Determinants of technical efficiency of smallholder farmers' bread wheat production and implications of seed recycling: A stochastic frontier approach [version 1; peer review: 2 approved]

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Abstract

Background: Due to decreasing productivity trends, enhancing farm level technical efficiency (TE) in bread wheat production (BWP) is central to Ethiopia's food security strategy. This requires increased BW productivity through the use of improvements in seeds and TE. However, there is some empirical research that examines the institutional, socio-demographic, economic, and agronomic determinants of the TE of BWP simultaneously. Therefore, the purpose of this study was to analyze determinants of TE and the implication of seed recycling on TE.

Methods: The data was gathered from 450 randomly selected sample respondents via structured interviews, focus groups, and interviews with key informants. Data collection took place from December 15, 2021 to January 15, 2022. BW growing smallholder farmers were the major respondent of the study. Quantitative type of data including the number of inputs used, amount of wheat produced, and socio-demographic, economic, agronomic, and institutional variables were gathered and analyzed. The TE and factors affecting it were examined using a stochastic frontier production analysis with a trans-log functional specification.

Results: The coefficients for labour (0.086), capital (0.22), fertilizer (0.042), weedicide (0.014), and machinery (0.005) were significantly positive at p<0.001 implying that an optimum increase to these inputs would increase BWP. The mean TE was found to be 79.99% indicating that farmers in the study operate 20.01% less than their potential. Nine of the hypothesized variables (69.2%) had significantly affected TE. Moreover, seed recycling reduced TE by 2.34%.

Conclusion: Findings suggest that few farmers are able to grow BW either on the frontier or very close to it, which denotes high TE and poor access to improved seeds leading to seed recycling. Therefore,
the farmer-to-farmer (F2F) extension method, which enables farmers to learn from their neighbors and create wider access to improved seeds through seed loans and vouchers are strongly suggested.

**Keywords**
Agriculture, Food Security, Recycled seed, Translog, Technical Efficiency, Inputs, F2F (Farmer-to-farmer), Frontier
Introduction

Agriculture has continued to be a crucial economic sector in developing countries for promoting growth, eliminating poverty, and providing food security. In Ethiopia, agriculture accounts for 41% of the country’s GDP, 70% of the nation’s industrial raw materials, 85% of the nation’s food supply, and 80% of all jobs. However, this sector is characterized as low-tech, rain-fed, subsistence-based, and very conventional. Crop production plays a key part in both agriculture and the country’s overall economic performance. It is the crop production sector’s poor performance that has kept the country under vicious poverty cycle for generations. Therefore, increasing agricultural yield is not only essential but also a requirement for ending the vicious poverty cycle that has gripped the majority of people in least developed countries (LDCs) for millennia.

Wheat has been widely grown in Ethiopia because of its many advantages and the country’s good climatic circumstances. In Ethiopia, the total cereal production during the 2020/2021 production season was reported to be 302,054,260.6 quintals and wheat contributes 19.14% (57,801,306.00 quintals) of the total cereal production. In East Gojam Zone, the total cereal production is reported to be 17,095,145.90 quintals and contributes 27.98% (4,743,813.9 quintal) of the total cereal production in the zone. The percentage contribution of wheat to the total cereal production in the East Gojam zone (27.98%) is relatively high as compared to the regional (18.89%) and national (19.14%) averages. The national average wheat productivity was reported to be 30.46 qt ha\(^{-1}\) against 28.31 qt ha\(^{-1}\) for Amhara region. The average wheat productivity for the East Gojam zone was reported to be 32.12 qt ha\(^{-1}\) which is relatively higher than both the national and regional average. This suggests the significance of wheat production for the farmers livelihood in the research area. Ethiopia continues to be a net importer of wheat. It has been using imports to meet about 25% of its domestic demand. Wheat is the only grain that is nearly always imported into Ethiopia. This proves the importance of wheat as a researchable agricultural commodity in Ethiopia.

The Government of Ethiopia (GoE) in collaboration with its partners has been doing its level best to bridge the potential and observed productivity gaps through wider diffusion and scaling-up of improved seeds. Dissemination of agricultural technologies will not substantially improve productivity if farmers are not technically efficient. Technical efficiency (TE) in crop production refers to farmer’s ability to maximize outputs given a set of inputs and technology. Similarly, the degree of technical inefficiency reflects an individual farmer’s failure to attain the highest possible output.
level given the set of inputs and technology used.\textsuperscript{17,18} Improving productivity and TE of wheat production is at the center of researchers and policymakers in Ethiopia. This is due to the urgent need to improve the food security and livelihood situations of smallholder farmers. There are sufficient empirical evidences about production improvement as a result of new genetic and breeding innovations.\textsuperscript{19,20}

However, available literature with regard to TE tend to be quite generic.\textsuperscript{21–26} As a result, farmers in Ethiopia don’t know the exact amount of inputs (land, labour, oxen power, fertilizer, seed, capital, etc) that go into the production of a particular commodity or crop in which case a generic TE analysis may be sound. Yet, such generic analysis has the potential to hide crop specific and relevant information for policy uptake. This means that if care is taken in generating empirical evidences, doing crop – specific efficiency analysis may bring policy relevant information. This study therefore aimed at generating policy relevant information for bread wheat production (BWP) through TE analysis by estimating farmers level of technical inefficiency and its determinants. Moreover, about 90% of the farmers in Ethiopia rely on multiple times recycled seeds for bread wheat production. However, bread wheat seed recycling beyond five production seasons was considered as unproductive and unwise practice as continuous recycling of the same seed causes deterioration in seed quality. Yet, farmers in the developing world and Ethiopia are continuously using the same seed over several production seasons.\textsuperscript{5,27,28} The nexus between TE and bread wheat seed recycling has never been empirically investigated. As a result, farmers are continuously making use of recycled seeds without knowing the implications of seed recycling on their TE. This study therefore has dealt with the nexus between seed recycling practices and TE of smallholder bread wheat producers. It has also aimed at investigating the determinants of farmers technical inefficiency.

**Methods**

**Ethical statement**

The proposal for this study was first reviewed and approved by the academic comission (AC) of the Center for Rural Development Studies during the 2020 academic year which is before the approval of the standard operation procedure (SoP) of the Addis Ababa University. The authors received retrospective institutional review board (IRB) approval for this study where the ethical review board of the Center for Rural Development Studies of the AAU reviewed the contents of the proposal, the associated research tools, and informed consents of the respondents retrospectively. As a result, the University found the proposal to be qualified for ethical clearance and issued an IRB certificate dated on February 18, 2023 with an IRB number 002/02/2023 indicating that the proposal fulfills the standard requirements described in the SoP of the Addis Ababa University, College of Development Studies.

The trained enumerators of the study have properly read the consent form for the participants. The consent form clearly contains the objectives of the study and their participation is on voluntary basis that they are free to disengage if they are not comfortable. Participants were told that there is no direct benefit that will be provided for them as a compensation for the data that they are going to provide for the study. They were also told that the data collected will be published to inform policy makers and the research community and will not be used for any other purpose. Besides, they were informed that the analysis of the study did not identify participant individuals and will be anonymized by assigning a unique identification number. Yet, a significant number of participants have refused to put their signature on the consent form. This is due to the fact that the long held tradition and culture of the participant farmers’ don’t allow them to put their signature on studies like this. Besides, a substantial portion of the participants are incapable of reading and writing to sign on the written consent. Traditionally, farmers of the study area are skeptical in providing written consent. After assessing this situation and the minimal risk that the study may cause to human subjects, the ethical review board has confirmed the documentation of written consent can be waived. Thus, the data collection took place only when respondents of the study gave their consent at the beginning of each interview. As a result, this study has relied on verbal consent of the participants.

The common difficulty in collecting data from poor farmers’ in the rural setting is that farmers may feel that they will not be targeted for aid, credit schemes, welfare packages, and other development interventions based on the data they unfold to outside researchers. Fearing such vulnerability to exclusions, they often under report their annual production, plot size, number of animals, inputs used, and assets owned. On the contrary, farmers may also exaggerate certain variable values such as their age, family size, and number dependent family members hoping that they will be entitled for aid and other welfare benefit packages. Yet, the authors make sure that such participants expectation did not harm the quality of the data by employing different methods. First, most of the variables that could be under reported or exaggerated are registered by the local government. Thus, we have triangulated the reported values with what is locally registered. Second, we have recruited enumerators (development agents) working with the local community who have long years acquaintance of the villages and the community members that participants don’t often hide information. The other challenge when collecting data using FGDs is that participants farmers’ may not feel comfortable to share their experience with development agents who often support them by providing inputs and agricultural advisory services. With the intention of avoiding this
potential problem, the facilitation and transcription of the FGDs were made by the authors themselves than the local development agents.

**Context: Setting and salient contextual factors**

This study was conducted among smallholder bread wheat growers in selected districts of the East Gojam zone of Ethiopia. There are two major crop growing seasons in the study areas. The major crop growing season is called ‘Meher’ in Amharic extends from May to September. The second and the shorter crop growing season is called ‘Belge’ extends from February to April. Smallholder farmers of the study areas culturally and historically grow bread wheat during the main season for several reasons. Lack of access to irrigation for all season production and the availability of sufficient rainfall during the main rainy season are the major reasons to heavily rely on ‘Meher’ wheat production. Agronomic recommendations such as crop rotation also can be cited as important reason to grow bread wheat during the main season only. Thus, we have considered smallholder farmers who grow bread wheat during the main production season.

The list of bread wheat growers during the 2021/2022 major production season was obtained from the farmers’ training centers’ (FTCs) of the selected villages. These farmers grow bread wheat using different varieties that were introduced at different points in time. However, this study has considered a bread wheat variety largely grown by the dominant section of the farmers. Respondents were further stratified into fresh and recycled bread wheat seed users based on their experience in seed recycling. Besides, the data was gathered during the weekends and holidays during which farmers were not busy to provide information required for the study. Production inputs and agronomic practices applied by the respondents are important variables of this study. Thus, we intentionally undertook the data collection effective from December 15, 2021 to January 15, 2022 during which wheat will be harvested.

**Description of the study area**

This study takes place in the East Gojam Zone of Ethiopia. East Gojam zone has a total of 18 Woredas and its headquarters, Debre Markos, is located 300 and 260 km far from Addis Ababa (the capital city of the country) and Bahir Dar (the capital city of the region), respectively. It is located at 10° 19′ 60.00″ North, and 38° 00′ 00″ East. The total population size of the East Gojam zone is estimated to be 2,358,051, out of which 1,154,740 and 1,203,311 were reported to be male and female respectively. Mixed farming system is the main occupation of farmers in the East Gojam zone. The area is dominated by mixed agricultural systems.29 Out of the 18 Woredas located in the East Gojam Zone, this study has especially considered Baso Liban and Debre Elias districts presented in Figure 1.

