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Technical Efficiency and Farm Income in Pakistan: A DEA-Based Analysis

Master's Thesis

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I have written this Research paper/Bachelor Paper independently. Any ideas or data taken from other authors or other sources have been fully referenced.

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19.05.2026

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1. INTRODUCTION -----	4
2. LITERATURE REVIEW -----	6
2.1 DEA and SFA Literature -----	8
2.2 Research Gap and Hypotheses -----	10
3. DATA AND METHODOLOGY -----	11
3.1 Data Source and Sampling -----	11
3.2 Variable Definitions -----	12
3.3 Data Cleaning Procedures -----	12
3.4 DEA Model Specification -----	13
3.5 Second-Stage Regression Model:-----	14
4. EMPIRICAL RESULTS AND DISCUSSION -----	14
4.1 Descriptive Statistics and Farm Heterogeneity -----	15
4.2 DEA Efficiency Results: CRS and VRS -----	16
4.3 Determinants of Technical Efficiency -----	18
4.4 Efficiency and Farm Income Analysis -----	19
4.5 Robustness Discussion -----	20
4.6 Summary of Findings -----	21
5. DISCUSSION AND POLICY IMPLICATIONS -----	22
5.1 Interpretation of Findings -----	22
5.2 Comparison with Previous Literature -----	23
5.3 Policy Implications -----	24
6. CONCLUSION -----	25
REFERENCES -----	26
APPENDIX -----	29
KOKKUVÕTE -----	30

ABSTRACT

This The technical efficiency level of 66 farmers of Pakistan is evaluated and the linkages between technical efficiency and household income are explored. The study, which measures efficiency using input-oriented Data Envelopment Analysis (DEA) metric, while having land, labor and fertilizer as inputs and crop production as output, shows that the efficiency gaps are significant; mean VRS efficiency is 0.5255 and mean CRS efficiency is 0.3852. The second stage robust OLS regression indicates that access to credit and farmer age positively influence efficiency, while farming experience and extension services have a negative influence on efficiency. More importantly, technical efficiency does not significantly influence household income ($p = 0.5121$); farm size and access to credit are the significant factors influencing household income. The results indicate a credit market and/or extension services productivity–welfare gap, indicating the need for institutional reforms besides agronomic improvements.

Keywords: technical efficiency, DEA, agriculture, Pakistan, farm income **JEL Codes:** Q12, C14, O13

1. INTRODUCTION

The economy of Pakistan is mostly agrarian and the majority of the rural population depends on agriculture for its livelihood and food security. Despite decades of government concentration, agricultural productivity has remained flat in comparison to the nation's growing population and food import demands. A basic question for academic research and economic policy is why farmers with similar resources perform differently.

Agriculture is the backbone of the Pakistani economy, the main driver of the country's growth, and a crucial source of living for the great majority of the rural people (Fatima et al., 2020; Murtaza & Thapa, 2017). The industry's contribution to the national accounts is significant as the sector contributes roughly 22.2% to 24% of the Gross Domestic Product (GDP) (Finance Division, 2023; GoP, 2024). Agriculture is the largest sector in terms of employment, contributing 37.4% to 42.3% of the total workforce and contributing directly to output (Finance Division, 2023; Murtaza et al., 2026). These two tasks make the sector vital for the food security of the rising population and for the delivery of necessary raw materials to local businesses, especially the textile and sugar sectors (Aslam et al., 2023).

Despite its significance, the agricultural industry in Pakistan is continually plagued by challenges such as financial limitations, restricted scope for innovative technology, and a significant 'yield gap' - the difference between potential and actual output (Aslam et al., 2023; Diro et al., 2024). Such gaps are commonly explored in the economic literature in

terms of technical efficiency in farming. Technical efficiency is a managerial skill of a producer to generate the maximum potential output, given a fixed number of inputs at the existing level of technology. The concept of technical efficiency is based on the pioneering work of Farrell (1957) (Coelli et al., 2005; Hussain et al., 1999). For the sustained growth of an agrarian economy like Pakistan, improvement in technical efficiency is an essential condition. Farms that are not on the 'best practice' frontier are technically inefficient, which means that they can produce greater output without using more physical resources (Khajjak et al., 2024).

