Spatio-temporal Economic Sustainability Convergence in Koga Irrigation and Watershed Project, Amhara Region, Ethiopia

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Abstract

The spatio-temporal economic sustainability convergence of twelve irrigation blocks in the Koga irrigation and watershed project was tested in this study. Data on technical efficiency were used to examine the expected growth and speed of convergence in order to reach the production frontier and achieve similar economic sustainability. The study used inefficiency parameterizations, convergence theory, and scenario development as a methodology on a survey questionnaire that includes household demography, operational, and farm-specific data in a trans-log stochastic frontier model. The efficiency parameterization was used to identify the level of economic sustainability, and the convergence theory and scenario development were used to calculate the expected growth rate of efficiency and the speed of convergence in years. The main findings are that a household at the project level requires 9.42 percent growth to achieve optimum efficiency over ten years, and a farmer requires 15.46 years if the minimum reasonable growth rate of 6 percent per year is assumed. The findings that policymakers appear to be increasingly emphasizing efforts to improve the efficiency of less efficient farmers rather than investing in new technologies and inputs to ensure higher levels of economic sustainability highlight the critical role of efficiency improvement. Over a five-year period, the economic sustainability catch-up effect requires a growth differential of 2.11 - 9.45 percent. Household size, frequency of consultation visits, male household heads, the sharecroppers' mentality, and non-farm income are thought to facilitate convergence at the frontier while fostering experience sharing towards a similar level of sustainability. On various grounds, the expected growth rate and speed of convergence were discovered to be reasonable targets in the study area. The calculated expected growth rate was very close to what other studies confirmed. As a result of the findings, local governments should consider convergence at the frontier as a long-term plan and catch up for short-term goals.

Keywords: Technical efficiency; economic sustainability; convergence
JEL Classification: O47, R11

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1. Introduction

Ruttan (2002) classified agricultural productivity growth into three stages. The first two stages focused on measuring single-or partial-factor productivity and then total factor productivity (TFP), while the third stage focuses on agricultural convergence tests in productivity and efficiency. The findings of efficiency studies are not limited to calculating technical efficiency in microdata (firm-level), but also involve macrodata and advanced calculation methods, such as efficiency convergence testing (Kneller and Stevens 2003; Carvallo and Kasman 2017). Are farmers producing at maximum capacity? Are farmers held to the same standard of efficiency? Can the farmer catch up to the frontier or others? Are there any successful farmers to emulate? Is it possible to learn from model areas? Coelli et al. (2005) defined efficiency in a more specific context, stating that technical efficiency occurs when producers manufacture different products with minimal input or when they optimize input to produce more products. Inefficiency occurs when production operates within its frontier. Technical efficiency can be measured and may fall short of optimal levels. When this situation arises, there is technical inefficiency. Countries can be thought of as operating on or within the frontier, with the distance from the frontier reflecting inefficiency (Osiewalski et al., 1998).

Technical efficiency change is an indicator of country catch-up and convergence; it is an indicator of a country's performance in adapting global technology, and thus represents the catch-up factor (Rao and Coelli, 1998). Efficiency convergence raises some intriguing questions. (1) the efficiency convergence moment approach, which detects regional efficiencies moving toward or away from the frontier; (2) the efficiency catching up moment approach, which highlights the catching-up effect caused by regions with lower efficiency on regions with higher efficiency; and (3) the efficiency dispersed convergence moment, which shows regions' efficiency convergence to the average level (Purwono and Yasin, 2020). Meanwhile, efficiency convergence takes two forms: convergence among countries (Barro and Sala-i-martin, 1992) and convergence at the frontier (Battese and Coelli, 1995; Kumbhakar and Wang, 2005). Inefficiency occurs in both forms when production operates within the frontier line, which is the most optimal production rate, because output can still be increased using the same technology and input levels.

It is unrealistic to expect a given firm's inefficiency level to remain constant over time. According to Battese and Coelli (1995), time (t) was found to affect the inefficiency rate. If time negatively influences the inefficiency level, efficiency convergence is achieved. In other words, the inefficiency level decreases over the following time and eventually converges to the optimum efficiency level. Over time, a country can become less efficient or more efficient and catch up to the frontier. Growth in efficiency also indicates a more efficient use of existing technology over time. This indicates that there is a trend toward the frontier, which is the optimal value of production. However, the issue of inequalities in agricultural development among countries and regions also continues to capture public attention. Excessive developmental differences in spatial systems are now considered negative characteristics. Ethiopia is no exception to this rule. Regionally, average technical efficiency ranges from 50 percent in the South Nation Nationalities Region (SNNP), the lowest score, to 57 percent in the Amhara regions, the highest score. When we look at the zonal level, there is a significant variation in the average technical efficiency scores of the sample smallholder farmers, which range from 33 to 62 percent. Mekonnen (2013) and Tirkaso (2013) discovered significant variation in location-specific mean technical efficiency, which is consistent with this finding. One of the goals of improving technical efficiency is to achieve spatial convergence. Improving production efficiency at the regional level is often considered a means to reduce regional inequality. Furthermore, the degrees of convergence in different regions and groups of countries are critical. The question is, “When will all of this gap be closed?” It could be the fastest or the slowest. The speed of movement toward the frontier corresponded to the catching-up effect of provinces with lower efficiency scores. As a result, provinces not only successfully catch up in terms of efficiency score but also discourage efficiency inequality among provinces by demonstrating the efficiency score trend over the last 15 years (Purwono and Yasin, 2020). Carlos (2020) conducted yet another study on Indonesian provinces. The efficiency dispersion is decreasing over time. The average Indonesian province is rapidly approaching the frontier (9 percent per year in overall efficiency). On average, the least efficient provinces are catching up to the most efficient ones. Convergence in technical efficiency appears to be the quickest. It is expected to cut its efficiency differences in half over the next 5.6 years.

Finally, means of improving technical efficiency and thus, accelerating the rate of convergence remains a long-standing question in development economics. It would be beneficial to have some sort of experience or best-practice-sharing platform among regions so that smallholders in different locations can increase their productivity to the level of the best-performing farmers. According to Astewale (2018), based on the time-trend variable and estimated level of technical efficiency correlation, lessons from development initiatives' actions in each year must be documented, disseminated using appropriate communication tools, and scaled up to a wider range of farming communities. Further research into the major location-specific causes of such large gaps between the most technically efficient and inefficient stallholder farmers is recommended.

The last few years have given rise to a considerable amount of research analyzing the importance of technical efficiency as both a source of output growth and economic convergence. The rise in productivity issues has been accompanied by economic viability issues among farmers in various areas. Economic sustainability is generally viewed as economic viability; whether a farming system can survive in the long term as during the professional life of the farmer, or across generations is related to durability, that is, the capacity of a farm to be transferred to a successor in a changing economic context may be driven by variability in output and input prices, yields, output outlets, and public support and regulation. Profitability, liquidity, stability, and productivity are the primary indicators of economic viability (Van Cauwenbergh et al., 2007). Farms have been assessed in terms of their economic sustainability using the productivity and profitability of the factors of production (Wrzaszcz and Zegar, 2016). Productivity and efficiency analyses have important implications for the evaluation of their economic viability and sustainability. The measures of efficiency are more accurate than those of productivity in the sense that they involve a comparison with the most efficient frontier. Moreover, efficiency is a relative concept that is measured by comparing the actual ratio of outputs to inputs with the optimal ratio of outputs to inputs. Efficiency, on the other hand, can be technical, allocative, or economic. There is no a priori reason for both technical and allocative types of efficiency to increase or decrease simultaneously, and their relative contributions should not be of equal importance for output growth. It seems difficult, though, to achieve substantial output growth gains at very high levels of technical and/or allocative efficiency (Karagiannis and Tzouvelekas, 2001). The latter also considers how the intervention is distributed or stretched to benefit the community at large, widely seen as the benefit of society in welfare economics (Palmer and Torgerson, 1999). In measuring the efficiency of producers, the focus is mostly on technical efficiency, and achieving technical efficiency is perhaps the utmost concern (Tsionas and

Kumbhakar, 2006). A high technical efficiency measure that ensures the economic viability and sustainability of a farm is a pre-requisite for economic sustainability (Gusmi, 2013). Furthermore, literature shows that technical efficiency has gained relative importance as a measure of economic sustainability in comparison to other indicators. Despite its importance, technical efficiency was studied separately, with no implications for economic sustainability. Despite efforts to investigate technical efficiency and the factors that influence it, the relationship between economic sustainability and technical efficiency has yet to be thoroughly investigated. Little attention has been paid to the role of technical efficiency in economic sustainability and convergence. Our approach addresses a previously overlooked aspect of economic sustainability convergence. Previous research has emphasized the importance of improving efficiency, but it is critical to go deeper to account for economic sustainability and convergence. It has been widely documented that there are technical inefficiencies in production. There have been a significant number of studies on efficiency convergence, but very few on regional and local technological efficiency variations, and none on economic sustainability convergence. They also lacked a detailed analysis of how long it takes for a farmer to become fully technically efficient if they work hard on determining variables and minimize differences with other farmers if the crop grows at a faster rate. The previous literature also lacked information on the expected rate of change in technical efficiency for convergence. However, this study goes beyond identifying farmers’ inefficiency by investigating the required efficiency growth rate and time to achieve optimum and comparable economic sustainability across different blocks in the Koga irrigation and watershed project. The variation in efficiency over time is used to predict sustainability (Gomes et al., 2009). In this study, an increase over time indicates improved economic sustainability, indicating temporal convergence. Improvements in technical efficiency enable not only economic growth and prosperity but also the reduction of unnecessary resource waste. This waste of resources is emphasized in our paper in terms of resource availability for future production during a farmer’s professional life or across generations related to a farm’s ability to be transferred to a successor. Reduced regional inequalities, on the other hand, are critical for long-term development, indicating spatial convergence in economic sustainability in the Koga irrigation and watershed project.

The current study is an attempt to utilize convergence theory to test economic sustainability convergence using technical efficiency values. The overall economic sustainability level at the project level is found to be low, with significant differences between the most economically sustainable and unsustainable households (ranging from 21 to 84 percent) or blocks (ranging from 33-53 percent). and the potential for increasing output with existing inputs and technology without scaling them up, that is, technical efficiency improvement pays off much more in terms of economic sustainability than investing in new technology and utilizing more inputs in agriculture, prompting us to conduct additional research on the following research questions: (1) How much efficiency improvement is required for blocks to achieve an optimal level of economic sustainability?; (2) What is the rate of convergence for each block in order to achieve maximum efficiency or economic sustainability?; (3) What rate of efficiency growth differentials are required for blocks to catch up with the most economically sustainable block?; (4) How quickly does each block reach the most economically sustainable region?; (5) What rate of differential growth in efficiency and speed is required for the cross-over or leapfrogging phenomenon? The study is based on a deductive approach that is designed to answer convergence questions using a convergence theory that defines the relationships between two or more economies. The theory is also known as the catch-up effect in economics, and it primarily addresses the relationship between less developed and more developed areas. It basically states that less-developed areas will grow faster than more developed areas. This progress is primarily due to advanced technologies, production, and establishments in developed areas. Because developing areas lag behind developed areas, they can simply replicate developed areas' technologies, methods, and establishments. Such replications could include utilizing developed areas' production technology as well as implementing their advanced services.

There is a lot of interest in agricultural productivity growth projections. Solid projections for this variable, however, have proven difficult to come by, particularly on a local level in Ethiopia. This is due, in part, to the difficulty in calculating historical productivity growth. As a result, scenario-based analysis was used in conjunction with cross-sectional data. Cross-sectional studies are more common than longitudinal studies because they are easier to conduct. Cross-sectional data, on the other hand, lack the temporal information needed to study the evolution of the underlying dynamics. In order to do so, we create several scenarios that logically assume data from surveys (as in so many real instances). There appear to be few, if any, papers technical efficiency that use panel data to estimate the technical efficiency of Ethiopian smallholders. Despite this, a significant proportion of farm technical efficiency studies in Ethiopia used cross-section data, most likely due to data limitations.

This study demonstrates the convergence of economic sustainability among the twelve blocks of the Koga irrigation and watershed project command areas in terms of the use of technical efficiency. This research is organized as follows: Section 2 introduces relevant literature on technical efficiency and convergence. We begin by defining terms and concepts related to convergence and efficiency measures. They discuss theoretical and empirical literature in the field. Finally, we reviewed other related models, theories, and concepts and demonstrated how our work differs from others. Section 3 provides a brief description of the technical efficiency estimation technique and growth convergence model utilizing an inefficiency parameterization, which we use to validate the problem statement related to convergence theory. Then, we create a scenario and conduct a systematic analysis of the convergence performance of each block. Section 4 presents the major results and discussion, as well as the study’s major findings. Section 5 presents the study’s conclusion and policy implications.

2. Literature Review

Three major strands of literature can be identified in the analysis of the economic performance of nations (Rao and Coelli, 1998). The first, and most typical, approach focuses on growth in real per capita income or real GDP per capita. This indicator can be considered a proxy for the standard of living achieved in a country. The second approach is to examine the extent of convergence achieved by the poor countries and measure disparities in the global distribution of income. The third and recent approach, which is also used in this study, is to consider productivity performance based on partial measures, such as output per person employed or per hour worked, and multi-factor productivity measures based on the concept of total factor productivity and its components, such as technical efficiency change and technical change. In terms of sustainability, various researchers have attempted to quantify it through various methods and indicators. Some indicators found in the literature to understand economic sustainability are: A cost-benefit analysis was then performed using the indicators of Net Present Value (NPV) and Benefit to Cost ratio (B/C ratio), which can rise even more if producers rely on optimal resource use (Deka and Goswami, 2021). Hepelwa (2013) focuses on technical efficiency, as the ratio between the farmer's actual production and the optimal production to measure sustainability. A significant amount of environmental damage could be avoid if the causes of inefficiency in crop production were addressed. The level of sustainable income was used as a measure of economic sustainability in agricultural enterprises in the study by Bayramoglu et al. (2018). The study defined economic sustainability as the generation of income by an agribusiness that covers its costs: people's livelihood, depreciation, and interest on fixed capital used in production. In terms of the correlation between efficiency and sustainability, Pourzand and Bakhshoodeh (2014) classified regions in Iran into three groups: sustainable, relatively sustainable, and unsustainable. The technical efficiency estimate depicts the potential for environmental improvement by reducing these polluting inputs (Piot-Lepetit, Vermersch, and Weaver 1997). Farmers can achieve both economic and environmental goals by improving the technical efficiency with which they use polluting inputs (De Koeijer et al., 1999). Environmental performance is solely determined by the environmental impact of polluting inputs, whereas reducing the use of polluting inputs (technical efficiency) is one method of improving environmental performance (De Koeijer et al., 2002). As a result, the emphasis on effective input use and sustainability principles must be a fundamental part of agricultural policy in order to incentivize and create a situation in which sustainable resources can be conserved.

Productivity gains are frequently entirely attributed to efficiency gains, while this is frequently incorrect. Agricultural policies tend to emphasize increasing productivity through technological change rather than making better use of existing technology. However, given the limited availability of natural resources such as land and water and the need to reduce agricultural production's environmental footprint, agricultural policies must be rebalanced to improve efficiency. Better use of existing technology may result in equivalent physical productivity gains and possibly even larger economic gains than switching to new technology. The latter may boost productivity temporarily, but at the expense of higher production and environmental costs (FAO, 2017). As a result, higher technical efficiency indicates better economic performance. A high level of technical efficiency is required for economic sustainability. To quantify technical efficiency, several methods can be used. They all follow roughly the same logic: identifying the share of productivity growth caused by efficiency changes by measuring the difference between observed productivity and theoretical, optimal, or average productivity. Measurement methods have traditionally been classified based on whether they rely on assumptions about the functional form of the production frontier: those that are considered parametric, while those that are considered non-parametric. Malmquist-type approaches based on Data Envelopment Analysis (DEA), for example, are non-parametric; whereas, approaches based on econometric estimation of a production function are parametric. Although these methods utilize different approaches of computation and assumptions, it is worth noting that the results are no frequently significantly different. For many agricultural commodities across multiple regions and countries as well as across various production systems and agro climatic regions, production frontier analysis has been widely used to estimate technical efficiency.