**Sampling technique and procedures**

**Sampling technique**

This study has followed a multi – stage systematic random sampling technique in the selection of sample districts and respondents. The study districts and kebeles [1] were selected purposively. The potential for wheat production, absence of sufficient prior studies, availability of sufficient representative sample respondents who make use of similar bread wheat variety, and the long year’s acquaintance of the study places by the researcher were the reasons to consider these Woredas. Debre Elias and Baso Liban districts have 15 and 22 kebeles, respectively. The researcher has decided to consider eight kebeles (around 22% of the total kebeles) from both of the districts with strong conviction that these kebeles are sufficient and representative due to their homogeneity in agro-ecology, agronomic practices, and potential for BWP. As indicated in Figure 1, Yelemelmo, Lemechem, Dendegeb, Kork, and Dogemo kebeles were considered from Baso Liban district while Guay, Yekegat, and Debre Elias zuria kebeles were considered from Debre Elias district. The number of kebeles from each Woreda was determined using the probability proportional to size (PPS) formula specified below (Equation 1):

\[ n_i = n \left( \frac{N_i}{N} \right), \text{and } n = \sum n_i \]  \hspace{1cm} (Equation 1)

Where \( n_i \) is the number of kebeles from each Woreda, \( n \) is total sample size of the study kebeles which is the sum of the sample size of the kebeles from the two Woredas (eight in this case), \( N_i \) is the total number of kebeles in each Woreda and \( N \) is the total number of kebeles in both Woredas (37 in this case). The specific sample kebeles were selected in collaboration with the development agents (DAs) based on their BWP potential and availability of farmers who make use of similar improved bread wheat production (IBWP) variety. Yamane’s sample size determination formula is often used in studies where the study population is finite and known. Henceforth, the total sample size of this study was also determined by using Yamane’s sample size determination formula,30 which is specified as below (Equation 2).

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1Kebele is the smallest administrative unit in Ethiopia.
\[ n = \frac{N}{1 + N(e^2)} = \frac{206,115}{1 + 206,115(0.05)^2} = 399 \]  
(Equation 2)

Where \( n \) is the desired sample size, \( N \) is the total number of population, and \( e \) is the level of precision or the quality of being careful and accurate which is equal to 0.05. Generally, the sample size for this study was 399 along with a 15% contingency which adds up to 459 total households. The analysis of the study has considered only 450 respondents as three of the respondents refused to provide information while six of the questionnaires collected were incomplete for analysis.

**Sampling procedures and participants selection**

The chief intention of this study was to investigate the major determinants of smallholder farmers' TE in bread wheat production. Thus, we have first obtained a list of smallholder farmer bread wheat growers in the selected sites from the FTCs. From the list of bread wheat growers, it was found that 83.5% of the smallholder farmers grow bread wheat using a bread wheat variety called ‘Ogolecho’. Since agronomic practices, input use, and productivity is likely to vary by the nature of bread wheat variety, we have included farmers that make use of the same variety. Thus, farmers who make use of varieties other than ‘Ogolecho’ were excluded from the study. Besides, as the study deals with the implications of seed recycling on smallholder farmers' TE, the respondents were further disaggregated into fresh (unrecycled) and recycled bread wheat seed users. Farmers who produce bread wheat using seeds reused more than five times were labeled as recycled seed users while those who produce bread wheat using fresh/unrecycled seed or recycled below five times.
were considered as fresh/unrecycled seed users. It was found that about 247 (54.9%) of the respondents were recycled seed users while 203 (45.1%) were found to be fresh seed users. Figure 2 depicts the sampling procedures. These sample respondents were used for the face–to–face household interview using a structured interview schedule. Thus, bread wheat growing households were the unit of analysis under the current research.

We believe that key informant pluralism or diversity from different background or sector will allow us to capture varying perspectives about the determinants of smallholder farmers TE and problems of seed recycling. As a result, we have included key informants from different walk of life and responsibilities in relation to bread wheat production. Doing so has helped us to avoid a one – sided or biased information that may result by interviewing people from a particular division. We have first prepared a long list of potential key informants from stakeholders or actors involved in the value chain of bread wheat production. Then, we have narrowed down the list into the most relevant and knowledgeable informants. Hence, the sample respondents for the key informant interviews (KIIs) were purposively selected based on their experience and knowledge to the subject under consideration. Development workers, agronomists, seed experts, researchers, district bureau heads, seed suppliers, agro-dealers, and seed multiplication and marketing cooperative members who do have ample information due to their position and expertise were selected as key informants. These informants were considered as they are the most important actors across the value chain of bread wheat production. They

Figure 2. Sampling procedures.

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are involved either in the inputs supply, business development support provision, organize the transport and marketing of agricultural inputs and products. The authors believe that inclusion of these individuals as key informants will assist to capture information that may be obscured during the quantitative data collection. These key informants were knowledgeable people who can talk on behalf of the farming community about the subject matter. These key informants were physically visited at their offices for the interview. These informants were busy experts and office position holders. Thus, we received appointments before the visit for the interview was made. The profile of the KII participants is provided in the supplementary table 1.31

Efforts were made to compose the FGD discussants from the homogenous group that have some natural characteristics in common such as gender, residential locations, and seed recycling practices so that to ensure participants feel comfortable speaking in the group. We have followed two approaches in composing the focus discussion groups. First, we made sure that there is sufficient homogeneity between groups so that to have comparable data among the groups. This approach has encouraged sense of uniformity and conformity among FGD participants and assisted participants to reach on some consensus on issues raised. Second, we make sure that there is sufficient diversity within the groups. This has helped us to bring together participants that assume different roles, varying experiences and dissimilar backgrounds that may end – up in unexpected views and results. The selection the FGDs participants has involved organizing group of community members based on important criteria relevant to the objectives of the study and their consent to takepart in the discussions. The first criteria in grouping discussants was bread wheat seed recycling practice. In this regard, we had two group of FGD discussants that include fresh and recycled bread wheat seed users. The second group of the FGD discussants were composed of female and male headed households. The third group was composed of smallholder farmers who are member of improved bread wheat seed multiplication and marketing cooperatives.

Data collection procedures

Data types and sources

This study has employed both quantitative and qualitative data types. Quantitative type of data including the number of inputs used in bread wheat production along with different agronomic practices such as amount of fertilizer, man - days, seeds, plot size, amount of capital invested, amount of pesticide applied, weeding frequency, seed recycling frequency, and spacing between rows were gathered. The study has also considered different socio – economic and institutional quantitative variables such as gender, age, grade level, family size, dependency ratio, tropical livestock unit (TLU), land size, frequency of extension contact, amount of credit, and membership in seed multiplication and marketing cooperatives, respectively. The qualitative type of data included smallholder farmers knowledge and perception towards seed recycling, reasons for seed recycling, perception about the impact of seed recycling, barriers affecting seed replacement, and major challenges affecting technical efficiency and bread wheat productivity. These study variables were selected after extensive review of relevant literature, pre – data collection discussions made with experts and elders in the study districts, and long years acquaintance and experience of the researchers about the issue under consideration. These data were gathered both from primary and secondary data sources. Smallholder farmers, district development workers, agronomists, and subject matter specialists were the primary data source of this study. In addition, secondary data sources such as published research findings, journals, articles, statistical reports, official websites, government reports, dissertations, and thesis were consulted to triangulate and support the information obtained primary data sources. A systematic desk review was conducted to gather relevant information related to the objective of the study. The authors have heavily relied on important secondary data sources related to the technical efficiency of improved bread wheat production and its determinants including PubMed, Semantic Scholar, and Google Scholar platforms. Two typical search phrases, separated by the operator “OR,” were used: “technical efficiency” AND “bread wheat production in Ethiopia” OR “technical efficiency” AND “determinants in Ethiopia.” We have applied this with the expectation that it will increase the likelihood that all studies conducted in Ethiopia would be found. For the systematic review, the authors have applied various articles inclusion and exclusion criteria including the following.

a) Articles concentrating primarily on technical efficiency or technical efficiency of bread wheat production were considered while articles related to other wheat or crop varieties were excluded from the review.

b) Articles evaluating the seed recycling practices of smallholder farmers and/or determinants of the TE of smallholder farmers were included.

c) The authors have focused on publications based on qualitative and quantitative empirical investigations.

d) The authors also focused on articles where the country of data collection is in Ethiopia and/or in the Sub – Saharan Africa.
e) The systematic desk review have emphasized articles published in scholarly journals and non-published documents such as government policies and strategies, agronomic training manuals, annual reports, and location specific agronomic recommendations.

The evidences obtained from these secondary sources were then checked against the findings of the current study. The authors have critically triangulate the data and findings between the current study and the secondary empirical evidences. We have further assessed the reasons and explanations for convergence, divergence, and complementarity of the data and findings between this study and the secondary data sources. Explanations were sought whenever we found strong degree of deviation between this study and the secondary sources. In general, the areas of divergence and convergence were further discussed.

Data collection methods

For a thorough understanding of the research problem, the study has used data collection methods employed in a mixed research design, which blends qualitative and quantitative research data. A mixed research design was used in order to compare the various viewpoints obtained from quantitative and qualitative data, as well as to demonstrate potential data convergence and divergence by combining the two database. We have applied convergent parallel mixed methods to gather quantitative and qualitative data, analyse each kind individually, and then compare the findings to see whether they support or refute one another. The main premise behind our preference for this approach is that both qualitative and quantitative data offer distinct forms of information. Authors apply this approach for the purpose of triangualtion and validation of findings from each method. As a result, the data for this study were collected using three important quantitative and qualitative data collection methods described below.

Tools translation and piloting

The tools used for both the quantitative and qualitative data were created in the English language based on extensive relevant literature reviews and discussions held with subject matter specialists. These tools were then translated into Amharic language using a group translation approach. The tools were given to two different certified and hired translators who independently translate the tools (meaning they don’t review each other’s translation). After the two translators complete the translation, a third translator has reviewed and reconciled the translation differences and produced a final translation. All the tools translated by all of the translators were submitted to the authors of this research and checked for their originality, meaning, and consistency. All of the tools used in this study incorporates informed consents that specifies the objectives of the study and seeks the consent of all of the respondents. The data collection was carried out under a complete private setting and keeps the principles of data confidentiality, privacy, and informed consent. Eight hired and trained enumerators were used for data collection. The training was provided by the corresponding author. The training encompasses line – by – line discussion of each questions, research ethics, and interviewing methods. Before starting the main survey, each enumerator was allowed to collect data from four randomly selected farmers that were expected to have similar characteristics with the sample respondents of the study. A debriefing session was then held after this field level pilot test and some modifications were made on the tools based on findings from the debriefing session. Finally, the hired enumerators were deployed to collect data under strict supervision of the corresponding author.