It is worth noting the gap between technical efficiency and total productivity growth. Productivity growth can be generated through moving the frontier up (technological change) with research and development (R&D). On the other hand, technical efficiency looks at assisting farmers to move closer to the frontier through improved management and education (Bravo-Ureta et al., 2007; Murtaza et al., 2026). The latter is the topic of this study, recognising how farmers use their current resource endowments to achieve their potential output levels.

The significance of agricultural performance to Pakistan's economy is well recognized, although there is a serious lack of analysis and understanding of the micro-level agricultural performance. Much of the existing research is based on secondary or heavily aggregated data that often obfuscate individual farm activity and ignore the large heterogeneity among farmers (Oumer et al., 2022; Fatima et al., 2020). Moreover, many studies in the Pakistani context suffer from data quality issues. For example, inconsistent reporting of measurement units (e.g., confusing local maunds with kilograms) can dramatically distort efficiency estimates (Silva & Pereira, 2022).

In the case of Pakistan, the extent to which the improvement in technical efficiency contributes to the increase in household income is mainly unexplored. This paper experimentally analyzes an under-researched analytical relationship between farm level efficiency and rural welfare.

Using a carefully cleaned, farm-level dataset, this study intends to determine the technical efficiency of farmers in Pakistan and to analyze its relationship with household income. This paper uses Data Envelopment Analysis (DEA) to distinguish management performance from scale effects and identify the institutional elements that influence farm success.

In order to achieve this aim, the project investigates the following separate **research questions**:

1. What is the level of technical efficiency among the sampled Pakistani farmers?
2. Which farm-level and institutional factors are significantly associated with technical efficiency?
3. Is there a statistically significant association between a farmer's technical efficiency and their total household income?

In alignment with these inquiries, the study evaluates multiple **hypotheses**:

- **H1:** Access to formal or informal credit positively affects technical efficiency by providing the liquidity necessary for timely input application.
- **H2:** Technical efficiency is positively associated with household income, serving as a driver for rural economic growth.
- **H3:** Higher farming experience is positively associated with higher efficiency due to accumulated managerial knowledge.

The subsequent sections of this work are organized as follows. The Literature Review and Theoretical Framework analyze the theoretical foundations of production frontiers and consolidates previous empirical studies on agricultural efficiency in Pakistan and worldwide. The Data and Methodology section delineate the two-stage analytical framework, which includes input-oriented DEA and robust OLS regression, as well as the data cleansing and standardization process. The Empirical Results and Discussion section delineates the distribution of efficiency scores, the determinants of efficiency, and the income regression analysis. The Discussion and Policy Implications section contextualizes the findings amid extensive policy debates, emphasizing the institutional reforms required to modernize Pakistan's agriculture industry. The Conclusion encapsulates the principal findings, recognizes limits, and suggests directions for future research.

2. LITERATURE REVIEW

The examination of performance in agriculture is based mostly on the Production Theory that studies how farms transform a vector of inputs (x) into a vector of outputs (y) in a given technical state (Coelli et al., 2005). The theory is based on the production function, which is the maximum amount of output that can be produced from a given set of inputs. In the ideal world of the economy, all producers would be on the “best-practice” frontier, but evidence from the field shows that most farms are below that potential, for a variety of technological and managerial reasons. Agricultural performance is measured by Total Factor

Productivity (TFP) in the economic literature. This study mainly concentrates on the technical efficiency aspect of TFP the degree to which individual farmers use their existing resources efficiently as opposed to the technological progress at the frontier level. (Bravo-Ureta et al., 2007; Coelli et al., 2005).