Farmers' efficiency differences persisted both within and between years. Reducing technical inefficiencies has always piqued the interest of economists, now it is even more important given the environmental case for lowering emissions and waste. The technical efficiency estimation has been designed to serve primarily two purposes, that is, identifying where farmers are in terms of resource utilization and testing efficiency convergence. The theory of convergence evolved from the Neoclassical Sollow growth model (Sollow, 1956), which asserts that a country's per capita economic growth has a negative relationship with its initial output and income levels. Furthermore, the convergence trend includes income using GDP per capita, inflation convergence, and efficiency convergence, which have been applied across various sectors at the national, regional, and local levels. Meanwhile, efficiency convergence can be divided into two types: convergence among countries (Barro and Sala-i-Martin, 1992) and convergence at the frontier (Battese and Coelli, 1995; Kumbhakar and Wang, 2005). Inefficiency occurs in both patterns when production operates within the frontier line, which is the most optimal production rate, because output can still be increased using the same technology and input levels (Margono et al., 2011). The production frontier is the set of inputs that results in the highest possible output. As a result, the best practice frontier is the production frontier (Charnes et al., 1978). It varies across countries and regions due to differences in the nature, quality, and availability of inputs such as soil quality, precipitation levels, and workforce qualification.

Three types of convergence tests are used to determine the occurrence of global agricultural catch-up and the degree of convergence across different groups of countries. The empirical results of a balanced panel of 126 countries from 1970 to 2014 show that there has been no global agricultural convergence. International trade, irrigation systems, and structural transformation will be used to improve agricultural efficiency and narrow the efficiency gap between countries in the future. On the one hand, groups of lagging countries such as Sub-Saharan African countries, low-income countries, less developed countries, and agriculture-based countries have achieved convergence. This suggests that the gap within each group is closing, which appears to be a good sign of catch up. However, all of the lagging country groups manifested a significant decrease in average efficiency, implying that they are now even further behind advanced countries than they were in 1970. Leaders in these lagging country groups are less efficient, reducing the gap within-group. The findings suggest that more countries are closing at the frontier. As a result, agricultural catch-up can be achieved if lagging countries improve their irrigation systems, international trade, and crop-livestock structure based on relative advantages. Countries with lower agricultural efficiency, on the other hand, may be unable to improve their level of relevant efficiency determinants on their own and thus, fail to close the efficiency gap (Yuan et al., 2021).

Using provincial data from 2002 to 2017, Indonesia’s efficiency convergence, as well as catching-up patterns, were accelerating towards the frontier. It has numerous practical implications: one of which is that it can inform economic development policymakers. It could also assess how macroeconomic performances are expanded, either in specific provinces by emphasizing productivity growth or in simultaneous analyses by emphasizing the efficiency convergence point so that proposed policies can be tailored to the specific situation of each province. Furthermore, the findings could highlight Indonesia’s current policies, such as investment intensification, allowing Indonesia to serve a model for other developing countries around the world (R. Purwono and M. Z. Yasin, 2020).

A study that looked at relative productivity levels and decomposed productivity change in European agriculture between 2004 and 2013 tested whether or not TFP is converging among member countries. The findings lend support to the productivity convergence hypothesis across a member of countries. Policies should also pay close attention to the learning process as a key driver of differences in TFP levels between countries, particularly, in laggard regions (Barath et al., 2016).

Improving regional production efficiency is frequently regarded as a means of reducing regional inequality. A study of regional efficiency convergence across provinces in Indonesia from 1990 to 2010 found that there is regional convergence in the overall efficiency, pure (technical) efficiency, and scale efficiency measures on average. These regions are more likely to reduce inefficiencies by coordinating inter-regional policies that encourage technology transfer from their closest and most technologically advanced neighbors (Carlos, 2020).

According to a study on Russian agriculture based on data from 75 territorial units from 1993 to 1998 focusing on technical efficiency (TE), there was a growing TE gap between regions. The results show that agricultural technical efficiency and technological progress vary dramatically across regions; there are some regions with a notable positive development of performance (improvement of technical efficiency and or substantial progressive technological change) and a wide range of regions with reverse trends (two digits negative). This demonstrates the existence of divergence in agricultural sector performance. When it comes to the development of efficiency, the initial conditions are the most important. Those regions with favorable initial conditions prosper and their technical efficiencies grow over time, while marginal regions become increasingly inefficient (Uvarovsky et al., 2000).

Different studies in the field with two forms are identified based on a thorough literature search. The first type of study utilizes technical efficiency as an indicator of overall sustainability including the environmental pillar. The studies of Aloyce S. Hepelwa (2013), F. Pourzand and M. Bakhshoodeh (2014), T. J. De Koeijer et al. (2002), and Gomes et al. (2009) can be cited in this category that use efficiency and a combination of two land and labor agricultural productivity measurements to determine sustainability. Despite the identification and discussion of the ecological, technical, social, and economic components of agricultural sustainability, the importance of economic sustainability in achieving total sustainability has been emphasized (Zeki Bayramoglu et. al., 2018). There were some beliefs and the importance of economic sustainability in achieving total sustainability was stressed. However, economic sustainability is not explicitly investigated in the context of technical efficiency in the first category of literature. The second type of study employs indicators other than efficiency to assess economic sustainability (income related variables such as cost-benefit analysis and benefit-to-cost ratio, sustainable income/revenue, permanent income parity and profitability, and partial productivity measures of sustainability). This category includes studies by Deka and Goswami (2021), Zeki Bayramoglu et al. (2018), J. Wisniewska (2011), J. Spicka et al (2019), and W. Wrzaszcz and J. St. Zegar (2016). As a result, our approach, which can be considered unique and a third form of examining efficiency and economic sustainability convergence, attempts to reconcile the two forms further. The current approach in the this study is another method of measuring economic sustainability through technical efficiency, and it emphasizes technical efficiency as the most important factor in economic sustainability convergence. It is based on the concept of crop production, which is the primary source of income for the study area's residents. If the causes of crop production inefficiency are addressed, significant amounts of inputs could be saved for future use. Our study's approach, on the other hand, recognizes this imbalance and takes economic sustainability into account on its own. As a result, our approach seeks to fill methodology gaps in the literature regarding measures of economic sustainability.

3. Methodology and Data Description

3.1. Description of the study area

The Koga River is used for irrigation and sand mining (Dagnew et al., 2014). The river is 64 km long and joins the Gilgel Abbay River after crossing the Debre Markos-Bahir Dar road downstream from the town of Wetet Abbay. The study area, including the irrigation dam site and some irrigation blocks, is given in Figure 1. The Koga irrigation and watershed project, built on Koga River, is an attempt by the government of Ethiopia to develop a large-scale irrigation scheme for rural farmers. It is with the support of the Ethiopian government and the African Development Fund that the construction of the Koga irrigation infrastructure was made so as to irrigate 7004 hectares of land, with the total size of the project being about 10,000 ha (Endrie et al., 2016).

3.2. Data type, source and description

The present study employed a household survey in the case of twelve irrigation blocks of the Koga irrigation and watershed project to understand economic sustainability convergence indicated by technical efficiency convergence. A list of blocks with irrigation potential measured in hectares was prepared prior to the start of data collection for the study. The list was prepared based on information from summarized irrigation block data obtained at the project office. It consists of twelve blocks with different irrigation potentials (see Table 17). The data were collected through a survey questionnaire designed to include household demography, operational, and farm-specific data to put it into a technical inefficiency model on one hand and output, revenue, and factors of production based on microeconomic theory of production to employ them in a trans-log stochastic frontier model for analysis on the other hand (see data type, description, and selection under Table 11). Some variables that proved to be statistically insignificant were ignored and eliminated during the regression process for both stochastic production frontier and technical inefficiency effect models. The accuracy and consistency of surveys form a significant aspect of research methodology. We used test-retest reliability for the questionnaire. This involves administering the survey to a small group of respondents and repeating some questions in the survey with the same group at a later point in time. We then, compare the responses at the two time points.

3.3. Sample size and sampling procedure

Reaching out to all twelve blocks would have been challenging due to the greater distance away from the main dam (it ranges from 3-19.7 km). However, utmost effort has been made to collect survey data from all twelve blocks. To determine the appropriate sample size, the basic factors to be considered are the level of precision required by users, the desired confidence level, and degree of variability. Cochran pointed out that if the population is finite, then the sample size can be calculated using two formulas given below. Where, n0 is sample size given in eq. 1 when population is infinite, z is the selected critical value of desired confidence level, p is the estimated proportion of an attribute that is present in population, q =1-p and e is the desired level of precision. Assuming the maximum variability, which is equal to 50 percent (p = 0.5) and taking the 95 percent confidence level with 5 percent precision, the calculation for the required sample size will be as follows: p = 0.5 and hence q =1-0.5 = 0.5 ; e=0.05; z=1.96 so that n0 = 384. While, the correction formula to calculate the final sample size is given by eq. 2: Here, n0 is the sample size derived from eq.1, and N=12000 is the population size. Since no/N is negligible, n0 =384 is a satisfactory approximation to the sample size. In this case, the sample size (384) less than 5 percent of the population size (12000). So, the researcher does not need to use the correction formula to calculate the final sample size.[3]

$$n_0 = \frac{z^2 pq}{e^2} \qquad \textbf{(1)}$$

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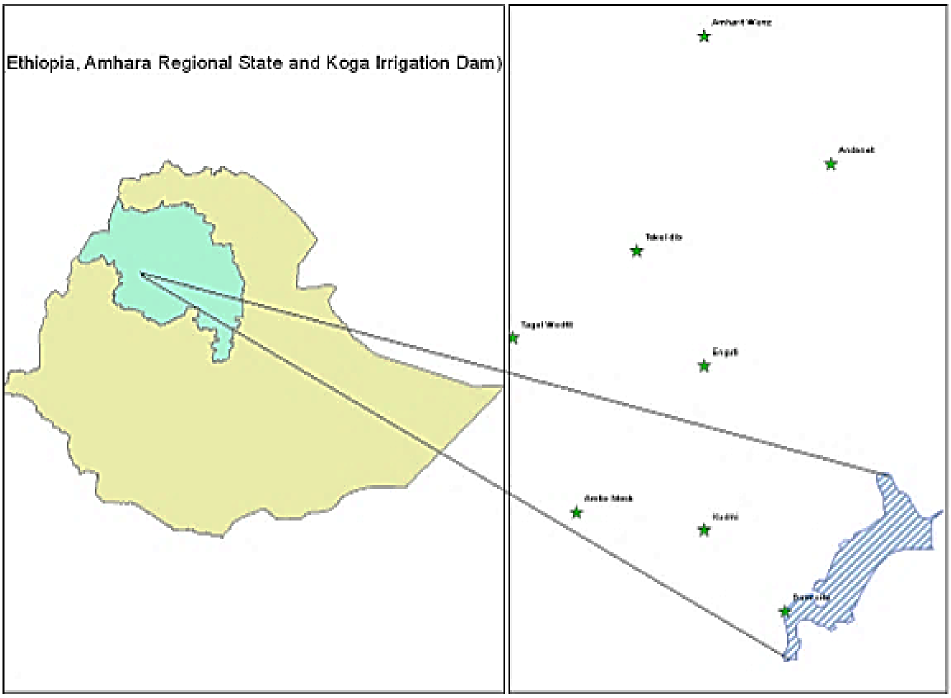
[3] LaTex typesetting System is utilized to generate all equations, tables and graphs

$$n = \frac{n_o}{1 + \frac{n_o - 1}{N}} \qquad \textbf{(2)}$$

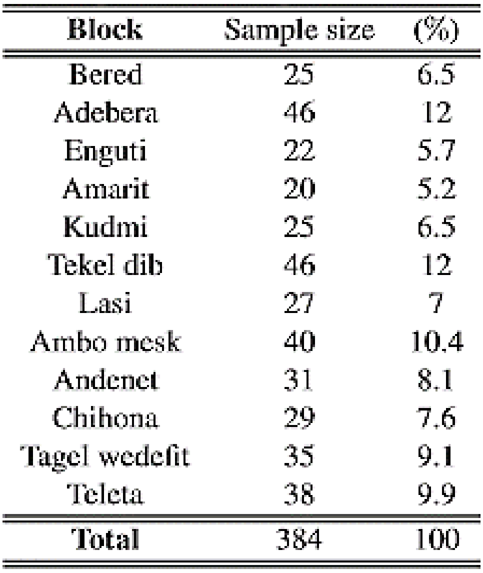
Once the sample size is determined using Cochran's formula, the basic factors to consider in determining the appropriate sample size in each block are the estimated 12000 households in the twelve command areas and the irrigation potential of each irrigation block. The irrigation potentials were used to guide the sample allocation procedure in each block. Samples were allocated according to the proportion total hectares of land in each block given in Table 17. Therefore, the sample size in each block and the proportion of the total sample are given in Table 1 and Fig. 2.

Figure 1: Study area (Koga Irrigation Dam, Dam Site and Command Areas)



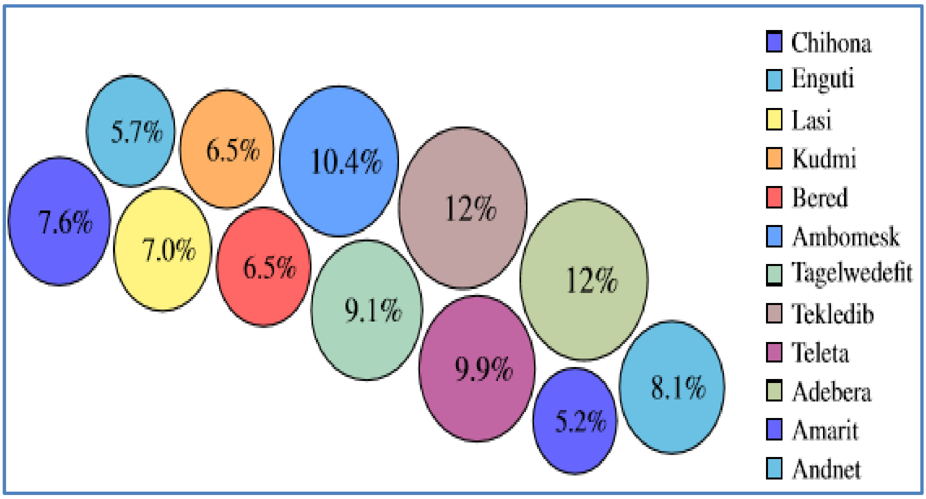
As a result, the largest sample (about 12 percent each) was taken from two regions: Tekledib and Adbera, the two largest irrigation land abundant regions in the study area, based on the stratified random sampling technique adopted based on sample size through the proportional allocation method. Indeed, the Amarit sample represents only 5.2 percent of the total sample size.