Quantitative data collection method

A structured questionnaire based interview was largely used as quantitative data collection method. The questionnaire used for the structured interview included questions with close ended response options only. The questions included in the structured interview were crafted in such a way that it enable us to capture the objectives of the study. Enumerators of the study were given the list of respondents identified using the procedures indicated above. Then they systematically select target respondents from the list at a regular interval to conduct a face – to – face interview using the structured questionnaire. The enumerators visit the selected household at his/her residential place for the interview. Enumerators of the study were trained to make several contact attempts for respondents who can’t be found at his/her residence for the interview. Yet, the maximum contact attempt was only three that all of the sample respondents were contacted for the interview during the first visit of the interviewers. The questions as well as their order was already scheduled that enumerators ask the questions accordingly and without change in the wordings of the questionnaire. The interview was conducting using the structured questionnaire detailed above that was translated into the local language (Amharic). The structure questionnaire both in English and Amharic along with the consent statement is available as extended data for this study.
**Qualitative data collection methods**

This study has employed key informants’ interview (KIs) and focus group discussions (FGDs) to gather qualitative data required to capture the objectives of the study. KIs were carried out to get an in-depth understanding of the different issues pertinent to seed recycling, technical efficiency, and challenges related to bread wheat production. The KIs were conducted with respondents such as development agents, subject matter specialists, researchers, and improved bread wheat seed suppliers who are believed to have ample information about the issues under consideration of this study due to their position, expertise, and leadership. A total of 14 key informants composed of four women and 10 men were approached for a face – to – face interview using the KII checklist. The interview was conducted at the office of each key informant. Appointments were taken through phone calls before visiting the key informant at his/her office so that they could have sufficient time to provide detail information. The data collectors approached and introduced themselves for the key informants and read the consent statement. After reading the consent statement, enumerators put a tick mark next to the option ‘yes’ to indicate that the respondent has verbally provided his/her consent to continue the interview. No key informant has declined to take part in the interview and his/her responses are recorded. The author himself was a note taker while a trained enumerator pose the questions from the KII checklist and facilitate the interviews. The data collection was conducted using a local language. The information obtained from the key informants was later transcribed by the authors. For the sake of confidentiality and privacy, pseudo names were used to identify the name of the KIs participants. The maximum amount of time to finish the KIs was 31 minutes.

FGDs were conducted to examine the existence of consensus among the different group of discussants on certain common agricultural practices such as seed recycling, planting methods, spacing, and other agronomic practices. Besides, these qualitative data collection methods were employed with the intention of triangulating the data obtained from the quantitative survey. Issues raised for the FGDs were reasons or pushing and pulling forces for seed recycling, farmers perception on the consequences of seed recycling, knowledge and awareness of factors hampering or promoting their technical efficiency in bread wheat production.

As indicated in supplementary table 2, a total of six FGDs (three in each district) were conducted.¹ All FGDs were properly recorded, transcribed, and translated into English by the corresponding author of this study. The highest group size for the FGDs was nine and a total of 49 discussants have participated in all of the FGDs. The FGDs were conducted at the FTCs assembly halls of each village. The date and the time for the FGDs was fixed to be on Sundays at 10:00 PM in consultation with the participants. Discussants prefer Sunday as it is observed as sabbath by the community that they don’t engage in other activities. The assembly halls where the FGDs took place were large enough with sufficient ventilation and lighting. It has allowed us to keep more than two meters distance between discussants so as to avoid risks of the COVID-19 spread. We also distributed face masks to participants to contain the spread of the virus. The group sitting was arranged in a circular setting so that all participants have a balanced eye contact with each other and can listen to what each other speaks. FGD was set up where each discussant of the FGDs were encouraged to feel free to speak on the issues raised by the facilitator. As a standard ethical procedure, we never keep personal identifying information such as names either in the notes or in the report. Rather we have used pseudo names so that the study doesn’t lose its human sense. Female facilitators and note takers were assigned in the female headed group of FGD discussants so that participants will openly discuss questions posed to them. The composition of the FGD participants along with their characteristics is summarized and presented in the supplementary table 2.¹ The data collection took place starting from September 15, 2022 to October 19, 2022. The longest discussion time was 72 minutes while the shortest was 61 minutes. This could imply that there is a relatively uniform level of discussion across the FGDs.

**Data analysis methods**

The data collected for this study were analyzed using both descriptive and econometrics models. One stage Stochastic frontier analysis (SFA) with the translog functional form was used in identifying the factors significantly contributing to BWP and in estimating the contribution of the hypothesized parameters on the technical inefficiency. The analysis was made using the STATA Software, Version 17 (https://www.stata.com/), R software (https://posit.co/download/rstudio-desktop/) which is an open source and freely accessible software, is also capable of the same analysis used in this study. The sub-headings below are a summary of the data analysis methods employed in this study.

**Descriptive and inferential statistics**

This study has frequently employed a number of descriptive statistics. It has used both measures of central tendency (mean, median, and mode) and measures of central dispersion (range, variance and standard deviation). Inferential statistics such as t-test and $\chi^2$ tests were frequently employed to check if there exists a difference in the different continuous and categorical variables considered in the study between farmers who recycled bread wheat seed and those who don’t recycle (use fresh) seed, respectively.
Econometric model specifications

Technical inefficiency model of the SFA

The SFA, a parametric technique, and the data envelopment analysis (DEA), a non-parametric approach, are important methods for estimating the level of efficiency/inefficiency in production economics. The DEA is preferred because it accommodates multiple inputs and outputs in TE analysis. Nonetheless, DEA disregards the potential effects of random shock, such as measurement error and other sorts of data noise. The SFA, on the other hand, does not accommodate multiple inputs and outputs and is more susceptible to misspecification problems. The SFA, however, boosted its application in the examination of TE of agricultural production since it included stochastic components in the model.32–34 Thus, this study has opted for the SFA than the DEA.

Agricultural production in developing countries is contingent upon factors that are beyond the control of the decision making units (DMU). External factors such as crop pests, disease infestation, drought, flood, frost/hail, and other exogenous factors which are beyond the control of the smallholder farmers do have significant effect on smallholder farmers’ crop production. Therefore, studies are expected to capture the effects of such uncontrolled variables. Moreover, studies are expected to account for technical errors that may arise due to measurement and observation during data collection. BWP in the study areas is reported to be hampered by the climatic variabilities that are least controlled by smallholder farmers’.18,34–41 In addition, sample respondents of this study were non-commercial and subsistence smallholder bread wheat growers’ who largely depend on family labour to operate their farm, and don’t have a tradition of keeping accurate records. Above all, the data for this study were collected using local units of measurement that their conversion into standard units of measurement may be erroneous. Thus, the data for certain variables like production, plot size, and amount of inputs used are likely to be susceptible to measurement and conversion errors.

Given the situations above, this study therefore adopts the SFA model as it enable the researcher to accommodate the effects of these uncontrolled variables and technical errors. The SFA was first proposed by Aigner, Lovell42 and Meuusen and Broeck.,43 and later modified by Jondrow, C. A. K. Lovell.33 The SFA model has also been used to model the technical efficiency effects of other observable explanatory variables.44 This approach splits the error-term (deviations) into two parts to capture purely random factors and are beyond the control of the DMUs. The first component is the technical inefficiency of the DMUs. The second component is the random shocks that among others include climatic variabilities, errors in measurement during data collection, and omitted variables. Therefore, the general stochastic frontier econometric model for this study is specified as below (Equation 3):

\[
\ln y_i = \beta_0 + \sum \beta_j \ln x_{ij} + \epsilon_i
\]  
(Equation 3)

Where \( \ln \) - refers to the natural logarithm, i - refers to the i\textsuperscript{th} farmer in the sample (i = 1, 2, …, N), \( y_i \) – refers to bread wheat yield (output) of the i\textsuperscript{th} farmer, \( x_{ij} \) – refers to the farm inputs used by the i\textsuperscript{th} farmer, \( \beta_0 \) – refers to the constant term, \( \beta_j \) - represents the regression coefficient, while \( \epsilon_i \) denotes the residual random error term which is composed of the following two elements (Equation 4).

\[
\epsilon_i = V_i - U_i
\]  
(Equation 4)

\( V_i \) is a symmetric component that captures/accommodates the random error associated with random factors which are beyond the control of the DMUs such as weather variabilities like drought, frost/hail, flood, omitted variables, measurement errors, and other exogenous shocks. \( U_i \) is the one-sided component that capture deviations associated with factors under the control of the DMU (i.e., inefficiency). The model is such that the possible production \( Y_i \), is bounded above by the stochastic quantity, \( f(x_i, \beta)^\beta \exp(V_i) \); hence the term stochastic frontier. The random errors \( (V_i) \), where \( i = 1, 2, \ldots, N \) were assumed to be independently and identically distributed as \( N (0, \sigma_v^2) \) random variable independent of the \( U_i'\)s which were assumed to be non-negative truncations of the \( N (0, \sigma_u^2) \) distribution (i.e. half normal distribution) or have exponential distribution. As far as TE is concerned, the variance parameters, \( \sigma_v^2 \) & \( \sigma_u^2 \) are of critical importance in this model. They are expressed as follows (Equations 5 and 6):

\[
\sigma^2 = \sigma_v^2 + \sigma_u^2
\]  
(Equation 5)

\[
\gamma = \frac{\sigma_v^2}{\sigma_u^2}
\]  
(Equation 6)
Where $\sigma^2$ = overall wheat output deviations, $Y$ is the ratio of farmers’ wheat output deviations due to technical inefficiency to the overall deviations. It ranges from 0 to 1, when $Y=0$ indicates that all output deviations are due to factors outside the farmers control ($\sigma_u^2 = 0$, thus $\sigma^2 = \sigma_v^2$), when $Y = 1$ indicates that all deviations are due to technical inefficiency ($\sigma_u^2 = 0$, thus $\sigma^2 = \sigma_v^2$). The TE of an individual farmer considered in this study can be defined as the ratio of observed or realized (actual wheat output) to the stochastic frontier output (potential output). The stochastic frontier output is the maximum output possible given the technology available and inputs used, it is given by (Equations 7 and 8):

$$q_i^* = \exp(x_i \beta + V_i)$$

(Equation 7)

Where $U_i = 0$ because production is technically efficient on the stochastic frontier.

$$TE_i = \frac{\text{Actual Output}}{\text{Potential Output}} = \frac{q_i}{q_i^*} = \frac{\exp(x_i \beta + V_i - U_i)}{\exp(x_i \beta + V_i)} = \exp(-U_i)$$

(Equation 8)

Where $TE_i$ is technical efficiency, the inefficiency term $U_i$ is always between 0 and 1. When $U_i$ is equal to zero, then production is on the frontier, $q_i = \exp(x_i \beta + V_i)$ and $TE_i =1$, therefore a farmer is technically efficient. When $U_i$ is greater than zero ($U_i >0$) the farmer is technically inefficient ($TE_i < 1$) since the production will be below the frontier. Factors affecting $TE_i$ was previously estimated by using a two-stage process. In the first stage, the level of efficiency/inefficiency was measured using a normal production function. In the second stage, a probit/logit model was used to investigate the factors that determine levels of technical efficiency. However, since 2000, STATA, Limped, and Frontier computing packages which apply the Maximum Likelihood Estimate (MLE) are available which has enabled researchers to jointly estimate the Stochastic Frontier and the inefficiency model. Therefore, this study has employed a single stage approach where TE and its determinants are estimated together.

