extension system, accessing credit service and irrigation, chemicals for crop protection appeared to increase the efficiency of farming households of the study area significantly. Consistent with the previous study of [22] stated that heads of households who read and write in any language are more efficient. However, farmers applying organic fertilizer experienced a decline the productivity of those crops by 2% (Table 9). As key informant interviewee indicated the reason for low productivity in using organic fertilizer was due to farmers’ low habit to use organic fertilizer and limited extension service support from the development agents in the study area.

Table 9. Determinants of Technical Inefficiency of major Crops in Southern Ethiopia.

| Variable                                      | Mean diff | Std. Err. | [95% Conf. Interval] |
|-----------------------------------------------|-----------|-----------|----------------------|
| Household participated in the extension system| −0.09 *** | 0.01      | −0.11−−−0.08         |
| Household Participation in credit service     | −0.07 *** | 0.01      | −0.09−−−0.05         |
| Household heads with access to irrigation water| −0.10 *** | 0.01      | −0.12−−−0.08         |
| Household with male headed                    | −0.03 *** | 0.01      | −0.06−−−0.02         |
| Household who apply crop protection chemicals | −0.06 *** | 0.01      | −0.08−−−0.05         |
| Household heads who read and write            | −0.05 *** | 0.01      | −0.07−−−0.04         |
| Household who apply organic fertilizer        | 0.02 **   | 0.01      | 0.01−−−0.04          |

*** *p < 0.01 and ** *p < 0.05 Note: Hh: Household. Source: Estimated from the SFA model.

Consistent with studies [18,22], key informants indicated that fertilizer consumption is difficult due to its packaging in large volume for all land size owners and loan repayment problems. Moreover, the inconsistency in demanding row sowing and extra-early-maturing varieties of seed are other challenges for the farming households. Sometimes, row-sowing is a challenging technology that cannot be fully practiced exceptionally for teff crop throughout the region. A study [51] reported that the broadcasting method of sowing was the most popular and widely practiced method of sowing teff in Ethiopia.

An alternative to the broadcasting method, row-sowing becomes the most widely practiced method of sowing maize crops in the study area. The same study [51] reported that the broadcasting method of sowing is the most popular and widely practiced method of sowing seeds in Africa. In addition, rainwater harvesting techniques for irrigation were encouraging practices that households had been using in the study area. This result is consistent with previous findings [52]. Promoting the use of high amount of organic fertilizer would increase the production of those considered crops. Consistent with the findings of [53–55].

Consistent with studies [18,30], key informants revealed that since SNNPR is one of the regions with diverse agro-ecologies and culture of farming, experiences of technology adoption and farming systems show marked variability as one moves from place to place. Thus, a one-size-fits-all approach is a challenge that hinders TC of farmers in the study area. It is also a cause for the failure and slow dissemination of various technologies/techniques in the area.

3.5. Total Factor Productivity Disaggregated by Crop Types

In this section, TFP disaggregated by major crop types is presented. According to the analysis, sorghum has the lowest TFP in the study area. In comparison, maize and teff are in the top list of the TFP ranking. The average fertilizer consumption of each major crop was also by far different from one another during the survey years. The average consumption of fertilizer for wheat was three folds greater than sorghum. The average household’s use of improved seed for maize and wheat crops was nearly similar during the survey years (Table 10). This is consistent with the findings of another study [6].
Table 10. The Average Values of Input-Total Factor Productivity of major Crops.

| Variables                          | Barley | Maize | Sorghum | Teff | Wheat |
|------------------------------------|--------|-------|---------|------|-------|
| TFP of crops                       | 6.36   | 7.34  | 4.37    | 7.13 | 5.76  |
| Household’s fertilizer used (in kg) | 35.84  | 57.27 | 43.98   | 56.67| 137.83|
| Household’s seeds used (in kg)     | 7.09   | 20.73 | 4.17    | 8.57 | 20.24 |
| Labor force used by man-days       | 315.12 | 557.69| 248.39  | 557.62| 188.77|
| Area cultivated (in hectare)       | 0.53   | 1.78  | 0.3     | 0.67 | 1.60  |
| Oxen allocated for plowing         | 1.46   | 1.06  | 0.28    | 1.17 | 1.19  |
| Household’s income generated (in ETB)| 20,190 | 22,063.5 | 12,181.9 | 26,808.5 | 16,681.8 |

Source: Authors’ estimation.