Table 1: Proportion of sample size in each block



Block	Sample size	(%)
Bered	25	6.5
Adebera	46	12
Enguti	22	5.7
Amarit	20	5.2
Kudmi	25	6.5
Tekel dib	46	12
Lasi	27	7
Ambo mesk	40	10.4
Andenet	31	8.1
Chihona	29	7.6
Tagel wedefit	35	9.1
Teleta	38	9.9
Total	384	100

Figure 2: Proportion of sample size in each block



3.4. Model specification and estimation techniques

3.4.1. Technical efficiency estimation procedure

The basic Stochastic Frontier Model developed concurrently by two groups of researchers, Aigner et al. (1977), in the first group and Meeusen and Broeck (1977) which considers deviation from the frontier to be due to the effects of technical inefficiency and random noise, was used as an estimation technique for technical efficiency. The true nature of production is stochastic, especially in agriculture. The choice of this technique is made on the basis of the variability of agricultural production, which is attributable to climatic hazards, plant pathology, and insect pests on the one hand, and management inefficiencies on the other.

$$Y_i = f(X_i; \beta) exp(V_i - U_i), i = 1, ...n \quad \textbf{(3)}$$

Based on eq. 3 Yi is the output produced on the i*th* plot/farmer, Xi is a vector of inputs used on the ith plot, and β is a vector of parameters to be estimated. Aigner et al. (1977) proposed stochastic models assuming that the disturbance term has two components, that is, Vi + Ui. The error component Vi represents the symmetrical disturbance that captures random errors caused outside the firms control such as measurement errors, random shock, and statistical noise. The Ui component of the error term is the asymmetrical term that captures the technical inefficiency of the observations and assumed to be independent of Vi, and also to satisfy that Ui ≥ 0. The non-negative component (Ui) reflects that the output of each firm must be located on or below its frontier. Hence, the stochastic production frontier at a technically efficient plot would represent the maximum attainable output (Yi*) as eq. 4:

$$Y_i* = f(X_i; \beta) exp(V_i), i = 1, ...n \quad \textbf{(4)}$$

This can then be used to measure the technical efficiency of all other plots, relative to this efficient plot. The technical efficiency of the plot (TEi) is given by in 5: Where TEi may be defined as the capacity of a producer i to produce relative to a maximum output from a plot using a certain amount of input and available technology.

$$TE_i = [Y_i / Y_i*] = exp(-U_i), i = 1, ...n \quad \textbf{(5)}$$

Before estimating model parameters using the Maximum Likelihood Estimates (MLE) method, the stochastic frontier production function using the flexible Translog (TL) specification in eq. 6 found to be more appropriate than Cobb-Douglas based on log-likelihood ratio test (see : LR ratio test results in Appendix 18).

$$LnY_i = \beta_o + \sum_{k=1}^{n} \beta_k Ln(X_{ik}) + \frac{1}{2}\sum_{k=1}^{n}\sum_{j=1}^{n} \beta_{ij} LnX_{ik} * LnX_{ij} + V_i - U_i \quad \textbf{(6)}$$

Where ln is the natural logarithms, β’s are coefficients of parameters to be estimated, Yi is the total value of output. X is are factors of productions, Vi is the idiosyncratic error that arises from measurement errors in input use and/or yield of production and Ui is the non-negative random variables in measuring the technical inefficiency of individual household. lnXik includes the squares and interaction terms of the input variables. The estimation of determinants of technical efficiencies, the inefficiency model (Ui) was estimated based on eq. 7 and the variables given by Table 11.

$$U_i = \delta_o + \sum_{i=1}^{n} \delta_i Z_i + W_i \quad \textbf{(7)}$$

Where, Zi s are various operational and farm specific variables describe70d. Since the dependent variable in eq. 7 is defined in terms of technical inefficiency, a farm-specific variable associated with the negative (positive) coefficient have a positive (negative) impact on technical efficiency. Given different facts explained in literatures which favored one step estimation, the maximum likelihood estimates (MLE) of the parameters of stochastic frontier production function and the inefficiency model were simultaneously obtained. The stochastic production frontier approach is also used to estimate capacity utilization. Full efficiency capacity output (potential yield) was estimated by scaling up actual output by the efficiency score generated from this estimation process (by dividing current output or actual output by the efficiency score) through the following formula in Equation 8.

$$Potentialyield_i = \frac{100}{Technicalefficiencyindex} * Actualoutput \quad \textbf{(8)}$$

3.4.2. Level of economic sustainability

The analysis mostly followed technical efficiency estimation (see Table 12, Table 13, and Table 14), and thereby, compare the economic sustainability of Koga irrigation and watershed project (see Table 15). Furthermore, to understand the economic sustainability level of the project, capacity utilization and inefficiency loss measures using both output and input orientation was performed using indicators of cost (input) saving by considering method from Kibret et al. (2016), output loss measured as proportion of potential output, output growth potential and loss in Millions of Ethiopian Birr (METB) (see: Table 16) . Finally, we used these data to for economic sustainability convergence. Hence, the economic sustainability level in each region is measured by technical efficiency indices during the time. Economic sustainability is the ability of an economy to support a defined level of economic production indefinitely. The core idea is how organizations stay in business by linking economic sustainability with productive efficiency (Jeronen, 2020). Farmers' technical efficiency is a proxy for economic sustainability (Ait et al., 2022). Technical efficiency can be taken to be a universal goal that is applicable in any economic system. On the other hand, allocative and overall economic efficiency presume the objective is profit maximization. The performance standards derived on the assumption of profit maximization should not be used to measure the performance of organizations whose objective functions include other elements than profit. Thus, the proposition that it is valid to estimate a producer's performance in terms of technical efficiency is usually accepted. In particular, measures of technical efficiency rely less heavily on the assumptions of perfect knowledge, perfectly competitive markets, and the profit maximization objective. (Uvarovsky et al., 2000). Hence, the production frontier is reached when available inputs are used optimally. A farm that reaches its production frontier has also reached its maximum level of technical efficiency (FAO, 2017). The production frontier is a theoretical concept and, as noted by Sadoulet and de Janvry (1995), represents the optimal productivity target and has to be compared to observed productivity to measure the degree of technical efficiency (or inefficiency) at the farm-level. Contextually, a farmer is said to be optimally economically sustainable if he reaches the optimal level of efficiency.

3.4.3. Spatio-temporal economic sustainability convergence

In a seminal paper by Kumar and Russell (2002), economic growth convergence can be viewed as countries' movements toward the world production frontier. Economic sustainability in terms of technical efficiency measures is interpreted in the context of growth convergence in this model, and the paper adopted an efficiency parameterization from which the rate of efficiency improvement and speed of convergence for economic sustainability can be assumed and computed. Thus, efficiency improvements are also explicitly related to economic sustainability improvement and convergence in this model.

A block's economic sustainability performance must be compared to a standard or norm. To examine the tendency of blocks to become optimum and two or more blocks to become similar in terms of economic sustainability levels measured by technical efficiency indices, including crossover or leapfrogging phenomena, the identification of each blocks' production frontier and best-practice frontier for analyzing temporal and spatial convergence in economic sustainability was initially done using technical efficiency estimation in Tables 15 and 16. Then, one can start with the relations given by the exponential growth in eq. 9 and eq. 10 concerning the actual level of economic sustainability measured by output per potential output, that is, the technical efficiency of two entities with different initial levels and annual expected average growth rates of efficiency improvement. The exponential growth is used to model various real-world phenomena, such as the population growth of bacteria, compound interest, economic growth, etc. Economic growth is generally modeled exponentially; our economic output grows by a set percentage every year, and while that percentage varies, it also compounds on itself. With a variable that is central to explaining long-run growth: productivity is usually modeled the same way.

$$Y_{t_c} = Y_{o_c}(1 + g_c)^n \tag{9}$$

$$Y_{t_T} = Y_{oT}(1 + g_T)^n \tag{10}$$

As a result, the current study is an attempt to apply the concept of growth and technical efficiency catching up for the temporal and spatial dimensions of economic sustainability convergence by identifying the rate of growth in efficiency improvement and speed of convergence that blocks with low initial levels of economic sustainability grow at such a faster rate in technical efficiency to overtake the level of economic sustainability of the benchmark block or blocks.

The inefficiency term ($Ui \geq 0$) measures the distance from the frontier for each region in the area, and economic sustainability convergence implies a shrinkage of Ui over time. For temporal economic sustainability convergence, Yoc is the initial level of economic sustainability measured by the actual level of income relative to potential or technical efficiency, and YoT is the targeted level of economic sustainability for the accession block, gc is the expected average annual efficiency growth index for the accession block, gT is the expected average growth efficiency at the optimal level of economic sustainability (i.e gT=

0). Therefore, temporal economic sustainability is achieved when the technical efficiency index is one, i.e Fully-efficient. Hence, for temporal seasons, since the target level of economic sustainability is to attain the optimum level where the technical efficiency index is one, convergence is achieved when the Ytc curve exactly touches the optimum economic sustainability line, a value of one, according to Equation 11.

$$Y_{o_c}(1+g_c)^n = 1 \qquad \textbf{(11)}$$

Therefore, the temporal economic sustainability methodology tries to answer the following two questions that were put forward to guide the temporal convergence, that is, (1) What rate of efficiency improvement is needed for regions to attain an optimum level of economic sustainability?; (2) What is the speed of convergence for each region to attain an optimal level of economic sustainability?

For spatial convergence, however, Yoc is the initial relative economic sustainability level (that is, relative technical efficiency), YoT is the targeted level for the accession block, gc is the expected average annual efficiency growth index for the accession block, gT is the expected average growth efficiency of the most economically sustainable region. Spatial economic sustainability is achieved when the level of economic sustainability measured by technical efficiency is equal over time. Catch up for spatial is achieved when the values of the two relations become equal and the curves of YtT and Ytc meet at the balance point according to Equation 12:

$$Y_{o_c}(1+g_c)^n = Y_{o_T}(1+g_T)^n \qquad \textbf{(12)}$$

By taking the logarithm and rearranging the terms, the time n is usually in years when the economic sustainability balance of two regions or the optimum level of sustainability will be achieved according to eq. 13. This time frame of economic sustainability convergence is determined by the initial or relative level of economic sustainability as well as the growth differential between accession and benchmark regions. This methodology answers the following three convergence question, that is, 1) What rate of growth differentials in efficiency is needed for two or more regions to catch up with the most economically sustainable region in the area? 2) Speed of convergence for each block to the most economically sustainable region? 3) What is the required rate of growth differential in efficiency and speed for the cross-over or leapfrogging phenomenon? To answer each of the spatio-temporal convergence questions, economic sustainability data from Table 15 and the spatio-temporal convergence methodology, including scenario development, were used.

$$n = \frac{log(Y_{oT}) - log(Y_{oc})}{log(1+g_c) - log(1+g_T)} \tag{13}$$

3.4.4. Scenario development

Scenario planning enables us to respond to an unknown future in real time. One type of methodology used in this study for forecasting the future expected growth rate of efficiency is scenario development. It is based on a literature analysis of the current situation, the development of informed assumptions about the expected growth rate of efficiency in the future, and government plans. The study's scenarios gain rigor through analysis. We incorporate logic into the analytical process. The scenario development process involves two plans: one for short-term planning (five years) and one for long-term planning (ten years). The short-term strategy corresponds to spatial economic sustainability convergence, whereas the long-term strategy corresponds to temporal economic sustainability convergence.

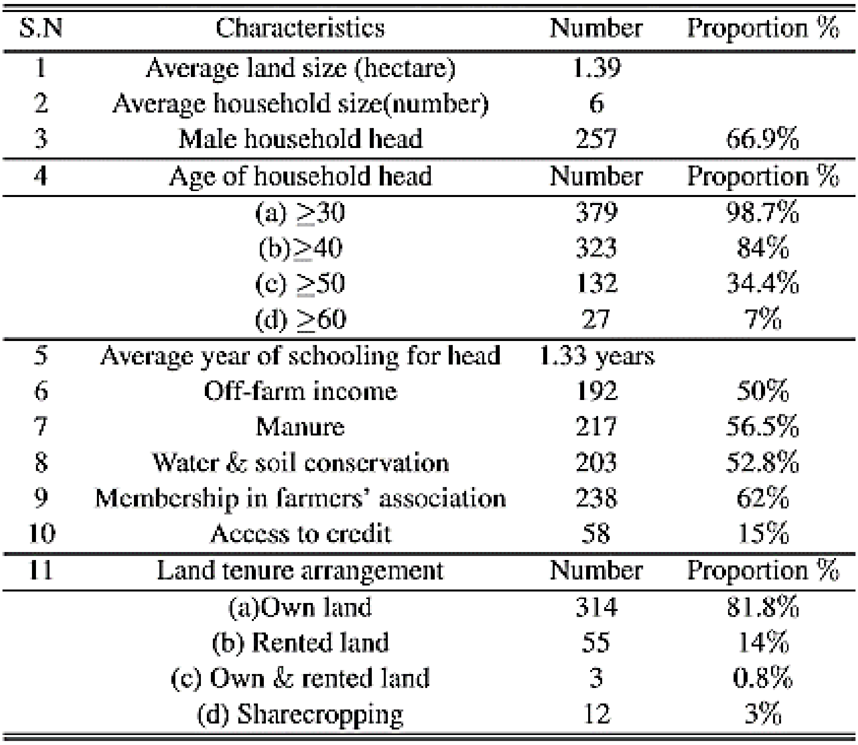
4. Results and Discussion

4.1. Descriptive statistics

4.1.1. Demographic variables

This section describes the demographic characteristics of the survey's sample respondents, such as age, gender, and household size. The goal of defining those variables is to understand the decision-making environment in which agricultural production takes place. More than 98 percent of respondents are over the age of 30. This indicates that the majority of the sampled farmers are of an active and energetic age, and they are regarded as an economically active force capable of performing its tasks effectively and efficiently. The average number of people in a household was six. Most of them were regarded as being in the labor force. Most rural Ethiopian children under the age of 14 are actively engaged in farming. It did not adhere to the labor force agreement group. In terms of the gender of the household head, 67 percent of the sampled households were male, while the remaining 33 percent were female farmers (see Table 2). This implies that male household heads dominate agricultural production in the survey. This could be because females are more responsible for the care and maintenance of the household and its members, including childbirth and care, food preparation, water and fuel collection, housekeeping, and family health care, than agricultural activity. Even when men and women are engaged in productive activities, their responsibilities and functions frequently differ.

Table 2: Socio-economic characteristics of farmers



S.N	Characteristics	Number	Proportion %
1	Average land size (hectare)	1.39	
2	Average household size(number)	6	
3	Male household head	257	66.9%
4	Age of household head	Number	Proportion %
	(a) ≥30	379	98.7%
	(b)≥40	323	84%
	(c) ≥50	132	34.4%
	(d) ≥60	27	7%
5	Average year of schooling for head	1.33 years	
6	Off-farm income	192	50%
7	Manure	217	56.5%
8	Water & soil conservation	203	52.8%
9	Membership in farmers' association	238	62%
10	Access to credit	58	15%
11	Land tenure arrangement	Number	Proportion %
	(a)Own land	314	81.8%
	(b) Rented land	55	14%
	(c) Own & rented land	3	0.8%
	(d) Sharecropping	12	3%

4.1.2. Socioeconomic variables

The average total land size of the households sampled was approximately 1.39 hectares. The irrigation blocks with the most and least irrigation land abundance, respectively, are Tekledib (864 hectares) and Amarit (290 hectares) (see Table 3). The Tekledib block has the highest proportion of land (12.3 percent) of the total potential 7004 hectares of irrigation land in the Koga irrigation and watershed project, while the Amarit block has the lowest (4.2 percent) (see Figure 3). The 384 households studied to collect farm and household-related variables for estimation farm on approximately 533.13 hectares, or 7.6 percent of the total potential of 7004 hectares of irrigation land. The highest proportion of sample farm land size, approximately 13.8 percent, was found in the Tagelwedefit region, and the lowest, approximately 5.1 percent, was found in the Enguti and Amarit regions (Figue 4). Table 3 also shows the total landarea in hectares investigated in each block. When technical efficiency values and land size were considered, the results of correlation tests revealed a weak correlation. When the Pearson coefficient value is less than 0.29, it is said to be a small correlation. Spearman rho's and Kendal-tau correlations were also weak (Table 20 in the Annex Part). As a result, there was little evidence to support the positive correlation between land size and efficiency improvement (Figure 5). The land size has a negligible effect on the economic sustainability level. Off-farm income is critical for contributing to agricultural product production in Ethiopia. Off-farm income activity participation was obtained by 50 percent of the sampled farmers. This demonstrates that farmers participated in off-farm income-generating activities in a moderate manner. In terms of education, the average year of schooling for a household head was approximately 1.33 years.

The majority, if not all, of the sampled farmers are not receiving formal education, with only a small percentage receiving basic education. Manure is a major input for crop production in the area. The majority of farmers (56.5 percent) used various fertilizer combinations, including organic fertilizer. In terms of farming management, they used various water and soil conservation mechanisms, even though farmers had fertile or good soil, in order to become more productive. This implies that the majority of farmers (52.8 percent) use good soil conservation practices in the study areas. During the survey, only 15 percent of respondents had access to credit. The majority of farmers (81.8 percent) were engaged in farming using only their own irrigated lands. The majority of farmers were members of farmers' associations (see Table 2).