**Empirical model specification of the production function**

The SFM can take either the Cobb-Douglas (CD) production function or the Translog (TL) production function. The CD production function imposes restrictions on the farm’s technology by assuming constant production elasticities and setting the elasticity of input substitution to unity. In addition, it assumes a fixed return to scale and a linear relationship between the output and inputs used in production. The TL production function, however, assumes existence of nonlinear relationship between the output and inputs, and production elasticities are not constant. Researchers prefer the TL functional form due to its flexibility and does not impose assumptions about constant elasticity of production nor elasticities of substitutions between inputs. Thus, this study too opt for the stochastic frontier production function using the flexible TL specification and is specified as follows (Equation 9):

$$\ln q_i = \beta_0 + \beta_1 \ln (X_{i1}) + \beta_2 \ln (X_{i2}) + \ldots \ldots + \beta_7 \ln (X_{i7}) + (\epsilon_i)$$

(Equation 9)

Where $q_i$ = wheat output per hectare of the $i^{th}$ respondent, $\ln$ = the natural logarithm, $\beta_0$ = Constant term, $\beta_i$ = regression coefficient of the $i^{th}$ variable, $X_{i1}$ = amount of labour (man-days ha$^{-1}$) by the $i^{th}$ respondent, $X_{i2}$ = amount of capital for wheat production per hectare by the $i^{th}$ respondent, $X_{i3} =$ amount of total fertilizer applied (kg/ha) by the $i^{th}$ respondent, $X_{i4} =$ amount of land allotted for BWP (ha) by the $i^{th}$ respondent, $X_{i5} =$ amount of seed rate used (kg ha$^{-1}$) by the $i^{th}$ respondent, $X_{i6} =$ amount weedicide applied (L ha$^{-1}$) by the $i^{th}$ respondent, $X_{i7} =$ Machine rent (Ethiopian Birr) by the $i^{th}$ respondent, $\epsilon_i$ = is an error term and defined as $V_i - U_i$

$V_i$ = random effects (measurement errors, omitted explanatory variables) assumed to be independent of $U_i$, identically and normally distributed with zero mean and constant variance $\sigma_v^2$. $U_i$ = non-negative random error variables which are assumed to account for technical inefficiency among bread wheat producers of the study areas.

$U_i$ - are the technical inefficiency effects which are assumed to be independent of $V_i$ such that $U_i$ is the non-negative truncation (at zero) of the normal distribution with mean $U_i$ and Variance ($\delta^2$). The inefficiency model for this particular study is specified as follows (Equation 10):

$$U_i = \sigma_0 + \sigma_1 \ln X_1 + \sigma_2 \ln X_2 + \ldots \ldots + \sigma_{12} \ln X_{12} + \epsilon_i$$

(Equation 10)

Where $U_i$ denotes the technical inefficiency of the $i^{th}$ farmer, while $X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, X_9, X_{10}, X_{11},$ and $X_{12}$ denotes gender, age, grade level, family size, dependency ratio, tropical livestock unit (TLU), land size, hand weeding frequency, row spacing, frequency of extension contact, amount of credit, and membership in seed multiplication and marketing cooperatives, respectively.
Generalized likelihood ratio (LR) test

This study has employed the generalized LR test to select the appropriate functional form that best fits to the data, the appropriate distributional assumptions of the technical inefficiency term and the existence or non-existence of inefficiency on the model and others. One hypothesis has been tested with regard to the model specification using the generalized LR test, which is defined as follows (Equations 11 and 12):

\[ LR = \hat{\lambda} = -2 \ln \left( \frac{L(H_0)}{L(H_1)} \right) \]  

(Equation 11)

\[ \hat{\lambda} = -2(\ln L(H_0) - \ln L(H_1)) \]  

(Equation 12)

Where, \( \lambda \) is the likelihood ratio (LR), \( L(H_0) \) = the log likelihood value of the null-hypothesis; \( L(H_1) \) = the log likelihood value of the alternative hypothesis; and \( \ln \) is the natural logarithm. This has a chi-square distribution with degree of freedom equal to the difference between the numbers of estimated parameters under \( H_1 \) and \( H_0 \). Yet, where the test involves a \( \gamma \), then the mixed chi-square distribution is used. The \( H_0 \) is rejected when the estimated chi-square is greater than the critical value.

Results

Descriptive statistics of the variables

The findings presented here were based on the data collected from 14 KIIs, four FGDs, and 450 structured interviews. The profile of the KIIs and FGDs participants are summarized and presented in the underlying data materials of this study.31 Smallholder farmers’ wheat production and their TE is not solely contingent upon the quantity, quality, availability, and affordability of farm inputs. As a result, this study has hypothesized that there are multiple agronomic practices, plot level variables, demographic, socio-economic, and institutional factors affecting smallholder farmers wheat productivity and their TE. Thus, it is essential to present findings of the descriptive analysis prior to presenting results of the SFM as it will provide a vivid picture of the study area and sample farmers who grow bread wheat using recycled and fresh seeds. The descriptive statistics for all the variables considered in this study are presented in Table 1 below and it includes the mean values, the mean difference, the standard error, t-value, and p values. As detailed in Table 1 below, a significant difference was observed between fresh and recycled seed users in terms age, family size, dependency ration, TLU, land size, frequency of extension contact, seed recycling frequency, yield per hectare, weeding frequency, row spacing, seed rate, fertilizer rate, herbicide rate, and technical efficiency score at p=0.000. Yet, no significant difference was observed between these two groups in terms of grade level, amount of credit, and gender.

Hypothesis test results

The GLR test has been conducted using the formula specified in equation 11 in order to select the model that best fits the data of this study. The test rejected the \( H_0 \) (null hypothesis) that asserts the translog stochastic frontier production function can be reduced to a CD production function at 5% level of significance. This favors the application of the Translog functional form at the expense of the CD. Thus, earlier studies based on the CD model18,34,37,38,41,48 may be misleading and hence can’t be replicated here. The second hypothesis test was conducted to check the existence of inefficiency parameters. The null hypothesis was that technical inefficiency effects are not in the model \( (H_0): \gamma = 0 \) for \( i = 0, 1, 2, \ldots, 13 \). The likelihood ratio test also rejected the null hypothesis \( H_0 \) at 5% level of significance. Thus, it can be concluded that there exist technical inefficiencies in BWP which in turn implies that the traditional production functions that do not account for technical inefficiencies are inadequate for modelling BWP in the study areas. The estimated parameter for \( \gamma \) was higher than 1, implying that the variation in BWP was mainly attributed to variations inefficiency.31 The GLR statistics value confirmed that the \( \sigma_u^2 \) was strongly biased towards \( \sigma_v^2 \). The third hypothesis was carried out to check the \( H_0 \) (null hypothesis) that the distribution of inefficiency can be reduced from truncated normal to half normal distribution \( \mu=0 \). The result has turned out in rejection of the null hypothesis. This means that the distribution of the inefficiency term is truncated at 0 normal distribution which is significant at 5%.31

Estimates of the Stochastic frontier production function

This study has employed the maximum likelihood estimates (MLE) of the TL functional form to investigate the major determinants of BWP difference among farmers. About seven variables were considered in the estimation of the frontier production function. The coefficients for the factors used in BWP were estimated under the full frontier production function (Maximum Likelihood Estimation). The coefficients presented in Table 2 below represents
individual elasticities. These individual elasticities adds-up to 1.49 indicating that farmers in the study area are facing increasing returns to scale. This portrays the potential to further increase the extent of BWP. This also means that there exist a wide opportunity to increase bread wheat production with an increasing rate of return. The result of the MLE gave the value of the parameter estimations of the frontier model along with the value of log-likelihood function for the stochastic production function. Table 2 below is a summary of the MLE of the parameter of TL functional form of the stochastic frontier model.

In this study, about seven hypothesized variables were considered in BWP function. Four of these variables (land, labour, capital, and fertilizer) had a significant effect in explaining the variation in BWP among smallholder farmers in the study area. The coefficient for labour measured in terms of man-days spent for BWP turned out to be significant and positive at p<0.01. This coefficient for labour implies that a 1% increase in man-days leads to a 0.086% increase in bread wheat productivity. This finding is backed by earlier studies that have revealed an increase in crop productivity is the result of intensive labour use for different farm operations and agronomic practices that augment production. Thus, the better wheat productivity in this study can also be attributed to the fact that farmers in the study area have allocated sufficient man-days for the various labour intensive agronomic practices such as maximum tilling frequency, row planting, weeding, and timely harvesting practices that enhance their productivity.

| Table 1. Results of descriptive statistics by seed recycling status. |
|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|
| Variables               | Mean (μ) Values          | Recycled Seed Users (n= 247) | Fresh Seed Users (n=203) | Difference | Std.Err | t – values | p – values |
| Age (Years)             | 38.976                  | 46.084                  | -7.108                  | .929       | 1.05     | .000       |
| Grade levels of Schooling | 1.899                  | 1.616                  | .283                    | .265       | .83      | .000       |
| Family size             | 5.158                   | 7.005                  | -1.847                  | .276       | 6.7      | .000       |
| Dependency Ratio        | 0.623                   | .436                   | .186                    | .022       | 8.3      | .000       |
| Tropical Livestock Unit | 4.537                   | 9.713                  | -5.176                  | .409       | 12.65    | .000       |
| Land Size               | 0.586                   | .861                   | -.275                   | .068       | 4.05     | .000       |
| Frequency of Extension Contact | 1.373               | 1.744                  | -.371                   | .106       | 3.5      | .001       |
| Wheat Productivity      | 36.858                  | 40.779                 | -3.92                   | .517       | 7.6      | .000       |
| Credit amount           | 3825.510                | 4220.699               | -395.19                 | 477.402    | .85      | .408       |
| Seed Recycling frequency | 6.450                  | 2.616                  | 3.833                   | .339       | 11.3     | .000       |
| Weeding frequency       | 1.425                   | 1.872                  | -.447                   | .063       | 7.15     | .000       |
| Row Spacing             | 14.433                  | 19.852                 | -5.419                  | .858       | 6.3      | .000       |
| Seed rate               | 214.778                 | 169.582                | 45.196                  | 8.957      | 5.05     | .000       |
| Fertilizer per hectare  | 112.595                 | 154.718                | -42.123                 | 8.12       | 5.2      | .000       |
| Herbicide per hectare   | 0.406                   | .741                   | -.335                   | .045       | 7.5      | .000       |
| TE Score                | 0.789                   | .813                   | -.024                   | .004       | 6.65     | .000       |