Farrell (1957) defined Technical Efficiency (TE) as the ability of a producer to produce maximum output from a given set of inputs with the existing technology. This study employed a Frontier-based approach, given that not all the producers are at the optimal “best-practice” level. The producers found below the border are technically inefficient and can increase their production without using more resources (Khajjak et al., 2024).

This paper combines Human Capital Theory with Institutional Economics. Age and experience have indicated that the success of input application depends on the cognitive and administrative skills of the farmer (Aslam et al., 2023; Hussain et al., 1999). This is the core of human capital theory. Farmers’ access to loans and extension services, as external constraints to reach production frontiers, are understood in the contextual framework of institutional economics (Iqbal et al., 2018; Burki & Shah, 1998).

The theoretical framework of this paper consists of four different but related economic theories to shed light on the performance of farms:

Frontier Theory: This theory, originating from Farrell (1957), differentiates between the advancement of the frontier (technological advancement) and the progression toward the frontier (efficiency).

Human Capital Theory: This theory, building on the work of Schultz (1964) and Becker (1964), asserts that investments in individual farmers via education, age-related wisdom, and experience improve their "allocative ability" to handle difficult agricultural biological processes.

Institutional Economics: This idea illustrates why technological advancements do not invariably result in economic growth. It proposes that market inefficiencies, credit limitations, and inadequate infrastructure function as "transaction costs" that dissociate efficiency from household welfare.

Technical Efficiency and Productivity Concepts: It is important to distinguish between productivity and technological efficiency. A more general measure is Total Factor Productivity (TFP). TFP is defined as the ratio of total output to total input. TFP growth may be generated by two main sources. The first is the Technological Change (TC) or the shift upwards of the production frontier through innovation (e.g. new seed varieties). The second is

the Technical Efficiency (TE) or the movement of a producer towards the existing frontier by improving managerial practices.

The production frontier can be mathematically expressed as:

$$y_i = f(x_i; \beta) \cdot \exp(v_i - u_i)$$

Where:

- Y_i is the output of farm.
- $f(x_i; \beta)$ is the deterministic frontier.
- V_i represents random noise (weather, shocks).
- U_i represents technical inefficiency ($u_i \geq 0$).

Technical efficiency has been defined as a ratio of actual output to the maximum achievable output: $TE_i = y_i / f(x_i; \beta)$. In developing countries like Pakistan, where money for high-tech innovation is scarce, the cheapest way to attain national food security is by boosting agricultural output. Ali and Chaudhry (1990) suggest that efficiency improvement allows immediate gains in productivity without the longtime frames required for research and development.

2.1 DEA and SFA Literature

The literature defines two primary methodological "families" for assessing efficiency: the non-parametric Data Envelopment Analysis (DEA) and the parametric Stochastic Frontier Analysis (SFA).

Data Envelopment Analysis (DEA), popularized by Charnes et al. (1978), use linear programming to construct a piecewise linear frontier (the "envelope") around the data. The main advantage is its "data driven" character, which does not require to assume a certain functional form (such as Cobb-Douglas or Translog). Hence it is less vulnerable to specification errors. DEA is particularly useful for identifying "referent peers" – efficient farms that act as benchmarks for their less efficient counterparts. DEA is deterministic and all deviations from the frontier are attributed to inefficiency. This results in DEA being highly sensitive to outliers and measurement errors (Silva & Pereira, 2022).

Stochastic Frontier Analysis (SFA) established by Aigner et al. (1977) and Meeusen and van den Broeck (1977) it provides a composite error term ($v_i - u_i$) that differentiates statistical noise (for example, 2022 floods in Pakistan) from real managerial failure. SFA is more robust to input noise, but it relies on a predefined functional form which might lead to biased results if the chosen form does not appropriately represent the underlying technology. In this study,

we follow the upward trend of using DEA in the literature because of its flexibility. We cite the literature based on SFA in order to contextualize institutional shocks.