Figure 3: Proportion of irrigation land in each block

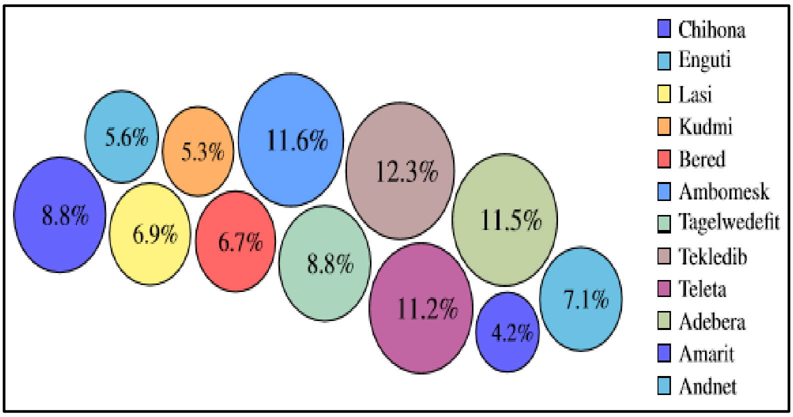


Figure 4: Proportion of sample land size in each block

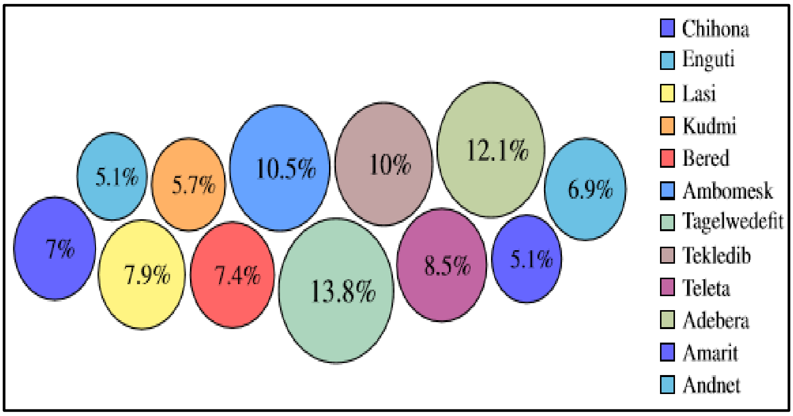
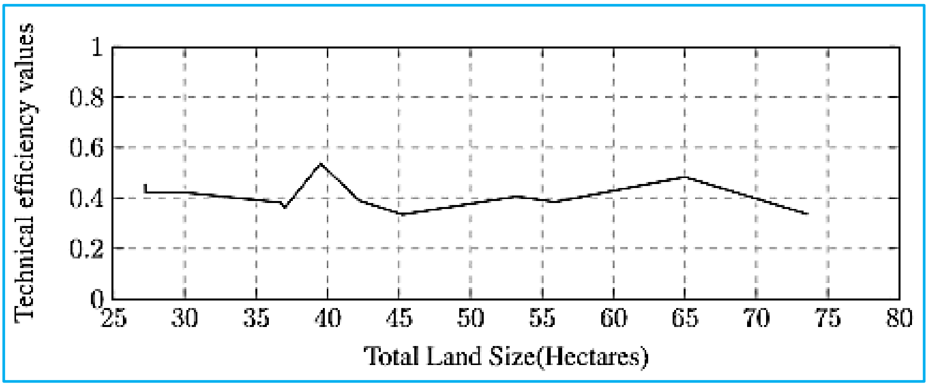


Table 3: Sample and sampling procedure

Blocks	Total land	%	Sample size	%	Sample land	%
Chihona	617	8.8	29	7.5	37	6.9
Enguti	393	5.6	22	5.7	27.25	5.1
Lasi	484	6.9	27	7.0	42.25	7.9
Kudmi	373	5.3	25	6.5	30.18	5.66
Bered	468	6.68	25	6.5	39.5	7.4
Ambo mesk	812	11.59	40	10.4	55.9	10.48
Tagel wedefit	616	8.79	35	9.1	73.6	13.8
Tekel dib	864	12.3	46	11.97	53.25	9.98
Teleta	787	11.2	38	9.89	45.25	8.48
Adebera	803	11.46	46	11.97	65	12.1
Amarit	290	4.1	20	5.2	27.25	5.1
Andenet	497	7.09	31	8.07	36.7	6.89
Total	7004	100	384	100	533.3 (7.6%)	100

Figure 5: Total sample land size in each block and technical efficiency values

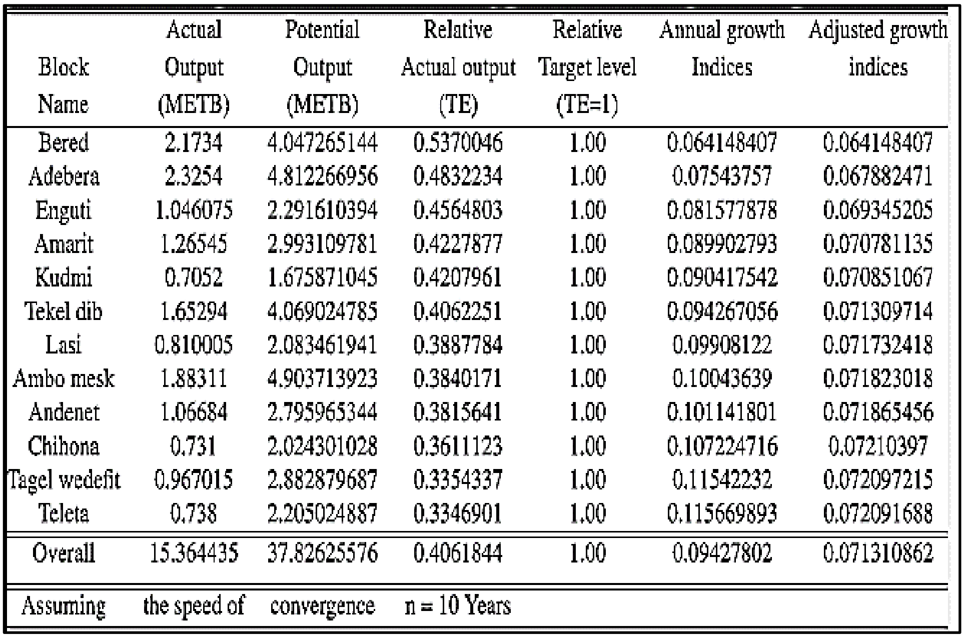


4.2. Spatio-temporal economic sustainability convergence

4.2.1. Scenario 1: Temporal convergence to optimum level of economic sustainability

The study employs convergence as a condition of movement toward a specific point; the concept of optimum level economic sustainability is derived from the concept of optimum efficiency, contextualizing efficiency convergence, which is defined as the condition of an increased efficiency level approaching optimum efficiency. This section is also related to the convergence of efficiency, which predominantly followed the classical literature of Barro and Sala-I-Martin (1992), who defined general convergence as a condition of movement toward a point resulting in the elimination of distance from the production frontier. In other words, the inefficiency level decreases over time and eventually converges to the optimum efficiency level, indicating optimum economic sustainability in this study. Each block's level of economic sustainability as measured by the technical efficiency index is much lower than the optimum level. The dynamics of the temporal and economic sustainability convergence of each block show the expected growth rate in technical efficiency and speed of convergence to this optimum level. The graphical illustration represented by the intersection between the exponential growth of each block's technical efficiency curve and the optimum economic sustainability line determines the speed of convergence and the expected growth rate of efficiency improvement. As stated in Table 4, data on the initial level of economic sustainability measured by the relative actual output to potential (Technical efficiency (TE)) (the actual and potential outputs based on a sample are given in millions of Ethiopian Birr, or METB), the speed of convergence, and results showing the expected annual growth rates in efficiency with their adjusted growth indices required to achieve convergence to the optimum level of economic sustainability for each block is provided. According to Table 4 and Fig. 6, households, on average, need to grow at 9.42 percent for the next 10 years of the planning period in the agricultural sector to reach the optimum level. The regional analysis, on the other hand, revealed that the farther a country is from the optimal level, the higher the growth indices are expected to be, and vice versa. The most unsustainable block, Teleta, is expected to grow annually at 11.56 percent (which is 1.81 times faster than the Most Economically Sustainable Block (MESB)) for the next 10 years of the planning period to reach an optimum level of economic sustainability. On the contrary, the most sustainable region, Bered, is expected to grow relatively at a lesser rate of 6.41 percent to reach the optimum level. However, direct comparison of these indices is misleading and inaccurate because the starting conditions (that is, the initial level of economic sustainability in the study) differ significantly from block to block. For policy implications, the most adequate picture can be obtained only after the catch-up effect is taken into consideration[4].

Table 4: Expected annual technical efficiency growth indices & temporal convergence



Block Name	Actual Output (METB)	Potential Output (METB)	Relative Actual output (TE)	Relative Target level (TE=1)	Annual growth Indices	Adjusted growth indices
Bered	2.1734	4.047265144	0.5370046	1.00	0.064148407	0.064148407
Adebera	2.3254	4.812266956	0.4832234	1.00	0.07543757	0.067882471
Enguti	1.046075	2.291610394	0.4564803	1.00	0.081577878	0.069345205
Amarit	1.26545	2.993109781	0.4227877	1.00	0.089902793	0.070781135
Kudmi	0.7052	1.675871045	0.4207961	1.00	0.090417542	0.070851067
Tekel dib	1.65294	4.069024785	0.4062251	1.00	0.094267056	0.071309714
Lasi	0.810005	2.083461941	0.3887784	1.00	0.09908122	0.071732418
Ambo mesk	1.88311	4.903713923	0.3840171	1.00	0.10043639	0.071823018
Andenet	1.06684	2.795965344	0.3815641	1.00	0.101141801	0.071865456
Chihona	0.731	2.024301028	0.3611123	1.00	0.107224716	0.07210397
Tagel wedefit	0.967015	2.882879687	0.3354337	1.00	0.11542232	0.072097215
Teleta	0.738	2.205024887	0.3346901	1.00	0.115669893	0.072091688
Overall	15.364435	37.82625576	0.4061844	1.00	0.09427802	0.071310862
Assuming	the speed of	convergence	n = 10 Years			

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[4] It is based on the hypothesis of the proportional offset hypothesis, or the proportional overlap hypothesis: "If the level of economic development of one country is times higher than the level of economic development of another country, achieving the same economic growth in the former will be times more difficult than in the latter"

To make comparison more meaningful and accurate, the proportional offset of the catch-up effect contextualized for the study, αij, in eq.14 according to (Papava 2012; Papava (2014)) is calculated as,

$$\alpha_{ij} = \frac{TE_i}{TE_j} \qquad \textbf{(14)}$$

Where, TE is technical efficiency for block j (the less sustainable blocks) and i (the reference block, Bered). If the expected efficiency growth of block j is equal to rj, then the efficiency growth of block j, corresponding to the efficiency growth in block i, under the catch-up effect hypothesis, that is, the adjusted efficiency growth of the j th blocks (less sustainable blocks (rij∗), is given by eq.15:

$$r_{ij}* = \frac{r_j}{\alpha_{ij}} \qquad \textbf{(15)}$$

Consequently, rij∗ is the hypothetical efficiency growth of block j which can be used to measure relative economic growth against block i. If we divide the hypothetical efficiency growth quotient for block j (rij∗) by the expected efficiency growth of block i (ri) in eq.16, we obtain a value that indicates how many times the efficiency growth of block j really exceeds that of block i for convergence analysis.

$$\beta_{ij} = \frac{r_{ij}^*}{r_i} = \frac{r_j}{r_i}\alpha_{ij} \qquad \textbf{(16)}$$

Thus, the study indicates that after taking into account the catch-up effect, in terms of economic sustainability, other less sustainable blocks exceed growth in Bered by a range of 1.06 to 1.124 times: for example, Adebera by 1.06 times and Tagelwedefit by 1.124 times to achieve temporal convergence. These can be compared with before taking into account the catch-up effect. It ranges between 1.18 to 1.8 times that Adebera exceeds by 1.18 times and Teleta by 1.8 times. The dynamics of the economic sustainability of convergence of each block and the optimum level of economic sustainability concerning the same six percent[5] efficiency growth rates is shown in Table 5 and Fig. 7. The abscissa in

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[5] However, under the proportional overlap hypothesis, Adebera's, Enguti's, Amarit's, Kudmi's, Tekledib's, Lasi's, Ambomesk's, Andenet's, Chihona's, Tagel's, Teleta's and Overall 6 percent growth corresponds to (5.4),(5.1),(4.72),(4.7),(4.54),(4.34),(4.3),(4.26),(4.0),(3.75),(3.74) and & (4.53) percent growth in Bered respectively, that is, in real terms Bered is growing faster than other regions.

Fig. 7 contains the time (number of years) necessary to achieve convergence, and the ordinate indicates the evolution of economic sustainability where inputs are being used to their utmost capacity therein in each block and overall at project level at the same 6 percent efficiency growth rate or approximately at 5.82 percent growth differentials with growth at optimum efficiency. Accordingly, if all blocks are growing at 6 percent, the overall farming system at the household level would need 15.46 years to become optimally economically sustainable. Whereas, the most economically sustainable block would need only 10.67 years and the most unsustainable would need about 18.78 years.

Figure 6: Expected growth rates for temporal economic sustainability convergence

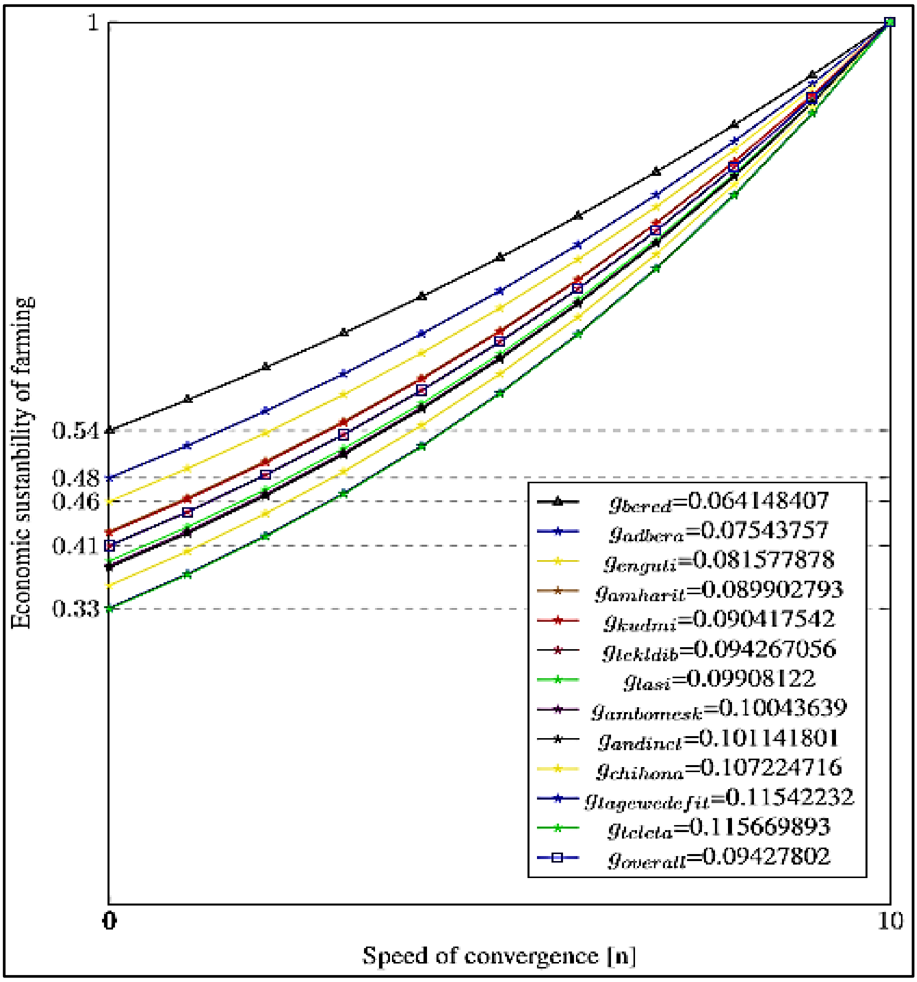
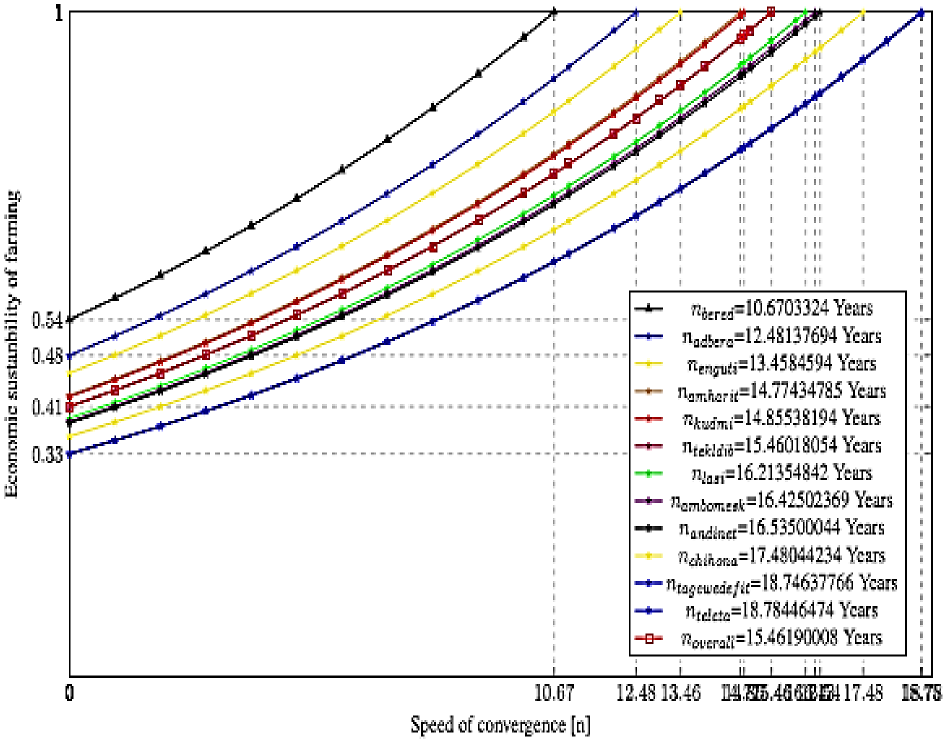