<table>
<thead>
<tr>
<th>Categorical Variables</th>
<th>Number</th>
<th>Number</th>
<th>Total</th>
<th>Pearson’s χ²</th>
<th>P - values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>223</td>
<td>185</td>
<td>408</td>
<td>0.100</td>
<td>0.75</td>
</tr>
<tr>
<td>Female</td>
<td>24</td>
<td>18</td>
<td>42</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Membership in Seed Multiplication &amp; marketing Cooperatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>No 90 186 276 143.101 0.000</td>
</tr>
<tr>
<td>Yes 157 17 174</td>
</tr>
</tbody>
</table>

Source: Own Computation (2022).
Similarly, the coefficient for capital invested measured in terms of Ethiopian birr was significantly positive at p<0.01. As expected, this coefficient indicates that an additional 1% rise in capital invested leads to a 0.22% increase in bread wheat productivity. This finding is backed by earlier studies. For instance, better annual income is reported to increase farmers’ propensity to be productive as it enables them to have access to production supplementing inputs and technologies. The positive impacts of income on production enhancing agricultural innovation is frequently reported.7,8,16,18 The effect of capital investment was higher than any other variable considered in the production function of this study. The extremely significant effect of capital on BWP could have several explanations. First, it may serve farmers as an incentive to purchase production improving and efficiency augmenting technologies. Key informants of this study including seed suppliers and DAs have revealed that better-off farmers adopt technologies earlier than poor farmers. This could be because better-off farmers are well above the poverty line that they took the risk of trying a new innovation. Conversely, farmers who are already below the poverty line or closer to it could not have the appetite for production enhancing innovations for two obvious reasons. First, farmers who are already below the poverty line could not afford the purchase of production enhancing technologies as they do not have sufficient capital for investment. Studies have also shown that poor farmers will not invest even on the cheapest farm innovations as they do have urgent consumption demand.12,14,51,52 Second, farmers closer to the poverty line do not have the incentive to try new innovations as risks of innovation failure will put them below the poverty line. This could be another explanation for the highly significant impact of capital investment in BWP. Besides, the agronomic practices in BWP are quite labour demanding. Higher income is likely to encourage farmers to make use of hired labour and machinery rent which in turn would improve production and efficiency of the farmers. This could be another explanation for a highly significant nexus between BWP and high capital investment.

Chemical fertilizer application was another important hypothesized determinant expected to have a considerable impact on bread wheat productivity in the study area. The coefficient for chemical fertilizer was positive and significant at p < .05 indicating that a 1% rise in chemical fertilizer application has contributed to a 0.042% increment in the amount of BWP per hectare. Several studies have revealed that the low wheat yield in Ethiopia is attributable to low fertilizer use, depletion

<table>
<thead>
<tr>
<th>InOutput</th>
<th>Coef.</th>
<th>St.Err.</th>
<th>Z-value</th>
<th>p-value</th>
<th>[95% CI]</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>lnlabour</td>
<td>0.086</td>
<td>0.006</td>
<td>14.210</td>
<td>0.000</td>
<td>0.075</td>
<td>0.098 ***</td>
</tr>
<tr>
<td>lncapitalin</td>
<td>0.220</td>
<td>0.005</td>
<td>48.730</td>
<td>0.000</td>
<td>0.211</td>
<td>0.228 ***</td>
</tr>
<tr>
<td>lnfertilizer</td>
<td>0.042</td>
<td>0.004</td>
<td>10.270</td>
<td>0.000</td>
<td>0.034</td>
<td>0.050 ***</td>
</tr>
<tr>
<td>lnland</td>
<td>-0.031</td>
<td>0.004</td>
<td>-8.870</td>
<td>0.000</td>
<td>-0.038</td>
<td>-0.024 ***</td>
</tr>
<tr>
<td>lnseedrate</td>
<td>-0.007</td>
<td>0.005</td>
<td>-1.420</td>
<td>0.155</td>
<td>-0.018</td>
<td>0.003 NS</td>
</tr>
<tr>
<td>lnweedicide</td>
<td>0.014</td>
<td>0.005</td>
<td>2.720</td>
<td>0.007</td>
<td>0.004</td>
<td>0.024 ***</td>
</tr>
<tr>
<td>lnmarent</td>
<td>0.005</td>
<td>0.001</td>
<td>6.260</td>
<td>0.000</td>
<td>0.004</td>
<td>0.007 ***</td>
</tr>
<tr>
<td>Constant</td>
<td>1.193</td>
<td>0.057</td>
<td>20.750</td>
<td>0.000</td>
<td>1.080</td>
<td>1.305 ***</td>
</tr>
</tbody>
</table>

Source: Own Computation (2022).

NS Not significant.
***p<.01.
**p<.05.
*p<.1.
of soil fertility due to continuous nutrient uptake of crops, and insufficient organic matter application. Besides, Ethiopia’s sole dependence on narrow imported fertilizer products (largely urea and di ammonium phosphate (DAP) is blamed to cause a considerable productivity loss. These two imported fertilizer products are rich sources of nitrogen (N) and phosphorus (P). But most Ethiopian soils lack other macro nutrients. The introduction of the blended NPS fertilizer in addition to the existing types of fertilizer could explain the positive impact of fertilizer in wheat productivity of the study area. Despite the observed positive nexus between wheat productivity and fertilizer application, it is worth noting that farmers in the study area have applied fertilizer rates well below the recommendation. This could be due to the blanket fertilizer rate recommendation that did not take spatial differences into consideration. This might call for study area specific fertilizer rates related agronomic trials. Thus, future research should focus on this critical issue. Similarly, argue for a soil test based application of plant nutrient rather than the blanket recommendation of urea and DAP, and especially those containing sulfur, boron, and other nutrients is recommended in averting problems caused due to nutrient deficient soil.

The coefficient for land is interestingly significant and negative at p<0.01. This implies that an extra one-hectare land addition to the current wheat production will lead to a 0.03% productivity loss. This finding is diametrically opposite to the findings reported in multiple empirical investigations. Unlike the finding in this study, these studies found a significant positive association between land and crop productivity. The production theory of diminishing marginal utility states that an increase in input can increase the production of crop and other commodities up to certain optimum levels. Any additional input use after this optimum level will lead to a flat production. Further input addition after the plain/flat production curve will cause a decrease in production. This theory could be a plausible explanation for the current finding. Besides, has indicated that a major reason for the non-attainment of achievable yields is low fertility of the soils which is partly due to low use of fertilizers. But low fertilizer use was not observed in this study. The declining soil fertility and land fragmentation could explain the negative relationship between total wheat productivity and land size.

The coefficient for seed rate was not significant at the conventional probability levels indicating that seed rate did not contribute to total wheat productivity. As indicated in Table 1 above, farmers in the study place have used an average seed rate of 194.39 kg ha\(^{-1}\) which is higher than the recommendation by 44.39 kg ha\(^{-1}\). During the FGD, participants have raised that recycled seeds are used from reserves saved during the previous production, can be borrowed from relatives and friends, and are cheaper in the market. They have also confirmed that the productivity of recycled seed is believed to be inferior to the fresh seeds, unless compensated by applying extra seed rates. This farmers attitude of increasing productivity by making use of extra seed rates is against the recommendation and the established scientific theory of diminishing marginal productivity (DMP). The relatively cheaper market price for recycled seeds might have encouraged farmers to apply more amount of seed rate per hectare. Besides, higher seed rates application imply a risk aversion behavior of farmers to ensure good plant stand and survival. This explanation can be adopted in this study too. Contrary to the current study, seed rate has shown the highest input effect on production and estimated elasticities. The positive contribution of seed rates on production and technical efficiency was attributed to the quality and quantity of the seeds. The insignificant contribution of seed rate in this study may therefore be explained by the inferior quality of the seeds and the seed recycling practices in the surveyed areas. Weeds remain a major challenge to increasing crop output as they compete with the crop plants for light, nutrients, and water. Such growth retarding weeds could not cause a significant harm if proper weeding frequency is followed. Thus, the application of weedicide was expected to increase total crops productivity. As expected, the coefficient for weedicide was positive and significant at p=0.007 indicating BWP is highly dictated by weed management.

Machine rent was expected to have a significant positive impact on total factor productivity. As expected, a 1% change in machinery rent has led to a 0.005% change in bread wheat productivity. There are studies that support the current finding. Higher productivity, which requires greater power and mechanization, is one of the most important technologies that can increase production when resources are limited. This implies that mechanization leads to production improvement under sufficient supply of land, labour, and other resources. This may be a plausible explanation for the significant contribution of machinery on BWP under the current study. In addition, key informants of this study have repeatedly mentioned that the state sponsored harvester and threshing machineries has helped farmers for timely harvest and substantially reduce post-harvest losses. It is also worthy to note that out of the seven variables expected to improve bread wheat productivity, machinery rent has the least contribution. This could be due to the fact that these machineries (especially combine harvesters) were brought to the study areas from other regions on rental basis with expensive prices which is likely to increase the operation cost of BWP.

Implications of bread wheat seed recycling on technical efficiency (TE)
In Ethiopia, making use of freshly purchased improved seeds and improved seeds recycled for a maximum of five seasons are considered as improved seed use. Therefore, fresh seed use in this study refers to the use of freshly purchased seed
and seeds recycled for a maximum of five seasons. This study has expected that multiple bread wheat seed recycling has a significant negative impact on the productivity and TE of smallholder farmers. Studies have shown that bread wheat seed recycling to a maximum of five production seasons can be considered as improved practice and don’t cause significant productivity loss. But, multiple seed recycling is reported to be a common practice in wheat growing areas of Ethiopia. For instance, about 84% of the farmers depend on recycled seeds while only 14% used new seeds. This practice produce seeds that have low germination percentage and is contaminated with weeds. The problem of recycled seed is serious in Ethiopia, where pathogens of the wheat rusts evolve quite rapidly, rendering farmers’ varieties less resistant to disease. To avoid yield losses from disease, farmers should replace their wheat varieties frequently and regularly.8,27 Given these existing literatures, this study had the following hypotheses as far as the nexus between TE and bread wheat seed recycling is concerned:

H_0: diff = 0. This hypothesis assumes that there is no difference in mean TE between wheat producing farmers with fresh and recycled seed use.

H_{11}: diff ! = 0. This is an alternative hypothesis with an assumption that the difference in mean TE between fresh and recycled bread wheat seed users is different from zero.

H_{12} = diff < 0. This is a second alternative hypothesis that expects the difference in the mean TE between recycled and fresh seed users is less than zero.

H_{13} = diff > 0. This is the third alternative hypothesis that expects the mean TE difference between recycled and fresh bread wheat seed users is greater than zero.