Besides, the households have been using more labor force in the production processes of maize and teff than any other crops included in the study. Among the crops, the average cultivated area allocated for maize was 1.78 hectares of land and had higher TFP than other crops in the area. The land allotted for maize was six-folds greater than sorghum. The low productivity of sorghum was due to the limited use of fertilizer, seed, labor force, and oxen. The average income generated from sorghum farms was also the lowest indicating that its amount produced and the crop’s market value is the weakest compared with other crops (Table 10).

Comparatively, teff is cultivated, on average, on 0.67 hectares of land and has got higher TFP next to maize in the study area. Getting access to extension services significantly affects the productivity of wheat and maize. Similarly, credit service delivered to farmers has positive effects on all crops considered except barley. The results of this study confirmed that households who participated in barley and wheat crop rotation got relatively better productivity than other major crops during the survey years (Table 11).

Table 11. Determinants of Total Factor Productivity by Crop types in Southern Ethiopia.

| Variables                                    | Barley | Maize | Sorghum | Teff | Wheat |
|----------------------------------------------|--------|-------|---------|------|-------|
| Participation in extension program (Yes = 1) | 0.41   | 0.71  | 0.37    | 0.60 | 0.84  |
| Credit service used (yes = 1)                | 0.84   | 0.57  | 0.56    | 0.73 | 0.63  |
| Households participated in crop rotation (yes = 1) | 1.05 | 0.57 | 0.50 | 0.60 | 0.76 |
| Households participated in erosion prevention (yes = 1) | 0.34 | 0.98 | 0.85 | 0.61 | 0.7   |
| Households head’s literacy rate (yes = 1)    | 0.4    | 0.41  | 0.02    | 0.73 | 0.80  |

Source: Authors’ computation from SFA.

Participation of households in erosion prevention activities has positive and significant effects on the TFP of all major crops. Moreover, the protection of crops like barley, teff, and wheat from erosion was vital to enhance their productivity. The effect of households’ ability to read and write in any language on productivity was also significant for all the major crops except sorghum (Table 11).

4. Conclusions and Implications for Policy

The study has come up with the following conclusions. Firstly, farmers can increase the output level of those crops considered by improving efficiency and technology adoption. The findings reveal that 59 percent of inefficient farming households in the study area can produce more by improving their TE levels. 22 percent of TC indicated that households are expected to improve rate of responsiveness for technological change in the study area. Therefore, it is possible to conclude that TC and TE in the study area are the major drivers of TFP growth of crops.

This study confirmed technical inefficiency declined over the survey years in the study area. The technical inefficiency effects were significant, and the TE rate is estimated to gradually increasing over time. This study mainly indicated that farmers increase the output level of crops with the same level of inputs by improving efficiency and technology adoption.
The average estimated TE for crops considered in the study area ranges from 0.036 to 0.79 with the mean TE of 0.41. This value indicates that most households are not technically efficient in producing crops in the study area. Conversely, farmers could decrease inputs (labor force, oxen for plowing, land, fertilizer, and seed) by 22 percent to get the output they are currently getting if they use inputs efficiently.

This study confirmed that households who participated in barley and wheat crop rotation got better productivity than other major crops. According to the findings of this study, improving the utilization of techniques by the producer farmers should be encouraged. Providing training on production technologies, land conservation, and bringing together farmers from different parts of the region for experience sharing on matters of technologies' effect on outputs. Improving access to equipment and other related facilities in small-scale irrigation activities and water harvesting should be a policy direction. A platform for regular agricultural information flow between extension workers and farmers that has valuable insight to share best experiences should be incorporated in development policy of the study area. Furthermore, the organic fertilizer utilization should be a policy priority issue by the government through the extension service. Finally, focusing on the drivers of productivity: input use, the technology adoption practices, and engagement in extension packages so that to improve TFP.

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