Table 5: Speed of temporal convergence to opt

Block Name	Relative Actual output (TE)	Relative Target level (TE=1)	Speed of Convergence [n]
Bered	0.5370046	1.00	10.6703324
Adebera	0.4832234	1.00	12.48137694
Enguti	0.4564803	1.00	13.4584594
Amarit	0.4227877	1.00	14.77434785
Kudmi	0.4207961	1.00	14.85538194
Tekel dib	0.4062251	1.00	15.46018054
Lasi	0.3887784	1.00	16.21354842
Ambo mesk	0.3840171	1.00	16.42502369
Andenet	0.3815641	1.00	16.53500044
Chihona	0.3611123	1.00	17.48044234
Tagel wedefit	0.3354337	1.00	18.74637766
Teleta	0.3346901	1.00	18.78446474
Overall	0.4061844	1.00	15.46190008
Assuming	g_c=6%, g_T=0%		
Growth differential	[ln (1 + g_c)-ln (1 + g_T)]	= 0.058268908	

Figure 7: Speed of temporal economic sustainability convergence



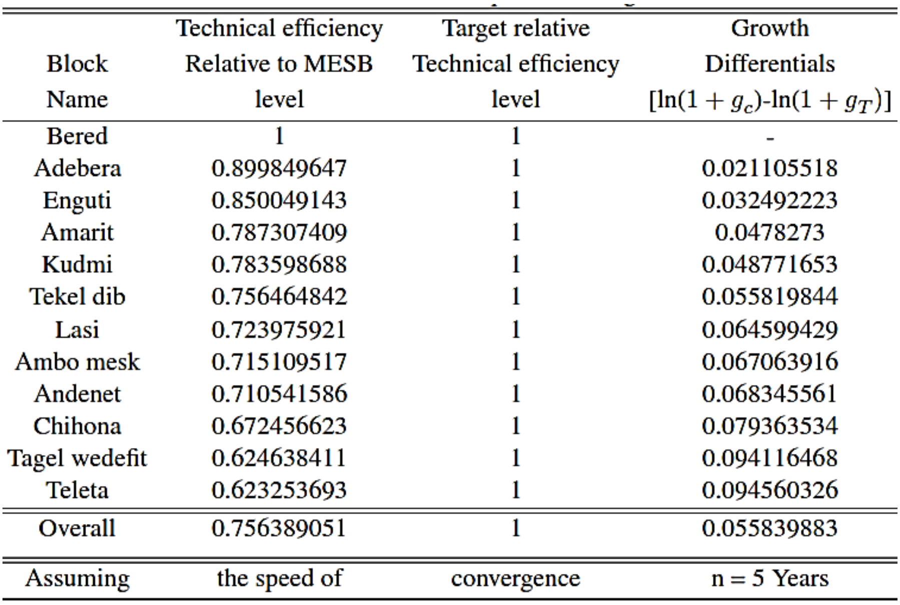
4.2.2. Scenario 2: Spatial economic sustainability convergence

The literature on catching-up suggests that due to the international diffusion and imitation of knowledge, technology, and innovation (for example R and D), including managerial procedures or organizational capabilities, relatively low-productive and low-economically sustainable states have the opportunity to adopt the techniques of the leader and hence catch-up with the higher productivity or economically sustainable states. The argument advanced in this debate is that, while technology adoption varies greatly across different segments of the same state or region, small farmers have reaped the benefits of new technology.

The technical efficiency indices, moreover, at the project level have a standard deviation (Std. Dev.) of 0.1069547, reflecting unbalanced economic sustainability among farmers in the project. Table 6 and Fig. 8 provide the concept of convergence as used in the current study, which refers to the tendency of two or more blocks to become similar in terms of economic sustainability levels through technical efficiency measures. Therefore, if the low levels of the economically sustainable block at the beginning of the period grow more rapidly in technical efficiency than those with high levels of sustainability, then convergence occurs, implying that the less economically sustainable blocks are catching up. The distance that separates it from the best practice block (that is, Bered) explains the relative performance of each block in economic sustainability. The growth differentials and the speed of convergence were calculated in order to perform a convergence analysis between accession blocks and best-performing blocks, that is, economic sustainability convergence to the most economically sustainable block (MESB) in terms of efficiency measure.

Wibisono (2005) regards technological transfer as the primary driver of regional income convergence and contends that government policies have a significant impact on technological diffusion among regions in order to achieve rapid and sustainable regional economic growth. Table 6 includes data on the initial level of relative economic sustainability of each block to the most economically sustainable, the target level of the relative sustainability, the five-year speed of convergence, and the results showing the expected annual growth differential efficiency, which is the difference in the efficiency growth rates between two blocks to achieve spatial economic sustainability convergence. Overall, regions need 5.58 percent growth differentials, that is, they have to register a 5.58 percent higher efficiency growth rate of MESB to catch up for the next five years. While the second most economically sustainable block, Adebera, need only a 2.11 percent higher efficiency growth rate and the most unsustainable block needs a 9.45 percent higher efficiency growth rate for spatial convergence in the next five years. According to Fig. 8, a 6 percent efficiency growth rate of the most economically sustainable block and about 8.26 percent of the second most economically sustainable, the convergence point between these regions, that is, curve intersection between the exponential growth of technical efficiency curve for two blocks after five years will be achieved at technical efficiency of about 0.72, and for the most unsustainable block, the same point of convergence will be achieved at a rate of 16.51 percent. Overall at the project level, it needs 12.08 percent growth rate to catch up with the level of economic sustainability of Bered at 0.72 states of efficiency. However, taking the catch-up effect into account to compare efficiency growth rate across blocks, that is, the relative efficiency growth against Bered[6], the second most economically sustainable block's 8.26 percent growth corresponds to 7.43 percent growth in Bered (8.26: 1.111= 7.43). The most unsustainable block's 16.51 percent corresponds to 10.29 percent growth in Bered.

Table 6: Growth differentials & spatial convergence to MESB



Block Name	Technical efficiency Relative to MESB level	Target relative Technical efficiency level	Growth Differentials $[\ln(1+g_c)\text{-}\ln(1+g_T)]$
Bered	1	1	-
Adebera	0.899849647	1	0.021105518
Enguti	0.850049143	1	0.032492223
Amarit	0.787307409	1	0.0478273
Kudmi	0.783598688	1	0.048771653
Tekel dib	0.756464842	1	0.055819844
Lasi	0.723975921	1	0.064599429
Ambo mesk	0.715109517	1	0.067063916
Andenet	0.710541586	1	0.068345561
Chihona	0.672456623	1	0.079363534
Tagel wedefit	0.624638411	1	0.094116468
Teleta	0.623253693	1	0.094560326
Overall	0.756389051	1	0.055839883
Assuming	the speed of	convergence	n = 5 Years

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[6] The numbers given in Table 7 are based on region-standard, which in this example is Bered. For a "region-standard" one could select the region that has the highest economic sustainability index in Koga irrigation and Watershed project, and following this standard, the rates of efficiency growth in other regions would be adjusted similarly

Figure 8: Spatial economic sustainability convergence

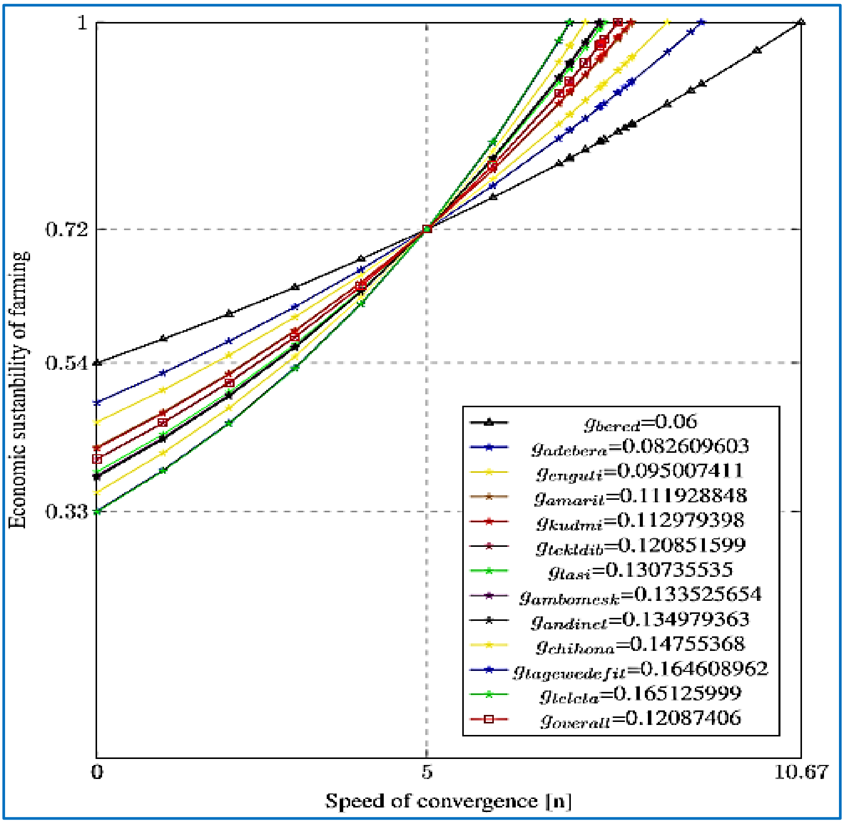
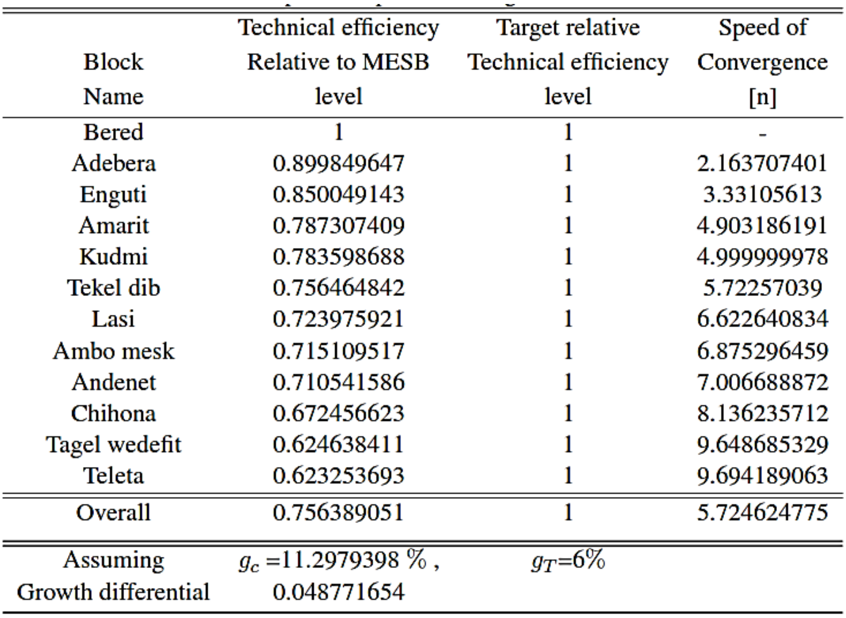


Table 7: Real efficiency growth rates adjusted for the catch-up effect

Block Name	Expected efficiency growth rate for next 5 years	Ratio of expected growth in a given block to that of Bered	Level of economic sustainability indices i.e. TE	Proportion of catch up effect(α_{ij}) i.e. ratio of sustainability of Bered to that of a given block)	Hypothetical efficiency growth rate i.e. after adjustments ($r_{ij}*$)	Ratio of a given block's hypothetical growth to Bered (β_{ij})
Bered	0.06	1	0.5370046	1	0.06	1
Adebera	0.082609603	1.376826717	0.4832234	1.111296763	0.074336222	1.238937036
Enguti	0.095007411	1.58345685	0.4564803	1.176402574	0.080760968	1.346016138
Amarit	0.111928848	1.8654808	0.4227877	1.270151899	0.088122411	1.468706854
Kudmi	0.112979398	1.882989967	0.4207961	1.276163444	0.088530508	1.475508467
Tekeldib	0.120851599	2.014193317	0.4062251	1.321938502	0.091419986	1.523666429
Lasi	0.130735535	2.178925583	0.3887784	1.381261408	0.094649379	1.577489657
Ambomesk	0.133525654	2.225427567	0.3840171	1.398387207	0.095485466	1.591424432
Andenet	0.134979363	2.24965605	0.3815641	1.407377162	0.095908451	1.598474177
Chihona	0.14755368	2.459228	0.3611123	1.487084766	0.099223449	1.653724157
Tagel wedefit	0.164608962	2.7434827	0.3354337	1.600926204	0.10282108	1.713684674
Teleta	0.165125999	2.752099983	0.3346901	1.604483073	0.102915389	1.715256478
Overall	0.12087406	2.014567667	0.4061844	1.322070961	0.091427816	1.523796926

Table 8: Speed of spatial convergence to MESB



Block Name	Technical efficiency Relative to MESB level	Target relative Technical efficiency level	Speed of Convergence [n]
Bered	1	1	-
Adebera	0.899849647	1	2.163707401
Enguti	0.850049143	1	3.33105613
Amarit	0.787307409	1	4.903186191
Kudmi	0.783598688	1	4.999999978
Tekel dib	0.756464842	1	5.72257039
Lasi	0.723975921	1	6.622640834
Ambo mesk	0.715109517	1	6.875296459
Andenet	0.710541586	1	7.006688872
Chihona	0.672456623	1	8.136235712
Tagel wedefit	0.624638411	1	9.648685329
Teleta	0.623253693	1	9.694189063
Overall	0.756389051	1	5.724624775
Assuming	g_c =11.2979398 % ,	g_T=6%	
Growth differential	0.048771654		

The dynamics of the spatial economic sustainability convergence with the same 11.29 percent[7] average efficiency growth rates of blocks as against 6 percent growth rate of Bered is shown in Table 8 and Fig. 9. Accordingly, the second most economically sustainable block, the most economically unsustainable block and overall at project level needs about 2.16, 9.69 and 5.72 years to catch up the level of economic sustainability of the benchmark block respectively. Generally, given about 4.87 percent growth differentials between “accession blocks” and the most sustainable block, it needs about 2.16,9.69 and 5.72 years to catch up for Adebera, Teleta, and Overall respectively. Fig. 9 also contains the time (number of years) necessary to achieve spatial convergence, and evolution of economic sustainability in each block where inputs are being used to their utmost capacity therein, as given by the same 11.29 percent efficiency growth of “accession blocks” and benchmark block growing at 6 percent. Accordingly, the curve of intersection between exponential efficiency growth rate curve of two blocks will be achieved at technical efficiency of about

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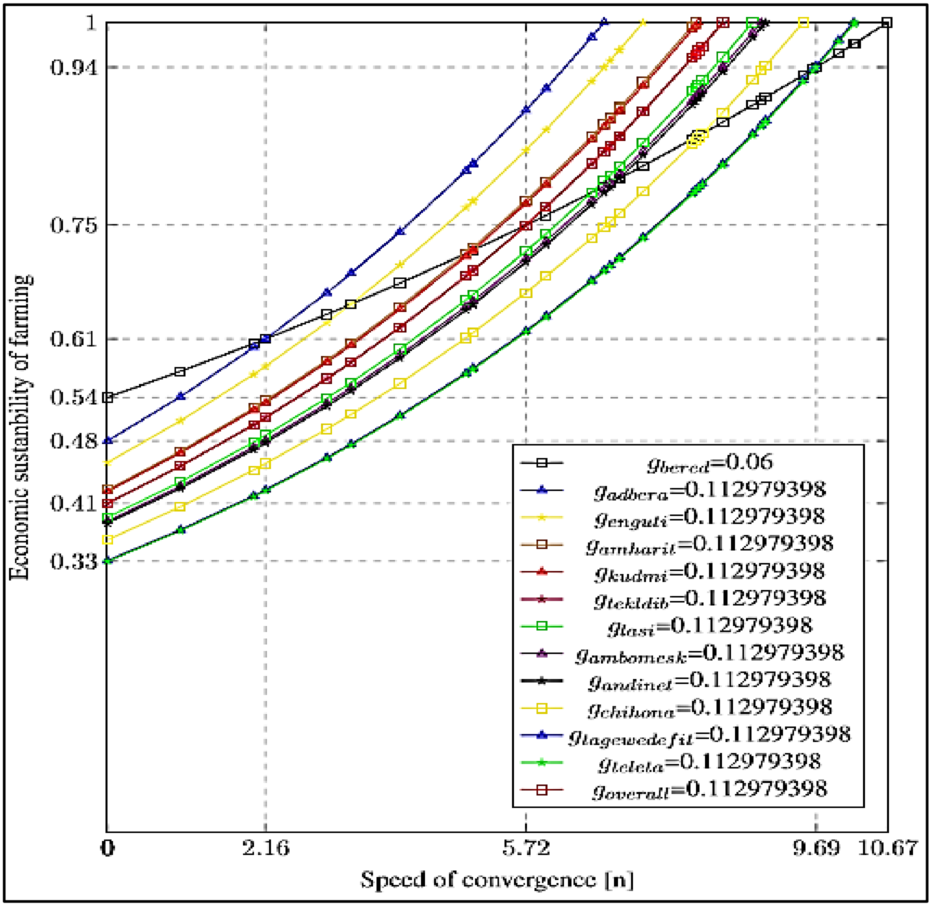
[7] Under the proportional overlap hypothesis, Adebera’s, Enguti’s, Amarit’s, Kudmi’s, Tekledib’s, Lasi’s, Ambomesk’s, Andenet’s, Chihona’s, Tagel’s, Teleta’s an overall 11.29 percent growth corresponds to (10.17),(9.6),(8.9),(8.85),(8.54),(8.18),(8.08),(8.03),(7.6),(7.06),(7.04) and (8.55) percent growth in Bered, respectively

0.61,0.94 and 0.75 for Adebera, Teleta, and the overall project level is about 2.16,9.69, and 5.72 years respectively.