Figure 3. Technical efficiency of farmers with seed recycling.
Appendix Table 3 presented as an underlying data of this study summarizes the TE of fresh and recycled bread wheat seed users. This study has found that about 247 (54.89%) of the respondents make use recycled seeds for more than five production seasons while about 203 (45.11%) make use of either freshly purchased seed or recycled seeds below five times. The average TE of fresh and recycled seed users were 0.8123 (81.23%) and 0.7789 (78.89%), respectively. This can be interpreted as a typical fresh seed user and recycled seed user are operating 0.1877 (18.77%) and 0.211 (21.11%) less than his/her maximum TE and this difference is highly significant at p=.0000. Figure 3 presented in the supplementary material paints a clear picture about the relationship between seed recycling and TE scores. It offers a strong evidence that the variance in distribution of the TE scores between recycled and fresh seed users. A substantial proportion of fresh seed users had a mean TE score of greater or equal to 0.8165 while none of recycled seed users hit a TE score of this magnitude.

This study has also examined the marginal effect of seed recycling on the overall TE of BWP. As presented in the Table 3 below, a unit increase in seed recycling frequency is associated with a.001 decline in TE. Based on the ordinary least square (OLS) estimation of the Generalized Linear Model, the marginal effects of successive seed recycling up to four, eight, twelve, sixteen, and twenty times on the TE of BWP were predicted, respectively. Farmers who make use of fresh seeds (fresh or seeds recycled less than five times had a mean TE of 80%. Further seed recycling up to eight, 12, and 16 times will cause a 0.003, 0.007, and 0.01 loss in TE, respectively. Generally, it can be concluded that seed recycling and TE have a significant inverse relationship. This finding is backed by other empirical investigations. Thus, from these findings, it is clear that the null hypothesis (H0: diff=0) that expects no TE difference and the fourth alternative hypothesis that expects a positive TE difference (H4: diff > 0) are rejected in favor of the 2nd (H1: diff ! = 0) and the 3rd H2: diff < 0) alternative hypotheses. This means that the assumption that seed recycling does not cause inefficiency in BWP does not hold water. In general, it can be deduced that seed recycling has caused considerable TE loss as compared to fresh seed. Recycled seeds are reported to be highly vulnerable to the most important wheat rusts, a group of diseases caused by fungal pathogens (Puccinia spp.), are stem rust (also called black rust), stripe rust (also called yellow rust) and leaf rust (also called brown rust). Stem and stripe rusts are the major biotic constraints to wheat production in Ethiopia, with frequently recurring epidemics. Studies revealed that recycled seeds are susceptible to weeds and pathogens. The biotic constraints and diseases may add financial and management burdens on farmers that might explain farmers technical inefficiency in this study.

### Table 3. Marginal effect of different levels of seed recycling frequency on technical efficiency (TE).

<table>
<thead>
<tr>
<th>TE Score</th>
<th>Coef.</th>
<th>Std. Err</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seed recycling frequency</td>
<td>-.001</td>
<td>000</td>
<td>-2.02**</td>
<td>.000</td>
</tr>
<tr>
<td>Constant</td>
<td>.804</td>
<td>0.003</td>
<td>297.19***</td>
<td>.000</td>
</tr>
<tr>
<td>Mean dependent var = .79963</td>
<td>SD dependent var = 0.037423</td>
<td>R-squared = 0.736</td>
<td># of obs = 450</td>
<td>F-test = 4.084</td>
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<td>Akaike crit. (AIC) = 1679.537</td>
<td>Bayesian crit. (BIC) = 1671.318</td>
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<tr>
<td>Delta-method</td>
<td>Margin</td>
<td>std.err</td>
<td>t</td>
<td>P&gt;t</td>
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<td>_at</td>
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<tr>
<td>1</td>
<td>0.800</td>
<td>0.002</td>
<td>447.440</td>
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<td>2</td>
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<td>0.002</td>
<td>351.570</td>
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<tr>
<td>3</td>
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<td>0.004</td>
<td>218.950</td>
<td>0.000</td>
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<tr>
<td>4</td>
<td>0.790</td>
<td>0.005</td>
<td>151.510</td>
<td>0.000</td>
</tr>
<tr>
<td>5</td>
<td>0.786</td>
<td>0.007</td>
<td>114.360</td>
<td>0.000</td>
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</table>

Adjusted predictions
Model VCE: OLSExpression: Linear prediction, predict().
1._at: Seed recycling Frequency = 4.
2._at: Seed recycling Frequency = 8.
3._at: Seed recycling Frequency = 12.
4._at: Seed recycling Frequency = 16.
5._at: Seed recycling Frequency = 20.
Variables that uniquely identify margins: Seed recycling frequency.
***p<.01.
**p<.05.
Discussion
Determinants of TE

This study has considered about 12 different socio-demographic, economic, institutional, and agronomic determinants hypothesized to influence TE of BWP. The graphical abstract presented in Figure 5 and deposited as an underlying data provides a vivid picture of the study variables. Among these variables, gender, grade level, plot size, and frequency of extension contact of the respondents did not have a notable contribution to BWP technical inefficiency. Figure 4 illustrates the nexus between TE scores and the different variables considered in the study. The coefficient for gender (being female) is negative but insignificant indicating technical inefficiency is not caused by gender differences. However, ample studies unfold that female headed households generally have less access to and control over different factors of production including land, credit, farm inputs, extension services, and irrigation water which contributes to their inefficiency in farm operations. A plausible explanation for the current insignificant impact of gender on technical inefficiency may be the traditional support system by which the community assist farm operation of widowed and divorced women. Moreover, participants of the female FGD have explained that helpless, single or unmarried, widowed, divorced, and women with disability are beneficiary of social welfare programs like the Productive Safety Net Program (PSNP) and other non-governmental organization (NGO) sponsored supports. These social welfare programs support women by providing farm inputs and emergency assistances in times of shocks and stresses that might have helped them to enhance their production and improve their TE. These same FGD participants have explained that there are women Village Economic and Social Associations (VESAs) that provide credit, saving, training, farm inputs, marketing services, labour, and social supports in times of misfortunes including crop production failures, livestock and human death. It was frequently mentioned that these VESAs have helped women to have access to and control over financial services which is not open to male headed households. The insignificant effect of gender on farmers technical inefficiency thus could be attributed to these support mechanisms. The finding in this study is backed by an earlier study of who have studied the TE of smallholder agriculture in developing countries.

The age of the farmer was hypothesized to have a statistically significant positive effect on the TE of BWP. Age is considered as a proxy indicator of farmers’ experience in making use of improved practices and farm inputs. The coefficient for this variable is highly statistically significant with a negative sign at p<.01, which indicates that age of the farmer is inversely related with inefficiency. This implies that younger farmers tend to be more inefficient than older ones. From Table 4 presented below, it is clear that a one-year increase in farmers age reduces technical inefficiency by 0.13%. This could be due to the fact that longer years and experience in agriculture has helped older farmers to weigh the merits
and demerits of efficiency enhancing practices and inputs which in turn motivate them for further adoption and improvement in production efficiency. In addition, longer years may bestow farmers the chance for better asset ownership and socio-economic status that embolden them to take risks in trying efficiency and production augmenting inputs and practices. Thus, the age of farmers can be considered as a vital socio-personal variable in improving efficiency of BWP. Similar finding was reported by other studies.\textsuperscript{13,37,41} However, few other studies are against this finding. For instance, it was found that older farmers are likely to be more conservative and hesitant to adopt new innovations and evade frequent experimentation with the new technologies that reduce their TEM\textsubscript{say}, Tesafye.\textsuperscript{48} This study has also mentioned that farmers managerial ability decreases with age that reduce their productivity and TE.

Education level of the respondent was expected to have a significant direct relationship with the farmers’ TE. Yet, the inefficiency coefficient found in this study is negative and insignificant. This means that farmers’ level of education measured in years of schooling attended don’t affect their level of TE. This is diametrically opposite to several established facts that have proven the highly significant positive impact of education on improving TE of farmers.\textsuperscript{16,41,48} These studies unfold that education improves the ability of the household to make informed and timely decision about production inputs. Educated farmers more often have better access to agricultural information and higher tendency to adopt improved inputs (like fertilizers and crop varieties) more optimally and efficiently. However, the discrepancy about the impact of education could have several explanations. The first explanation may be the difference in the level of education attained by farmers. The mean grade level attained by farmers of this study area is less than two years. The average years of schooling reported by the studies mentioned are higher than two years. Thus, few years of schooling in the study area could plausibly explain the insignificant contribution of education on farmers TE. Second, the difference in the scale of farm operation could be another explanation. For instance, the positive efficiency impact of education is observed in large and medium farms than small farms.\textsuperscript{40} However, this is against the established facts by the proponents of the small farm approach. For instance, studies have proved that land productivity of small farms was at least twice that of the largest ones. Small farms enable to make use of family labour intensively and also help in avoiding supervision...
Larger family size has been associated with better productivity and TE. Studies unfold that households with larger family sizes have better advantage by being able to use labour resources to accomplish different labour demanding farm operations at the right time.20,69 Yet, higher household size has also been linked to less productivity and technical efficiency, when the actual family members are sick, unproductive, old, and disabled.18 These findings sheds light on the need to consider family size and dependency ratio separately. In this study dependency ratio refers to the number of dependent household members (which includes children less or equal to 14 years, elderly people greater or equal to 64 years, along with sick and people with disability) divided by the number of productive household members (which include working age people from 15 to 64 years). The same definition was used in several studies.70 Given these evidences, this study therefore has hypothesized that family size will have a highly significant contribution to TE while dependency ratio will end-up in curtailing farmers TE. The findings for both of these variables was congruent with prior expectations. From the coefficient presented in Table 4 above, it can be inferred that a 100% increase in family size reduces technical inefficiency by 50.2% at p<.05. On the contrary, a 100% increase in dependency ratio has increased farmers technical inefficiency by 1.9% at p<0.05. From these findings, it is also clear that the TE gains from an increase in family size can be cancelled by the efficiency loss as a result of higher dependency ratio. This finding is in agreement with the study made at Wolmera district of West Gojam in Ethiopia.18

Studies have shown that bigger land size makes production operations difficult and costly to fulfill the production input requirements. Moreover, big farm owners with limited family and hired labour, draught power, and no access to labour saving technologies tend to poorly manage their plots.38,45 As a result, land size allocated for BWP was expected to have an inverse relationship with farmers TE. The coefficient for land size, however did not show any noticeable impact on farmers TE and was not in line with a priori expectation of the study. This means that the amount of land allocated for BWP did not affect farmers TE. Several findings are against what has been observed in this study area. For instance, a significant and positive impact of plot size on wheat producers’ inefficiency was reported in another study.38 The same author has argued that the significantly high positive impact of plot size on technical inefficiency is due to the inherent nature of big plot sizes that hamper farmers ability to carry out important agronomic practices that must be done on time given the limited resources available at farmers disposal. On the contrary, farmers with larger area of cultivable land have the capacity to use compatible technologies that could increase their efficiency and enjoy the benefits of the economies of