Determinants of Efficiency: This analysis synthesizes the complicated and frequently contradicting findings in the literature about the drivers of efficiency in Pakistan, focusing on human capital and institutional support.

Human Capital (Age and Experience): In theory, efficiency should improve with both age and experience. This means that there is a “traditionalist trap” as shown by recent empirical research by Aslam et al. (2023) and the results of the present study (positive correlation with age and negative correlation with experience). With age comes the cognitive maturity to handle risk, but too much experience without formal education can lead to “path dependency,” where farmers continue to use old practices that worked in the past but are now outmoded.

Credit Access: A strong consensus in the literature links credit access to higher efficiency by providing the liquidity necessary for timely input application, which is critical in time-sensitive cropping systems (Iqbal et al., 2018; Burki & Shah, 1998).

The Farm Size Debate: According to Burki and Shah (1998), the “inverse size-efficiency relationship” is the core of agricultural economics in South Asia and smaller farms are more efficient due to intensive family work. According to recent research, large farms take advantage of the Scale Efficiency because of their more ability to mechanize and share fixed costs (Murtaza & Thapa, 2017; Fatima et al., 2020). This study uses both CRS and VRS models to separate managerial talent from scale effects.

Extension Services: Although extension services are supposed to increase efficiency, a number of studies in Pakistan (Ullah et al., 2016; Ali et al., 2020) have reported negative or zero benefits. This suggests an “Information Gap” where the quality and relevance of advice is so low that farmers do not change their practices even after interacting with extension professionals.

This paper contributes greatly to the solution of the “Productivity-Welfare Gap.” The conventional theory of production is that increases in efficiency (TE) increase output and increases in output result in increases in wealth. This relationship, however, is controlled by the Institutional Environment as evidenced by Fatima et al., (2020).

If a farmer sees a 20% gain in efficiency, but has a 30% fall in market prices due to poor infrastructure or exploitative middlemen, their household income will remain unchanged despite their technical progress. The occurrence of “decoupling” poses a serious challenge to

Pakistan's economic development, as it suggests that telling farmers to produce more is not enough without eliminating institutional barriers for market integration.

2.2 Research Gap and Hypotheses

Many DEA research in Pakistan neglect the influence of variations in measuring units (e.g., maunds versus kilograms), which Silva and Pereira (2022) recognize as a significant source of bias in frontier estimation.

Most studies presume the correlation between efficiency and growth yet neglect to empirically validate it through a controlled regression analysis.

This study evaluates the subsequent hypotheses based on these **Hypotheses**:

- **H1:** Access to formal or informal credit positively affects technical efficiency by providing the liquidity necessary for timely input application.
- **H2:** Technical efficiency is positively associated with household income, serving as a driver for rural economic growth.
- **H3:** Higher farming experience is positively associated with higher efficiency due to accumulated managerial knowledge.

Taken together, the literature suggests that efficiency scores differ across farms primarily because of heterogeneity in human capital, access to financial resources, and the quality of institutional support. Extension results are inconsistent because the effectiveness of advisory services is highly regional and crop-specific — where guidance is outdated or poorly targeted, contact with extension agents may reinforce rather than challenge inefficient practices. Institutional conditions matter because technical performance does not automatically translate into economic welfare: market fragmentation, credit constraints, and inadequate infrastructure create transaction costs that decouple productivity gains from income improvements. These insights motivate the empirical framework developed in the following section.

This paper makes a substantial contribution to the agricultural economics in Pakistan. It provides, first, micro-level evidence of technical efficiency from a highly cleaned dataset of 66 farmers. Contrary to many studies that consider data cleaning as a trivial activity, this research prioritizes it in the technique. Local units are standardized and outliers removed to give reliable frontier estimates (Silva & Pereira, 2022).

The study also does a detailed explanatory analysis of performance determinants, separating the effects of the farmer's age (that is a proxy for maturity and cognitive insight) and agricultural experience (that may be associated with traditional, less efficient practices)

and therefore clarifying the role of the individual as the primary decision maker (Aslam et al., 2023).