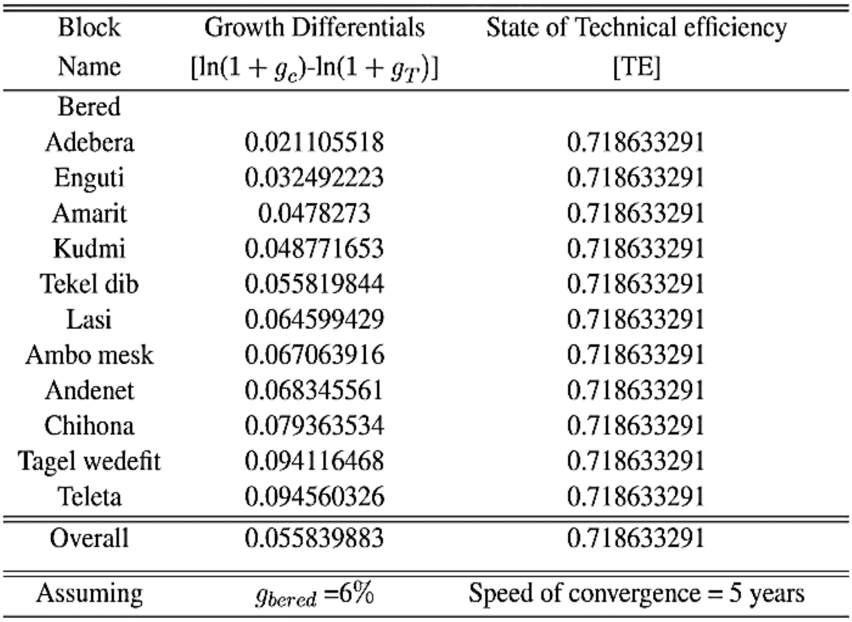
Figure 9: Speed for spatial economic sustainability convergence



4.2.3. Scenario 3: Cross-over or leapfrogging phenomenon in economic sustainability

Initially, economically less sustainable blocks may not only manage to catch up with more sustainable ones, indicating convergence, but they may also cross over and continue to surge ahead. The crossover scenario, thus, could again cause an increase in the dispersion of economic sustainability levels. Table 9 and Figure 10 show the cutoff points of technical efficiency state (can be considered as state of economic sustainability in this study) and growth differentials[8] given five years of the speed of convergence and a 6 percent efficiency growth of the most economically sustainable block. It will take only slightly greater than 2.11 percent higher efficiency growth rate of Bered for Adebera to surge ahead in terms of economic sustainability, similarly, the cutoff point technical efficiency is about 0.72 beyond which the Adbera will become more economically sustainable than Bered. However, for the most economically unsustainable block, it requires more than 9.45 percent higher efficiency growth rate of Bered to surge ahead to become the most economically sustainable after five years. At the project level, overall it needs more than 5.58 percent higher efficiency growth rate to surge ahead of the most economically sustainable block.

Table 9: Growth differentials for cross-over or leapfrogging phenomenon in economic sustainability



Block Name	Growth Differentials $[\ln(1+g_c)-\ln(1+g_T)]$	State of Technical efficiency [TE]
Bered		
Adebera	0.021105518	0.718633291
Enguti	0.032492223	0.718633291
Amarit	0.0478273	0.718633291
Kudmi	0.048771653	0.718633291
Tekel dib	0.055819844	0.718633291
Lasi	0.064599429	0.718633291
Ambo mesk	0.067063916	0.718633291
Andenet	0.068345561	0.718633291
Chihona	0.079363534	0.718633291
Tagel wedefit	0.094116468	0.718633291
Teleta	0.094560326	0.718633291
Overall	0.055839883	0.718633291
Assuming	g_{bered} =6%	Speed of convergence = 5 years

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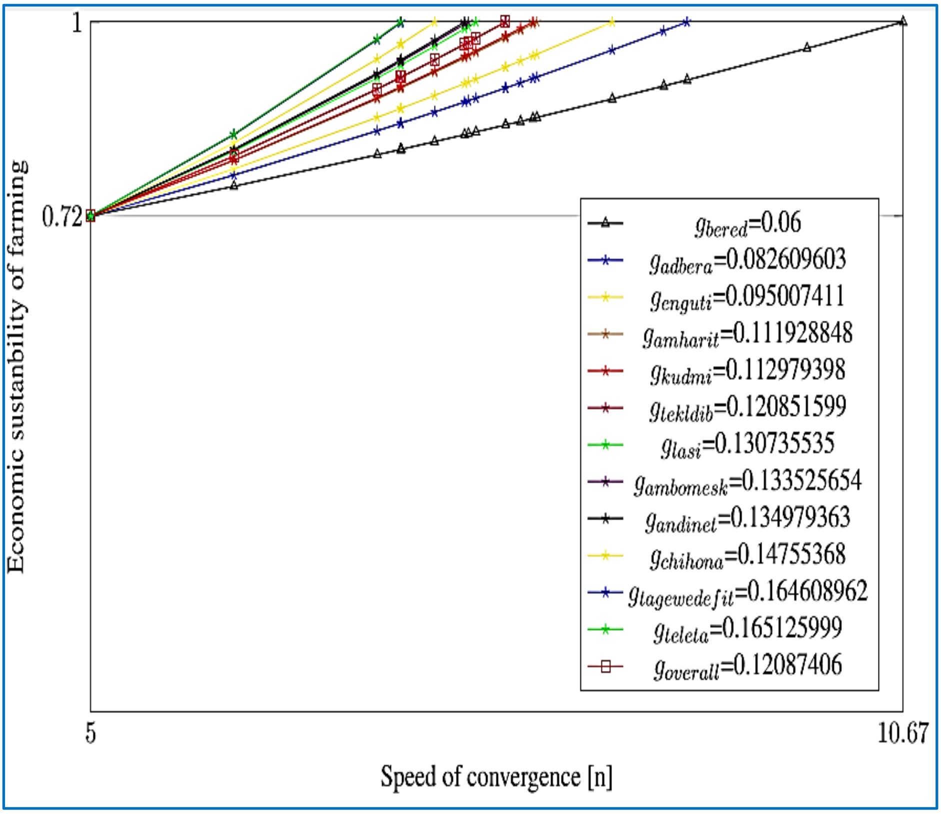
[8] There was a little deviation of growth differentials as a result of exponential function and its log-transformations

Figure 10: Growth differentials for cross-over in economic sustainability

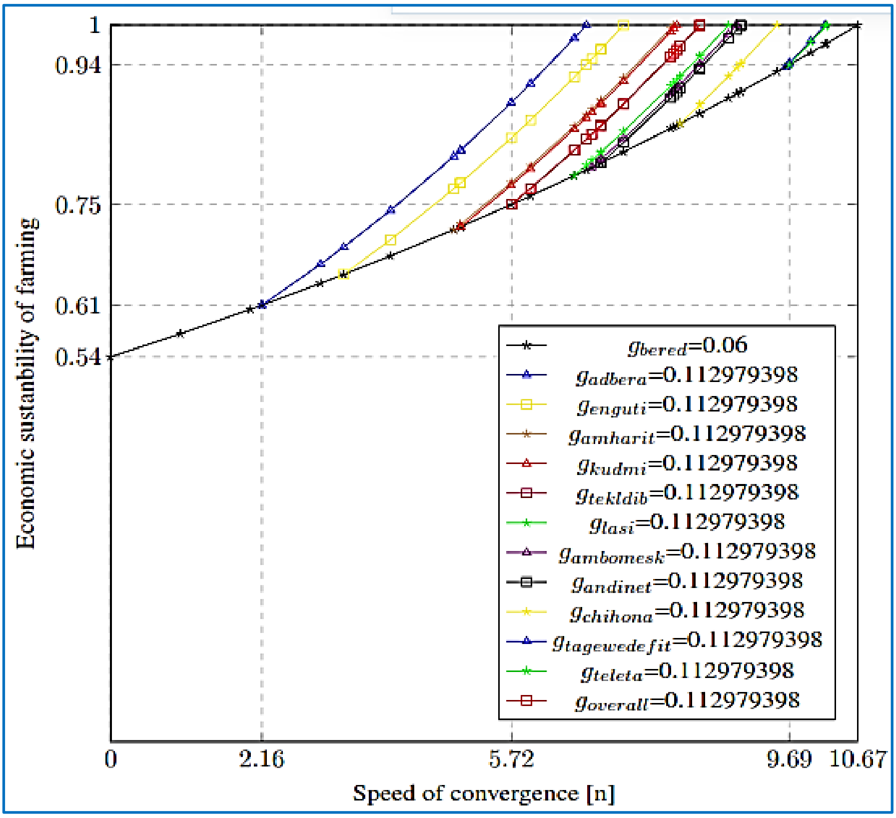


As far as leapfrogging time is concerned in Table 10 and Figure 11, with growth differentials of about 0.0487 (provided that all blocks are growing at a rate of about 4.87 percent higher than the most sustainable block) and two growth rates given in Table 10, overall at project level it will take more than 5.72 years to surge ahead (that is beyond 0.75 level of efficiency). The second most economically sustainable block surge ahead of Bered after 2.16 years with 0.61 states of efficiency beyond which Adebera will become the most sustainable block in the project area. For the most economically unsustainable block, it will take more than 9.69 years, that is, beyond 0.95 states of efficiency to surge ahead of Bered in the level of economic sustainability.

Table 10: Speed of cross-over or leapfrogging phenomenon in economic sustainability

Block Name	Cross-over/ leapfrogging time [n]	State of Technical efficiency [TE]
Bered		
Adebera	2.163707401	0.609161565
Enguti	3.33105613	0.652038536
Amarit	4.903186191	0.714590725
Kudmi	4.999999978	0.71863329
Tekel dib	5.72257039	0.74953618
Lasi	6.622640834	0.789895542
Ambo mesk	6.875296459	0.801610379
Andenet	7.006688872	0.807771136
Chihona	8.136235712	0.862725213
Tagel wedefit	9.648685329	0.942207022
Teleta	9.694189063	0.944708555
Overall	5.724624775	0.74962591
Assuming Growth Differentials	g_c =11.2979398% ,g_{bered} =6% =0.048771654	

Figure 11: Speed for cross-over phenomenon in economic sustainability



In Figure 11, for "accession blocks" growing at a rate of about 11.29 percent and the most economically sustainable block growing at a rate of 6 percent, the abscissa points of 2.16, 5.72 and 9.69 and the ordinates 0.61, 0.75 and 0.94 are showing cutoff leapfrogging times and states of economic sustainability beyond which Adebera, overall at project level, and Teleta respectively surge ahead.

4.3. Discussion of results

It is argued that individual farm- and farmer-specific characteristics determine economic sustainability. Such characteristics can be divided into two categories: demographic characteristics, which dominate the farmer's decision-making process, and socioeconomic and institutional characteristics, which influence a farmer's ability to apply farm-level decisions. This variation in the degree of economic sustainability was caused by socioeconomic variables. Differences in economic sustainability have been attributed to characteristics that are expected to differ between households and blocks.

Before estimating model parameters with the Maximum Likelihood Estimates (MLE) method, it is critical to test the model's specification and validity. Unfortunately, none of them are known a priori; instead, they must be determined from the available data. The study used flexible Trans-log (TL) specification to specify the stochastic frontier production function and then performed a log likelihood ratio test to see if the Trans-log (TL) reduces to the CD production function. As a result of the log-likelihood ratio test, the TL functional form was found to be more appropriate than Cobb-Douglas Table 18 in Annex Part. Cobb-Douglas is a special case of the trans-log production function in which the coefficients of the squared and interaction terms of the trans-log frontier input variables are assumed to be zero. The diagnostic test in the functional specification demonstrated that the squared and interaction terms of the trans-log frontier input variables are not equal to zero. At the 5 percent level of significance, the null hypothesis that all determinant variables in the inefficiency effect model are simultaneously equal to zero is rejected in Table 19 in the Annex Part. The explanatory variables associated with the inefficiency effect model are all greater than zero. As a result, these variables explain differences in farmer inefficiency.

The positive coefficients of access to credit and the two types of land ownership (that is, own and rented land) in the model, reveal that variables reduce the farmer's level of sustainability in the analysis of the technical inefficiency effects model. Other statistically significant variables that influence convergence positively include household size, frequency of consultation visits, male household head, and non-farm income. The discussion of these farm-specific demographic and socioeconomic variables follows. Households with larger families are economically more sustainable in terms of technical efficiency, indicating the benefit of increased labor supply during peak farming season, as confirmed by Tekalign (2019), Andaregie, A., and Astatkie, T. (2020). The impact of household size could indicate labor-intensive crop production. Because of the block's traditional production system, the most labor-intensive and time-consuming harvesting and threshing operations are performed solely by human and animal power. The study also confirms that advisory services improve farmers' technical efficiency. Access to advisory services provides farmers with enormous productivity and efficiency gains by facilitating the introduction of new technologies and providing access to technical knowledge and new skills. Marios (2006), Zewdie et al. (2021), Tekalign (2019), and Andaregie, A., and Astatkie, T (2020) all agree that extension services contribute positively to efficiency improvement (2020). As a result, our findings imply that if more resources are invested on extension services, farmers' economic sustainability will improve and converge as technical efficiency will converge to the frontier level and to the most sustainable block. Off-farm income (also known as non-farm income) by easing financial restrictions on the timely purchase of inputs such as labor, capital, and fertilizers helped improve economic sustainability. The positive impact of off-farm income also confirmed by Tekalign (2019), Andaregie, A., and Astatkie, T. (2020). In contrast to the availability of off-farm income as an alternative to credit, access to credit has a positive impact on technical inefficiency unlike a study by Marios (2006), Tekalign (2019). Thus, credit lowers the level of economic sustainability of farmers. The money received in the form of loans was not used for productive activities. Farmers were reluctant to return it. Political instability and unrest in Ethiopia during this time may contribute to this effect. In terms of household head gender, women are technically less efficient than men. Households led by female heads were economically less sustainable.

Farmers in the Koga Irrigation and Watershed Project's adjacent Kebeles support the project because they expect to participate in irrigation-based sharecropping arrangements and benefit from the project's specialization and diversification. The share cropping agreement is very efficient in comparison to other types of land ownership agreements in the Koga watershed and irrigation project. The vast majority of farmers (81.8 percent) farmed exclusively on their own irrigated lands. Sharecropping takes a little share (3 percent). Farmers must use resources wisely and conduct business in accordance with the performance of share croppers. In the farming business, they must develop the share cropping mentality. They must learn and share experiences from share cropping arrangements in order to close the efficiency gap between themselves and their more efficient counterparts and become more sustainable.