<table>
<thead>
<tr>
<th>Variables</th>
<th>Coef.</th>
<th>Std.Err</th>
<th>Z-value</th>
</tr>
</thead>
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<tr>
<td>Gender (Female)</td>
<td>0.015**</td>
<td>2.982</td>
<td>0.100</td>
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<tr>
<td>Age</td>
<td>-0.125**</td>
<td>0.734</td>
<td>-0.170</td>
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<tr>
<td>Grade</td>
<td>0.089**</td>
<td>0.273</td>
<td>0.330</td>
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<tr>
<td>Family size</td>
<td>-0.502**</td>
<td>0.690</td>
<td>-0.730</td>
</tr>
<tr>
<td>Dependency Ratio</td>
<td>0.019**</td>
<td>32.844</td>
<td>0.000</td>
</tr>
<tr>
<td>Number of animals (TLU)</td>
<td>-0.095**</td>
<td>1.037</td>
<td>-0.090</td>
</tr>
<tr>
<td>Land size</td>
<td>0.014NS</td>
<td>5.077</td>
<td>0.000</td>
</tr>
<tr>
<td>Hand weeding frequency</td>
<td>-0.075**</td>
<td>2.401</td>
<td>-0.030</td>
</tr>
<tr>
<td>Row spacing</td>
<td>-0.031***</td>
<td>0.169</td>
<td>-0.180</td>
</tr>
<tr>
<td>Extension contact</td>
<td>-0.026NS</td>
<td>1.147</td>
<td>-0.020</td>
</tr>
<tr>
<td>Credit amount</td>
<td>-0.002**</td>
<td>0.001</td>
<td>-1.990</td>
</tr>
<tr>
<td>Cooperative Membership (Yes)</td>
<td>-0.060**</td>
<td>2.616</td>
<td>-0.020</td>
</tr>
<tr>
<td>Constant</td>
<td>0.511***</td>
<td>48.329</td>
<td>0.010</td>
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</tbody>
</table>

Number of obs = 450 Log likelihood = -146.4552 Wald chi2(7) = 20.67
Prob > chi2 = 0.0043 Mean TE Score = .7996 SD Dependent var. = .037482

Source: Own Computation (2022).
NS Not significant.
***p<.01.
**p<.05.
*p<.1.
Quite often, livestock and crop production tend to be complementary. Animal wastes can be used as a soil conditioner while crop residues and remnants serve as livestock feed. Animals can be a good source of cash and draught power which in turn enhance productivity and efficiency. Furthermore, animals can be used as a hedge and shock absorber to artificial and natural shocks and stresses. Thus, the number of animals owned expressed in TLU was hypothesized to have a highly significant positive impact on the TE of farmers. The parameter estimate was significant and negative indicating technical inefficiency decrease with increasing TLU at p<0.1. The parameter estimate has indicated that a 1% increase in TLU decrease farmers probability of being inefficient by 0.095%. This is in line with the prior expectation of the study.

Hand weeding frequency was expected to enhance production and TE of farmers in the study area. The coefficient for this variable is highly significant and negative implying a unit increase in weeding frequency reduces the probability of being technically inefficient by 0.05 at p<0.01. Farmers in the study area make use of both mechanical and chemical weed control methods that may have assisted them to enhance their production and TE. Earlier studies have also stated weed control as quintessential practice for efficient and profitable BWP. Weeds have direct and indirect impact on BWP. Directly weeds compete with the wheat crop for space, water, light, and nutrients while they harbor insects and disease-causing organisms indirectly.

This study found that row planting and cluster farming is widely practiced in the study area. This is because the extension advisory service has been actively pushing farmers to move from the conventional broadcasting wheat sowing method on fragmented plots to row planting and cluster farming. However, earlier studies unfold that it is not only the sowing method that counts most in improving productivity and TE. The spacing between seeds and rows have also considerable impact on crop productivity and production efficiency. Given these findings, this study has assumed that the spacing between rows has a highly significant positive impact on the TE of BWP. This assumption holds water under the current study. A unit increase in the spacing between rows has reduced technical inefficiency by 0.005 at p=0.001. Given this finding, encouraging farmers to stick to keeping the optimum row spacing will lead to reduction in technical inefficiency and improve BWP.

The frequency of extension contact was hypothesized to have a significant positive impact in improving farmers TE in BWP. Unlike the prior expectation, the coefficient for extension contact turned out to be insignificant. However, this finding should be cautiously interpreted. The insignificant contribution of this variable could be due to its focus on other crop items than BWP. Key informant DAs have indicated that they have been intensively working on bread wheat advisory service for more than 30 years. Thus, they have shifted their attention to introduction of economically superior and industrial crops than conventional crops production. Extension may have significant impact in earlier stage of technology introduction when farmers lack sufficient information and skill. But at later stages, there will be information equilibria between the farmer and extension worker. Thus, this assessment has focused on later stage during which information, improved practices, and inputs for BWP has already been fully diffused and no new ways of BWP is generated. This late assessment may belittle the impact of the extension service at earlier time of improved bread wheat production technology introduction. This could explain the trivial contribution of the extension service. However, several findings reported the highly significant positive contribution of agricultural extension service in enhancing producers TE. The majority of farmers in Ethiopia are not exposed to multiple agricultural technology and information sources. It is only the state-led agricultural extension system that often provides them with agricultural advisory services and innovation.

Evidences from extensive literature review indicates that crop productivity and efficiency are enhanced when credit and other financial services are tailored to the needs of smallholder farmers. These empirical evidences further argue that farmers decision to invest and produce crops and other agricultural commodities is substantially influenced by access to a mix of financial instruments. Given these evidences, amount of credit was expected to produce a highly significant impact on the TE of BWP. Nevertheless, the coefficient for the amount of credit has turned out contrary to a priori expectation of this study. The amount of credit did not show any marked effect on the TE of BWP. This is due to the fact that the majority of the farmers in the study area don’t have access to formal financial institutions. This study has conducted FGDs with recycled and fresh seed users to understand the major challenges in BWP. Participants of the FGDs have frequently and unanimously explained that access to credit and financial services is very limited. These FGD participants further mentioned that it is only Amhara Credit and Saving Institution (ACSI) that provide credit service for the community. These participants have complained about the highest interest rate and the targeting criteria to access credit. It was mentioned that all farmers are not entitled to access credit. Land certificate, membership in the PSNP, assets ownership, and repayment ability are considered as major targeting criteria. It was also explained that farmers get access to
credit from their own Rural Saving and Credit Cooperative (RuSACCO). The interest rate from the RuSACCO is mentioned to be fair as compared to other sources. But RuSACCO’s do not have the financial capacity to meet the financial requirements of all members. Thus, they give insufficient amount of credit to be repaid only within one year. Similarly, some credit arrangements reportedly discourage farmers from adoption of new agricultural technology, purchasing main farm inputs, or making other decisions that can increase their productivity and efficiency. This is due to expensive collateral requirements, unaffordable interest rates, lack of appropriate risk mitigation products, and supply driven nature of the financial services that don’t match smallholder farmers felt needs. The insufficient credit supply that has retarded agricultural production was reported in several studies.15,56,60,75,76 These facts on credit could explain the unmarked contribution of credit on the TE of BWP in this study area. Therefore, in order to increase the TE in BWP, farmers must be provided with sufficient amount of credit and easy access on favorable terms through formal institutions.

The study area is known for its wheat production suitability. Thus, the Ethiopian Seed Enterprise (ESE) and the Amhara Seed Enterprise (ASE) establish wheat seed multiplication and marketing cooperatives. There are evidences that producers’ cooperatives boost productivity and improve TE as they reduces transaction costs and play a significant role in input supply and the procurement of members produce in times of unfavorable market prices.77,78 Given these findings, this study has assumed a highly significant positive association between farmers membership in seed multiplication and marketing cooperatives and their technical efficiency. The coefficient is in line with the hypothesis. The coefficient indicates that the probability of being inefficient is reduced by 0.003 for members than non-members at p<0.05.

Policy implications
From results of this study, the following recommendations are made

- There are strong evidence that few farmers in the study areas are capable of producing bread wheat either on the frontier and/or extremely closer to the frontier that implies their high TE. Therefore, this study highly recommends a farmer – to – farmer (F2F) extension system that allow farmers to learn from their neighbor farmers on how to enhance their TE and improve their productivity. In this regard, Farmers’ Field School (FFS), farmers’ field days, excursions, and other group extension methods are strongly suggested. This could also be a financially viable informal technology diffusion and training modality for the existing extension system. Implementation of these group extension methods will also have a complementary effect on the face – to – face (individual) extension methods.

- The number of man-days allocated and the amount of capital invested had significantly high positive contribution for wheat production. Therefore, improving labour use efficiency through training and increasing farmers’ access to financial sources and services is strongly recommended.

- Respondents access to credit has helped farmers to substantially reduce their production inefficiency. This study therefore calls for an urgent policy design and implementation geared towards improving farmers financial access.

- Dependency ratio has a considerably high contribution to farmers technical inefficiency. It is therefore quintessential to introduce labor saving technologies that would ease the work burden of families of with the highest dependency ratio induced by availability of family members with disability, old age, sick, and unproductive children.

- Farmers continue bread wheat seed recycling that substantially curtail their productivity and efficiency. This is largely due to absence of supply, supply insufficiency, and expensiveness of early generation seeds (EGSs) and improved varieties. It is therefore highly recommended to encourage the establishment of seed multiplication and marketing cooperatives that could solve these problems. Besides, seed aids, seed loans, seed vouchers, and financial credits geared towards smallholder farmers seed security are strongly recommended as they can serve as an incentive for wider use of fresh and EGSs.

- Social welfare programs and Village Economic and Social Associations (VESAs) have helped some sections of the bottom poor farmers to have access to and control over production augmenting and efficiency enhancing inputs and technologies. Yet, these social welfare programs and VESAs are few in number and benefit a minor portion of the society. Moreover, members of these VESAs support each other in times of agricultural labour requirement, crop production failure, livestock and human death. Yet, seed is not part of the VESAs support arrangement. Thus, it is highly recommended to scale – up and establish as many VESAs as possible and the multiple economic and social objectives in the existing VESAs should also be relaxed to include village level seed saving and seed loans provisions.
• The findings in this study are based on a cross sectional data. Yet, farmers’ seed recycling practices tend to be dissimilar on longitudinal basis. This calls for the need to undertake similar empirical investigations using panel data in the future.

Conclusions
The elasticities from the MLE under the full frontier production function adds – up to 1.49. Thus, one can conclude that farmers in the study area are facing increasing returns to scale and there is a room to increase bread wheat production beyond its current level of production. In addition, the coefficients of the stochastic frontier production function for labour (0.086), capital (0.22), fertilizer (0.042), weedicide (0.014), and machinery (0.005) were positive and significant at p<0.001 implying that an optimum increase to these inputs would increase BWP. In other words, from these coefficients in the stochastic frontier production function it can be deduced that amount of labour employed (man – days), capital invested, fertilizer, weedicide, and machinery rent had significantly high contribution to the existing level of bread wheat production. However, the coefficient for land was negative and significant suggesting additional land allocation for BWP would likely reduce bread wheat productivity.