Although the twelve blocks are close together and face similar natural and market conditions, economic sustainability varies. In the inefficiency effects model discussed above, the differences can be attributed to farm and farmer's characteristics, which are expected to vary from household to household and from block to block. The plot analysis also confirmed the inefficiency model's variation in economic sustainability. The trend line for the plot analysis shows that, with the exception of household size, all of the above statistically significant farm and household specific variables contributed to the variation in the degree of economic sustainability. As a result, large household size, extension and training services, non-farm income, and production activities led by male heads must be used in the future to improve agricultural efficiency (temporal economic sustainability convergence) and close the efficiency gap between blocks (to achieve spatial economic sustainability convergence). All of these factors, including the sharecropping work spirit, aid in the convergence of temporal and spatial economic sustainability.

Farmers' perceptions of current production levels, the source of production loss, perceptions of efficiency improvement, and satisfaction with current farm performance may all be related to technical efficiency. In contrast to the quantitative results of the maximum likelihood estimates, the majority (45 percent) believed their land was performing to its potential. The majority of farmers (61 percent) also believe it is possible to improve efficiency without changing the amount of inputs and technology. As a result, farmers should be communicated well in order to become aware off their level of efficiency. In a broader sense, not only demography but also socioeconomic characteristics, and perceptions are important for temporal and spatial convergence. The spatial-temporal economic sustainability of the Koga irrigation project could be achieved if the government at the local level emphasized the role of various demography, socioeconomic characteristics, and perception-related issues discussed above for economic sustainability convergence in the project's command areas.

The five convergence questions were guided by the following scenarios in terms of short- and long-term plans, as well as reasonable growth rates and growth differentials. The study separated the convergence analysis into short-and long-term goals. The short-term (5-year plan) goal is to achieve a comparable level of economic sustainability through technical efficiency measures, that is, the catch-up effect. A growth rate that makes farmers fully efficient within 10 years is taken as long-term plan. While the long-term plan (ten years) seeks to achieve fully technical efficient farms in each block (temporal convergence. For the long-term goal, growth rates were calculated, and the lowest possible growth rate (that is, 6 percent) was assumed, which was triangulated with other studies used to calculate the rate of convergence to their respective frontiers. As a short-term plan for catching up, the expected growth differential for the MESB was calculated, and a relatively higher growth rate for other blocks and a minimum possible growth rate of 6 percent for the MESB were assumed to calculate the speed of convergence for catch up.

The first scenario for long-term planning considers the growth rate of efficiency farmers becoming optimally economically sustainable after ten years and the speed of convergence for each region to achieve an optimal level of economic sustainability if a minimum growth rate of 6 percent is assumed. According to our findings, in order to reach the optimal level, technical efficiency should increase at a rate of 9.42 percent per year on average over the next ten years. To achieve the optimal level, it ranges from 6.4 to 11.56 percent per year for the most and least sustainable blocks. By connecting the realities, we attempted to provide clear justification for the finding. When compared to the 10 percent assumed technical efficiency change by Birhanu et al. (2021) and the technical efficiency of Ethiopian farm households over years in the Time-varying Inefficiency Effects (TIE) model between 1994-2004 of 16.4 percent, and 1999-2009 of 19.4 percent (Tenaye, 2020), the 9.42 percent expected growth rate at the project level in the first scenario result is not overly ambitious and is attainable.

The majority of the increase in productivity can be attributed to improved technical efficiency. When the source of the change is broken down, an increase in technical efficiency is the main contributor. The efficiency trend in 2013 was 61 percent, which showed a 7 percent improvement compared to 54 percent in 2011 (Wendimun, 2016). Increasing efficiency is the primary driver of agricultural productivity. The majority of the productivity increase can be attributed to increased technical efficiency. When the source of the change is examined, the main contributor is an increase in technical efficiency. According to Prime Minister Abiy Ahmed’s (Ph.D.) parliamentary report, the target agricultural growth rate for 2021 was 5.9 percent, with a potential of 8 percent. According to Mellor and Dorosh (2010), non-agricultural sectors grow faster than agricultural sectors during the normal process of economic growth. Agriculture's slower growth, its relative decline, concerns about the difficulty of modernizing agriculture, and pessimism about the potential for technological change in agriculture all suggest to some that agriculture should not be prioritized for scarce resources in the interests of rapid overall growth. Maintaining a six percent growth rate in agricultural GDP (the Comprehensive Africa Agriculture Development Programme's (CAADP) target of six percent per year) would provide enough employment growth to contribute to the economy's rapid economic transformation and rapid decline in poverty. Fast agricultural growth countries, which are typically middle-income countries, grow agriculture at a four-to-six percent annual rate. Despite its lower-income status, Ethiopia has significant productive agricultural resources and has made a good start in institutional development. Between 2011 and 2013, the efficiency trend improved by 7 percent (Wendimun, 2016). Based on Wendimun (2016) target agricultural growth rate and its potential, following Mellor and Dorosh (2010) and Tenaye (2020), we took a 6 percent increase in efficiency as a reasonable minimum target to calculate speed for catch up effect. If blocks grow at the minimum rate, it takes 10.7 to 18.9 years for a block to become economically sustainable.

Ethiopia also has a five-year development plan. This study's short-term goal is to calculate growth differentials and achieve economic sustainability convergence among blocks in the Koga project. The most sustainable block grows at the lowest reasonable rate; other blocks require a 2.1-9.4 percent growth differential, or 8-16.5 percent. However, assuming 11.29 percent growth in other blocks and the MESB growing at the lowest reasonable level, it will take 2-10 years to catch up. Between 1994 and 1999, technical efficiency of Ethiopian farm households was 11.23 percent in the True Fixed Effect (TFE) model, and 11.6 percent in the Time-varying Inefficiency Effects (TIE) model (Tenaye, 2020). According to Tenaye (2020), a 5-year growth rate of 11.29 percent is a reasonable goal.

5. Conclusions and Policy Implications

This study has many practical implications, one of which is informing economic sustainability policymaking. It could also assess how economic sustainability is being expanded in specific regions, either by emphasizing technical efficiency growth or by emphasizing the efficiency convergence point, so that proposed policies can be tailored to the condition of each block. The economic sustainability level of blocks in the Koga irrigation and watershed project as measured by the extent to which observed output deviates from the potential output, called “frontier,” varies across blocks. Twelve blocks are further categorized as more sustainable and less sustainable blocks. Despite the twelve blocks being nearby and facing similar natural and market conditions, there is momentous variation in economic sustainability attributed to differences in farm and household characteristics, which are expected to vary from household to household and region to region. The dynamics of temporal economic sustainability convergence show that the farmer in the agriculture sector needs to grow at 9.42 percent for the next 10 years of the planning period to reach the optimum level despite the fact that observed output is significantly lower than the optimum level. If they are growing at 6 percent normal high growth (or approximately with 5.82 growth differentials), the farming system would need 15.46 years to become optimally economically sustainable. The tendency of the farming system in the area to become similar in terms of economic sustainability levels makes the most economically sustainable block require 2.11 to 9.45 percent growth differentials for the next five years. Based on the study’s scenarios, the expected growth rate and speed of convergence were feasible in the study area. Furthermore, statistically significant variables that positively influence convergence include household size, frequency of consultation visits, male household heads, sharecroppers’ mentality, and non-farm income, which are thought to facilitate convergence at the frontier. Experience sharing from the most sustainable blocks is being put forward for spatial convergence in order to close the efficiency gap between themselves and their more efficient counterparts. The policy implication is that the local government can consider spatial economic sustainability as a short-term goal (a five-year plan) in the agriculture sector in the study area, while temporal sustainability is a long-term goal (a ten-year plan) in the sector. Such plans have numerous reasonable grounds.

Understanding the drivers of convergence at the temporal and spatial levels can give policymakers valuable insights into the conditions needed for faster economic sustainability and balanced community development. Current efficiency testing methodologies, on the other hand, are based on cross-sectional data and generally rely on comparing results across farmers and identifying determinate variables. Future research should place more emphasis on estimating convergence at the panel data level rather than relying on scenario development as a methodology. To comprehend the dynamism of agricultural production efficiency and identify trends in the sector, more research is required to be carried out.

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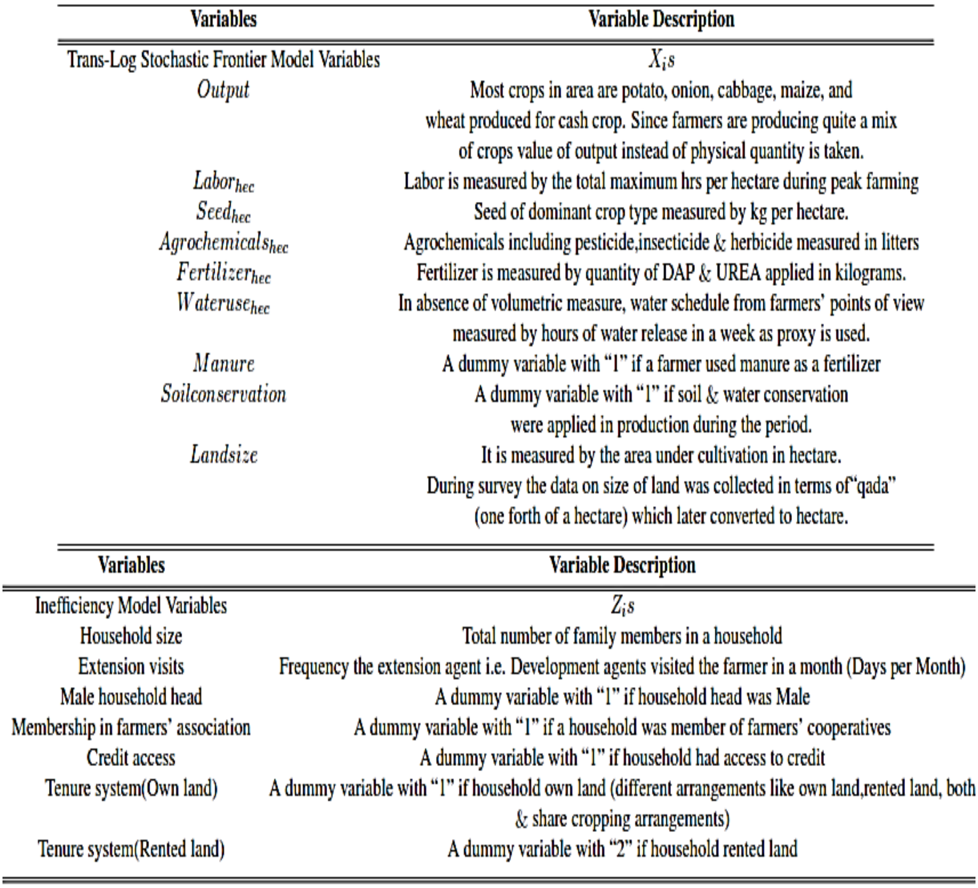
Annex

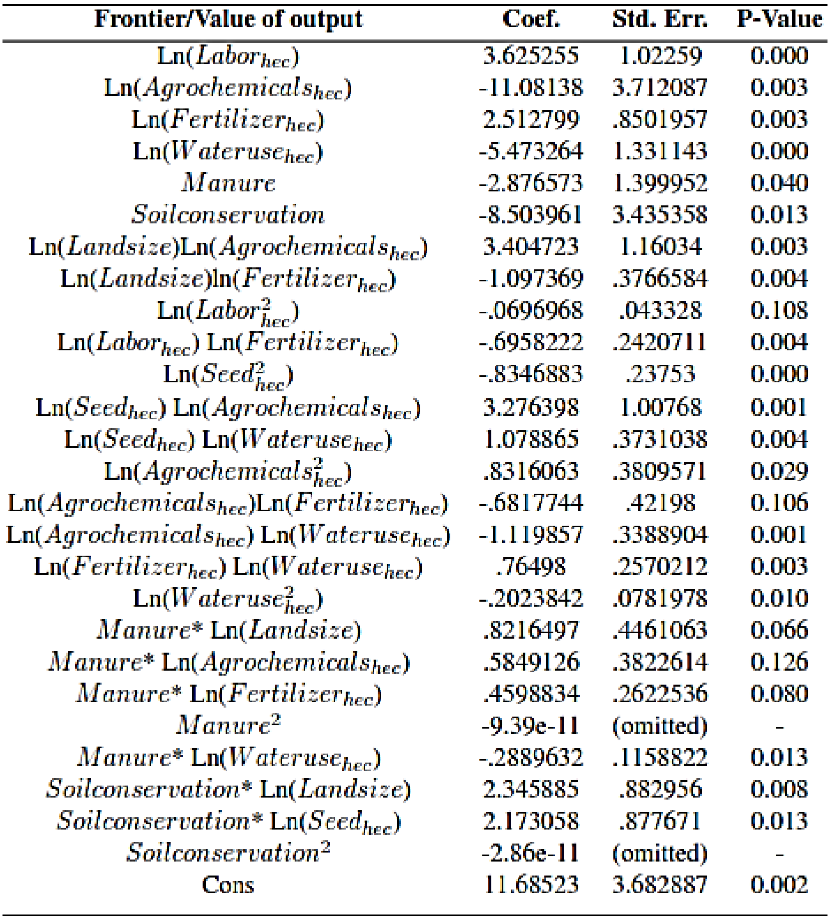
Table 11: Trans-Log stochastic frontier & inefficiency model variable



Variables	Variable Description
Trans-Log Stochastic Frontier Model Variables	$X_i s$
$Output$	Most crops in area are potato, onion, cabbage, maize, and wheat produced for cash crop. Since farmers are producing quite a mix of crops value of output instead of physical quantity is taken.
$Labor_{hec}$	Labor is measured by the total maximum hrs per hectare during peak farming
$Seed_{hec}$	Seed of dominant crop type measured by kg per hectare.
$Agrochemicals_{hec}$	Agrochemicals including pesticide,insecticide & herbicide measured in litters
$Fertilizer_{hec}$	Fertilizer is measured by quantity of DAP & UREA applied in kilograms.
$Wateruse_{hec}$	In absence of volumetric measure, water schedule from farmers' points of view measured by hours of water release in a week as proxy is used.
$Manure$	A dummy variable with "1" if a farmer used manure as a fertilizer
$Soilconservation$	A dummy variable with "1" if soil & water conservation were applied in production during the period.
$Landsize$	It is measured by the area under cultivation in hectare. During survey the data on size of land was collected in terms of"qada" (one forth of a hectare) which later converted to hectare.