The mean TE was found to be 79.99%. The maximum likelihood estimates for the inefficiency parameter portrayed that farmers in the study area operates 20.1% less than their potential. It is therefore evident from this finding that there is an opportunity to increase the existing BWP without extra inputs allocation and through improving farmers TE or reducing their level of technical inefficiency. From the MLE, there is also strong evidence that few farmers in the study areas are capable of producing bread wheat either on the frontier and/or extremely closer to the frontier that implies their high TE. From the inefficiency analysis one can easily infer that longer years,79 higher number of animal ownership (TLU), credit amount, and membership in seed multiplication and marketing cooperatives have helped farmers to significantly reduce their technical inefficiency. Similarly, agronomic related parameters such as hand weeding frequency and row spacing had significantly enhanced farmers technical inefficiency. However, dependency ratio has significantly curtailed farmers level of technical efficiency. Also, from analysis of the nexus between seed recycling and TE, a typical recycled seed user was 2.34% less than fresh seed users in its TE. This testifies that seed recycling has significantly contributed to farmers’ inefficiency. Generally, it can be concluded that seed recycling and TE have a significant inverse relationship. Bread wheat seed recycling up to five times is considered as improved practices. However, a substantial TE difference was observed even among farmers who had recycled seed less than five times. Thus, one can conclude that the recycled seeds do have higher chance of contamination with impure and genetically inferior seeds that contribute to lower productivity and technical efficiency.

Data availability
Underlying data

The project contains the following underlying data:

• Supplementary Material 5: Data for TE Analysis CSV.csv. (Anonymised responses from questionnaire).
• Supplementary Material 6: Data for TE Analysis Stata.dta.
• Supplementary Table 1. Profile of key information interview (KII) Participants.
• Supplementary Table 2. Distribution of focus group discussion (FGD) Participants.
• Appendix Table 1: Study assumptions and hypothesis test for model specification.
• Appendix Table 2: Technical efficiency difference between fresh and recycled seed users.
• Appendix Table 3: Distribution of technical efficiency score by seed recycling status
• Variables key (Variables key for questionnaire headings in supplementary materials 5 and 6).

Data are available under the terms of the Creative Commons Zero “No rights reserved” data waiver (CC0 1.0 Public domain dedication).
Extended data

This project contains the following extended data:

- Supplementary Material 3: English Questionnaire.pdf.
- Supplementary Material 4: Amharic Questionnaire.pdf.
- Figure 1: Map of the study areas.
- Figure 2: Sampling procedures.
- Figure 3: Technical efficiency of farmers with seed recycling.
- Figure 4: Combined Graph of the study.

Data are available under the terms of the Creative Commons Zero “No rights reserved” data waiver (CC0 1.0 Public domain dedication).

Acknowledgments
Authors of the study are grateful for the men and women farmers engaged in the focus group discussions and the household survey. The authors also acknowledge the agronomists, experts, and officers who took part in the key informant interviews.

References


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Dear authors,

I'd like to congratulate you and your team for the good research work presented in your submitted paper for possible indexing in this prestigious journal. The topic is interesting, and I enjoyed it. However, before your work is recommended or accepted, a few comments must be included or addressed to improve the quality of your work. I have the following observations that may help improve your work: The authors must modify the following points in detail:

1. In the abstract, please include 2-3 special quantitative achievements from the findings of this study in the context of the environment by combining the research objectives and problems. Please limit your abstract to 250 words. Check spellings for many words that are misspelt or written in haste.

2. The introduction section needs a few more sentences to strengthen the article, and please include the research problem, objective, and novelty in the last paragraph of the Introduction section.

3. Include a few more sentences at the beginning of the introduction explaining your paper's contribution to the environment, climate change impact, and sustainability, as well as your attempts to deal with or present solutions to a specific problem/s and your unique contribution with this research paper.

4. Please also present the methodology section in a concise graphical format.

5. The literature review section is very weak; please revise it.

6. Please present your literature review in the form of a SmartArt chart.

7. Just after the Methodology, please mention the societal benefits of your research in terms of evaluating its key determinant.
8. In 500-750 words, explain research problems, solutions, and the theoretical contribution of your study in the "Results" section.

9. Please include graphical presentations of your findings.

10. Describe why you placed this study in a separate section of "Policy Suggestions" just before the section of "Conclusions."

I found that the literature section is VERY weak, bring sustainability in your study, therefore it requires more studies to be reviewed. I suggest to you that you may include the following work:

https://doi.org/10.1016/j.jclepro.2021.128585
https://doi.org/10.1016/j.jclepro.2021.128109
https://doi.org/10.1016/j.techfore.2023.122370
https://doi.org/10.1016/j.resourpol.2022.103169
https://doi.org/10.1016/j.heliyon.2021.e06952
https://doi.org/10.1016/j.energy.2022.123619
https://doi.org/10.1016/j.energy.2021.122365
https://doi.org/10.1016/j.eneco.2022.105884

I think above all studies will make this study more relevant in bridging the gap with literature. Looking forward for your revised submission.

References
Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and is the work technically sound?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Yes

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Technical efficiency and productivity analysis

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Reviewer Report 23 June 2023

https://doi.org/10.5256/f1000research.141558.r174037

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Habtamu Taddele
Institute of Climate and Society, Mekelle University, Mek’ele, Tigray, Ethiopia

The authors have raised important and noble research agenda for the scientific community. I have copied the title of this research in several search engines including Google Scholar, PubMed, and Google Semantic. I did not come across a single study that links bread wheat technical efficiency with seed recycling. The authors have captured with proper analytical methods the major determinants of smallholder bread wheat growers Technical Efficiency and clearly indicated the nexus with seed recycling. I do have strong conviction that the findings presented in this study will have paramount policy implications for people in the agricultural policy making circle and offers some pragmatic solutions to farmers and researchers engaged in improving wheat productivity and technical efficiency.
Criteria 1: Is the work clearly and accurately presented and does it cite the current literature?

I have checked the sources cited in the manuscript. I can assure you that the sources cited in the text are well acknowledged in the reference list. Moreover, the authors have summarized/paraphrased the sentences they borrowed from the different sources. The authors have applied reference management platforms/software and the reference style is well aligned to the scientific paper publisher’s standard. I believe that the manuscript has cited a sufficient number of articles relevant to the objectives of the article. I can confirm that the references cited are recent and not outdated.

Criteria 2: Is the study design appropriate and does the work have academic merit?

I can confirm that the study design is appropriate and has a strong academic merit. I can witness that the authors have used proper sampling design and provide sufficient details as to the context/setting under which the data collection was made. They have clearly indicated the data quality assurance mechanisms they have followed. I have also checked the underlying materials the authors have deposited in the Open Science Framework. I have seen the IRB approval along with the original and translated versions of the tools they have used in the data collection.

Criteria 3: Are sufficient details of methods and analysis provided to allow replication by others?

○ The authors have used multiple sampling methods. They have employed different sampling methods including stratification, purposive, random, and probability methods. This blending of sampling methods is highly commendable because pluralism in the sampling method will assist them to get representative and unbiased samples. I have cross-checked the CSV data deposited by the authors for public access in the Open Science Framework (OSF). I found that the number of data deposited is congruent with the predetermined sample size.

○ Data Collection Methods: again they have employed quantitative (structured interview) and qualitative data collection (KIs and FGD) methods. I believe this combination of the data collection methods will assist the authors to properly triangulate data. The data collection tools used in the study along with the rationale behind their use are well explained in sufficient details. The tools (both the original and the translated) are also deposited as an underlying data and are made openly accessible for public use.

Criteria 4: Data analysis and interpretation:

The SFA applied by the authors was appropriate for the data type they have gathered. The type of analysis selected was first tested for its suitability with their data. The findings from the quantitative analysis were sufficiently backed and supported by findings from qualitative analysis. The interpretation of the analysis was very clear and excellent.

Criteria 5: Are all the source data underlying the results available to ensure full reproducibility?

I have checked the OSF link provided by the authors as far as the underlying data and extended materials is concerned. It is properly deposited and is made publicly available for reproduction.
found the way the main data was presented interesting due to the fact that it is properly and clearly coded and labeled that others can easily use it.

**Criteria 6: Are the conclusions drawn adequately supported by the results?**

I have proved that the conclusions are drawn based on the findings of the study. Commendable conclusions were reached based on the analysis of the data.

**Final Assessment Decision**

**Approved with minor editorial work as indicated below.**

Saying these, I strongly suggest the authors to consider the following minor editorial comments for further improvement of their manuscript:

- Please be consistent in using terminologies like district vs woreda. Both are used frequently

- Title: The title looks interesting. However, the following minor revision is suggested. “Determinants of technical efficiency of smallholder bread wheat production and implications of seed recycling: A stochastic Frontier Approach”

- Abstract: Background - Line 5: Please rephrase “However, there is some empirical research that examines ....” To “However, there are limited studies that examine...”

- Methods - Line 1: “The data was...” correct as “Data were...”

- Methods-line 5: Bread wheat growers were the major respondents... Did you include others? I think, for the questionnaire survey, only BW growers were the target group. If other respondents were involved, please justify.

- Methods-line 8. TE and factors affecting it, just “TE” is enough. Because, at this section, TE is the key term.

- Results-line 2. ‘Weedicde’ changes it with “Herbicide”. Because it is unusual and colloquial term in agronomy.

- Key word. Too many key words. I suggest to delete at least “Agriculture” and “Inputs”

- Context-line 3 (and throughout the document as well). Meher -use English (Autumn), to make it clear for international audience

- Study area- --- The study takes place... need to be “the study was carried out....”

- I suggest to indicate your study area in range of coordinates (from -------- N, -------E to ------- N, --------E). This is because the coordinate you put indicates only a point, not the study area coverage.

- Sampling- “----by the researcher -----” should be changed to “----by the researchers ---”. Use
plural as there are two researchers

- Line 5: The researcher has decided...to "The researchers decided". Use past tense and plural.

- Page 6 line 1. Rewrite the equation n=1+N1...in scientific equation form (use Microsoft equation editor).

- Sampling procedures and participant selection - Line 1: Change the word “chief” by “main”

- Data types and sources - Consider the type and quantity of seed used rather than number of seeds/inputs

- Source for Tables in result section: Better to describe as “Researchers' computation” rather than “own Computation”

- In Table 2, you don’t need the last column as it is described below the table. In addition, merge the two columns for 95% CI. Also present all the tables in a more scientific way.

- Figure 3, the texts in the X-and Y-axes and the legend are with low contrast. May be, you have snapshotted it. Try to correct it. The same for other figures

- Conclusion-line 1. Farmers are facing increasing returns to scale—this is a positive attribute. I suggest to use other word like "are experiencing" instead of “facing”

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and is the work technically sound?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Yes

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Yes

**Competing Interests:** No competing interests were disclosed.

**Reviewer Expertise:** Climate Change and Rural Development

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.
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