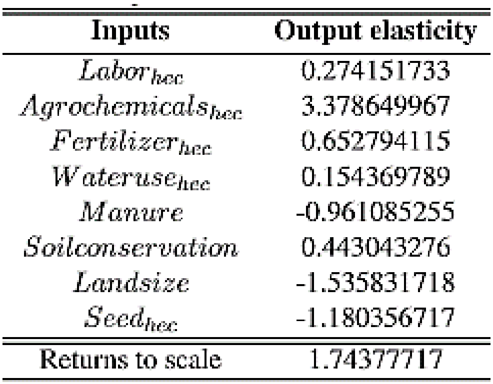
Variables	Variable Description
Inefficiency Model Variables	$Z_i s$
Household size	Total number of family members in a household
Extension visits	Frequency the extension agent i.e. Development agents visited the farmer in a month (Days per Month)
Male household head	A dummy variable with "1" if household head was Male
Membership in farmers' association	A dummy variable with "1" if a household was member of farmers' cooperatives
Credit access	A dummy variable with "1" if household had access to credit
Tenure system(Own land)	A dummy variable with "1" if household own land (different arrangements like own land,rented land, both & share cropping arrangements)
Tenure system(Rented land)	A dummy variable with "2" if household rented land

Table 12: Trans-Log Stochastic Frontier Model Results



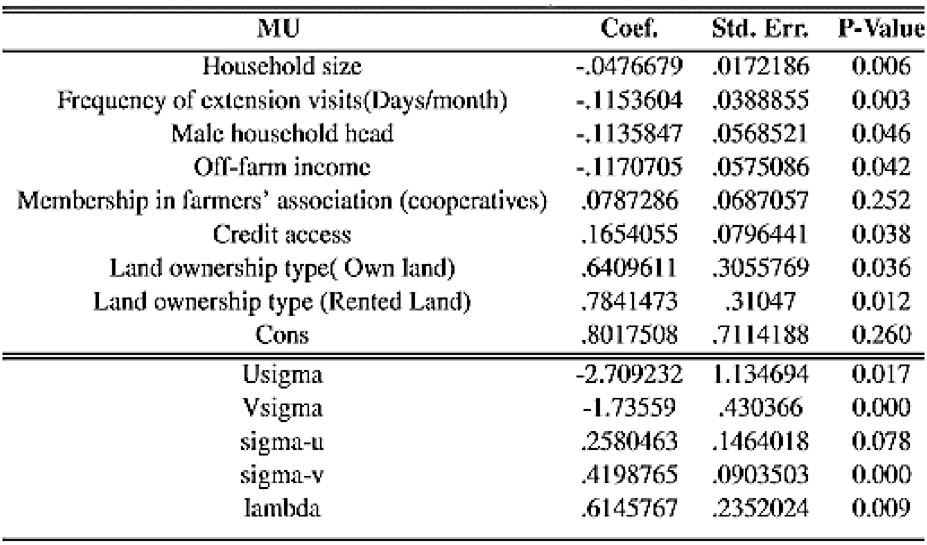
Frontier/Value of output	Coef.	Std. Err.	P-Value
Ln($Labor_{hec}$)	3.625255	1.02259	0.000
Ln($Agrochemicals_{hec}$)	-11.08138	3.712087	0.003
Ln($Fertilizer_{hec}$)	2.512799	.8501957	0.003
Ln($Wateruse_{hec}$)	-5.473264	1.331143	0.000
$Manure$	-2.876573	1.399952	0.040
$Soilconservation$	-8.503961	3.435358	0.013
Ln($Landsize$)Ln($Agrochemicals_{hec}$)	3.404723	1.16034	0.003
Ln($Landsize$)ln($Fertilizer_{hec}$)	-1.097369	.3766584	0.004
Ln($Labor^2_{hec}$)	-.0696968	.043328	0.108
Ln($Labor_{hec}$) Ln($Fertilizer_{hec}$)	-.6958222	.2420711	0.004
Ln($Seed^2_{hec}$)	-.8346883	.23753	0.000
Ln($Seed_{hec}$) Ln($Agrochemicals_{hec}$)	3.276398	1.00768	0.001
Ln($Seed_{hec}$) Ln($Wateruse_{hec}$)	1.078865	.3731038	0.004
Ln($Agrochemicals^2_{hec}$)	.8316063	.3809571	0.029
Ln($Agrochemicals_{hec}$)Ln($Fertilizer_{hec}$)	-.6817744	.42198	0.106
Ln($Agrochemicals_{hec}$) Ln($Wateruse_{hec}$)	-1.119857	.3388904	0.001
Ln($Fertilizer_{hec}$) Ln($Wateruse_{hec}$)	.76498	.2570212	0.003
Ln($Wateruse^2_{hec}$)	-.2023842	.0781978	0.010
$Manure$* Ln($Landsize$)	.8216497	.4461063	0.066
$Manure$* Ln($Agrochemicals_{hec}$)	.5849126	.3822614	0.126
$Manure$* Ln($Fertilizer_{hec}$)	.4598834	.2622536	0.080
$Manure^2$	-9.39e-11	(omitted)	-
$Manure$* Ln($Wateruse_{hec}$)	-.2889632	.1158822	0.013
$Soilconservation$* Ln($Landsize$)	2.345885	.882956	0.008
$Soilconservation$* Ln($Seed_{hec}$)	2.173058	.877671	0.013
$Soilconservation^2$	-2.86e-11	(omitted)	-
Cons	11.68523	3.682887	0.002

Table 13: Output elasticities and returns to scale



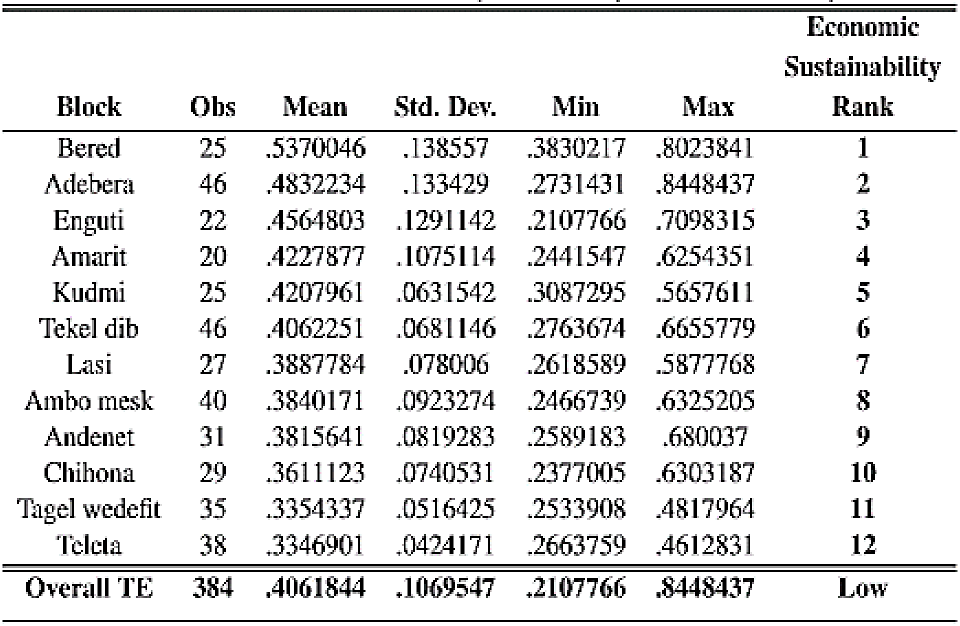
Inputs	Output elasticity
$Labor_{hec}$	0.274151733
$Agrochemicals_{hec}$	3.378649967
$Fertilizer_{hec}$	0.652794115
$Wateruse_{hec}$	0.154369789
$Manure$	-0.961085255
$Soilconservation$	0.443043276
$Landsize$	-1.535831718
$Seed_{hec}$	-1.180356717
Returns to scale	1.74377717

Table 14: Technical Inefficiency Model Results



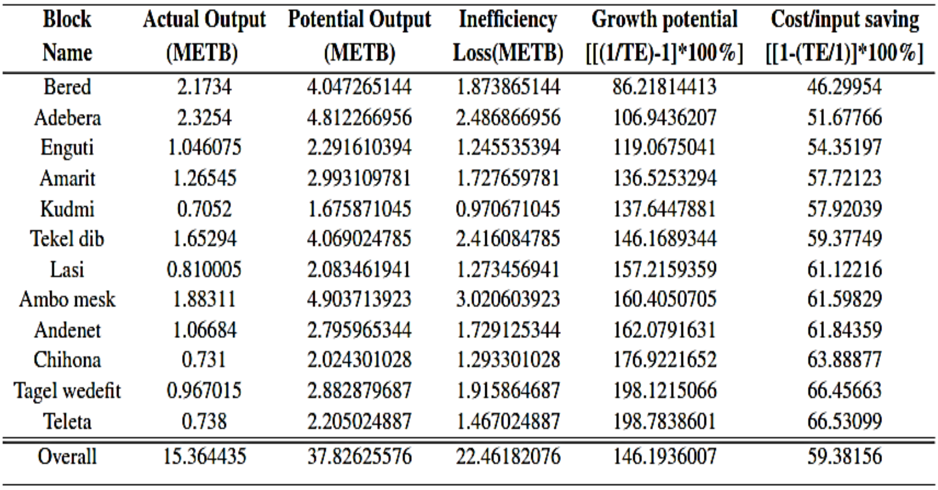
MU	Coef.	Std. Err.	P-Value
Household size	-.0476679	.0172186	0.006
Frequency of extension visits(Days/month)	-.1153604	.0388855	0.003
Male household head	-.1135847	.0568521	0.046
Off-farm income	-.1170705	.0575086	0.042
Membership in farmers' association (cooperatives)	.0787286	.0687057	0.252
Credit access	.1654055	.0796441	0.038
Land ownership type(Own land)	.6409611	.3055769	0.036
Land ownership type (Rented Land)	.7841473	.31047	0.012
Cons	.8017508	.7114188	0.260
Usigma	-2.709232	1.134694	0.017
Vsigma	-1.73559	.430366	0.000
sigma-u	.2580463	.1464018	0.078
sigma-v	.4198765	.0903503	0.000
lambda	.6145767	.2352024	0.009

Table 15: Level of economic sustainability indicated by technical efficiency indices



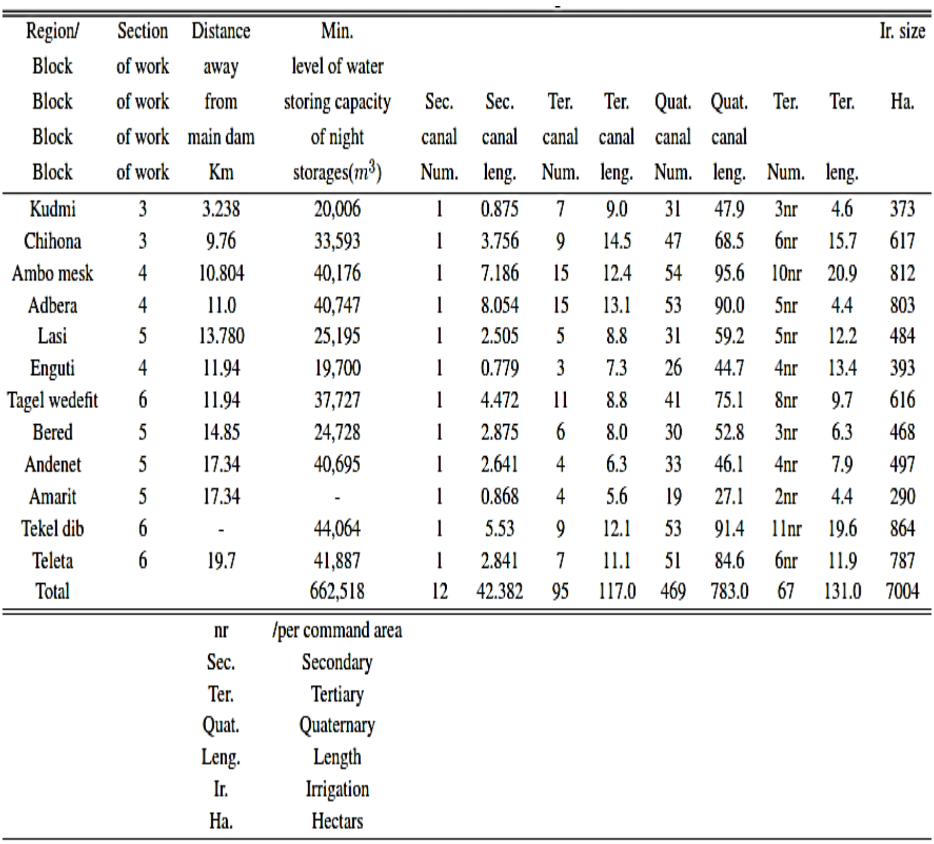
Block	Obs	Mean	Std. Dev.	Min	Max	Economic Sustainability Rank
Bered	25	.5370046	.138557	.3830217	.8023841	1
Adebera	46	.4832234	.133429	.2731431	.8448437	2
Enguti	22	.4564803	.1291142	.2107766	.7098315	3
Amarit	20	.4227877	.1075114	.2441547	.6254351	4
Kudmi	25	.4207961	.0631542	.3087295	.5657611	5
Tekel dib	46	.4062251	.0681146	.2763674	.6655779	6
Lasi	27	.3887784	.078006	.2618589	.5877768	7
Ambo mesk	40	.3840171	.0923274	.2466739	.6325205	8
Andenet	31	.3815641	.0819283	.2589183	.680037	9
Chihona	29	.3611123	.0740531	.2377005	.6303187	10
Tagel wedefit	35	.3354337	.0516425	.2533908	.4817964	11
Teleta	38	.3346901	.0424171	.2663759	.4612831	12
Overall TE	**384**	**.4061844**	**.1069547**	**.2107766**	**.8448437**	**Low**

Table 16: Capacity utilization, and inefficiency loss measures



Block Name	Actual Output (METB)	Potential Output (METB)	Inefficiency Loss(METB)	Growth potential [[(1/TE)-1]*100%]	Cost/input saving [[1-(TE/1)]*100%]
Bered	2.1734	4.047265144	1.873865144	86.21814413	46.29954
Adebera	2.3254	4.812266956	2.486866956	106.9436207	51.67766
Enguti	1.046075	2.291610394	1.245535394	119.0675041	54.35197
Amarit	1.26545	2.993109781	1.727659781	136.5253294	57.72123
Kudmi	0.7052	1.675871045	0.970671045	137.6447881	57.92039
Tekel dib	1.65294	4.069024785	2.416084785	146.1689344	59.37749
Lasi	0.810005	2.083461941	1.273456941	157.2159359	61.12216
Ambo mesk	1.88311	4.903713923	3.020603923	160.4050705	61.59829
Andenet	1.06684	2.795965344	1.729125344	162.0791631	61.84359
Chihona	0.731	2.024301028	1.293301028	176.9221652	63.88877
Tagel wedefit	0.967015	2.882879687	1.915864687	198.1215066	66.45663
Teleta	0.738	2.205024887	1.467024887	198.7838601	66.53099
Overall	15.364435	37.82625576	22.46182076	146.1936007	59.38156

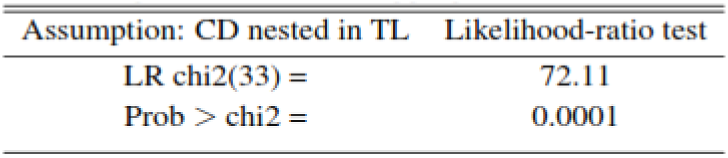
Table 17: Summarized date of irrigation blocks



Region/ Block Block Block Block	Section of work of work of work of work	Distance away from main dam Km	Min. level of water storing capacity of night storages(m^3)	Sec. canal Num.	Sec. canal leng.	Ter. canal Num.	Ter. canal leng.	Quat. canal Num.	Quat. canal leng.	Ter. Num.	Ter. leng.	Ir. size Ha.
Kudmi	3	3.238	20,006	1	0.875	7	9.0	31	47.9	3nr	4.6	373
Chihona	3	9.76	33,593	1	3.756	9	14.5	47	68.5	6nr	15.7	617
Ambo mesk	4	10.804	40,176	1	7.186	15	12.4	54	95.6	10nr	20.9	812
Adbera	4	11.0	40,747	1	8.054	15	13.1	53	90.0	5nr	4.4	803
Lasi	5	13.780	25,195	1	2.505	5	8.8	31	59.2	5nr	12.2	484
Enguti	4	11.94	19,700	1	0.779	3	7.3	26	44.7	4nr	13.4	393
Tagel wedefit	6	11.94	37,727	1	4.472	11	8.8	41	75.1	8nr	9.7	616
Bered	5	14.85	24,728	1	2.875	6	8.0	30	52.8	3nr	6.3	468
Andenet	5	17.34	40,695	1	2.641	4	6.3	33	46.1	4nr	7.9	497
Amarit	5	17.34	-	1	0.868	4	5.6	19	27.1	2nr	4.4	290
Tekel dib	6	-	44,064	1	5.53	9	12.1	53	91.4	11nr	19.6	864
Teleta	6	19.7	41,887	1	2.841	7	11.1	51	84.6	6nr	11.9	787
Total			662,518	12	42.382	95	117.0	469	783.0	67	131.0	7004

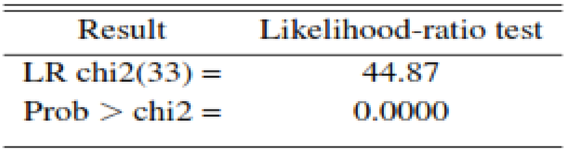
nr	/per command area
Sec.	Secondary
Ter.	Tertiary
Quat.	Quaternary
Leng.	Length
Ir.	Irrigation
Ha.	Hectars

Table 18: Optimal model and appropriate functional form



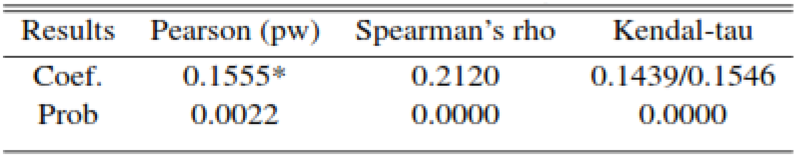
Assumption: CD nested in TL	Likelihood-ratio test
LR chi2(33) =	72.11
Prob > chi2 =	0.0001

Table 19: Determinants in inefficiency model are simultaneously zero



Result	Likelihood-ratio test
LR chi2(33) =	44.87
Prob > chi2 =	0.0000

Table 20: Land size and technical efficiency test for correlation



Results	Pearson (pw)	Spearman's rho	Kendal-tau
Coef.	0.1555*	0.2120	0.1439/0.1546
Prob	0.0022	0.0000	0.0000