Third, and most significantly, this study is linked to economic welfare empirically. The study uses a monitored regression model to analyze the link between technical efficiency and household income, observing a potential “productivity-welfare gap.” This indicates that while productivity improvements are crucial, their effect on the welfare of rural communities may be constrained by structural issues like access to finance and market integration (Fatima et al., 2020; Iqbal et al., 2018). This has important implications for policymakers because technical assistance needs to be supplemented by far-reaching institutional adjustments to attain efficiency.

3. DATA AND METHODOLOGY

3.1 Data Source and Sampling

Any frontier analysis is only as good as the source data it is based on. This research employs a cross-sectional data set of 66 agricultural families from Pakistan collected during the 2026 cropping season in the two main agricultural regions of Punjab and Sindh. The sample includes mostly farmers from Punjab (37 farmers, 56.1%), the most productive region in Pakistan in terms of agriculture, especially wheat and cotton output. and 27 farmers (40.9%) with dominant rice and sugarcane farming systems in the lower Indus basin. Two further observations from Khyber Pakhtunkhwa (KPK) have been included but are treated as part of the overall national sample, rather than a separate regional stratum. Data were acquired using a multi-stage purposive sampling approach considering the variation of farming practices in the major agricultural zones of the two provinces.

The survey was conducted through interviews using a standardized questionnaire which enabled the collection of comprehensive data on input quantities (fertilizer, labor, land), output levels and socio-economic characteristics (age, access to credit, extension contact). The sample size of 66 farmers is fewer than the sample size of the comprehensive national surveys such as Pakistan Social and Living Standards Measurement (PSLM), but it is very suitable for Data Envelopment Analysis (DEA). DEA is a non-parametric approach and is especially helpful when used on narrowly defined smaller samples where “referent peers” may be clearly identified. The sample was a mixture of smallholders (1 acre) and larger commercial farms (up to 65 acres) so as to ensure representativeness.

3.2 Variable Definitions

To deliver a precise estimate of the production frontier, the variables were categorized into two groups: those utilized for constructing the DEA frontier and those employed as environmental factors in the second-stage regression analysis.

In accordance with traditional production theory, the study delineates one principal output and three essential inputs for the DEA model. Total Production (Output) quantified as the aggregate mass of crops gathered in kilograms (kg). The average production for the sample was 24,027.32 kg, with a considerable range from 80 kg to 120,000 kg. Farm Size (Input 1) aggregate land area utilized for cultivation, quantified in acres. Land constitutes principal fixed factor in Pakistani agriculture. Fertilizer (Input 2) Total kilograms (kg) applied were measured. This signifies the principal chemical expenditure incurred by farmers to enhance yields. Labor (Input 3) quantified by the total count of individuals (including both family and paid labor) involved in the production process.

The second-stage regression employs five explanatory variables. Farmer age (mean 37.08 years) serves as a proxy for cognitive maturity. Farming experience (mean 14.15 years) measures years as primary decision-maker. Credit access is a binary variable (1 if the farmer accessed formal or informal credit). Extension services is a binary variable indicating contact with agricultural advisory agents. Finally, household income (mean PKR 3,752,442) serves as the dependent variable in the welfare regression.

3.3 Data Cleaning Procedures

DEA is a deterministic model, indicating it is highly sensitive to outliers; a single erroneous observation can alter the entire "best-practice" frontier and skew the efficiency scores of all other units.

I recognized and eliminated instances indicating "unrealistic" input-output ratios, such as farms exhibiting 0% output despite substantial fertilizer and labor utilization. A notable problem in Pakistani research is the combination of local units (maunds) with international units (kilograms). In accordance with the advisories of Silva and Pereira (2022), all production metrics were normalized to kilograms utilizing a conversion factor of 1 maund = 40 kg.

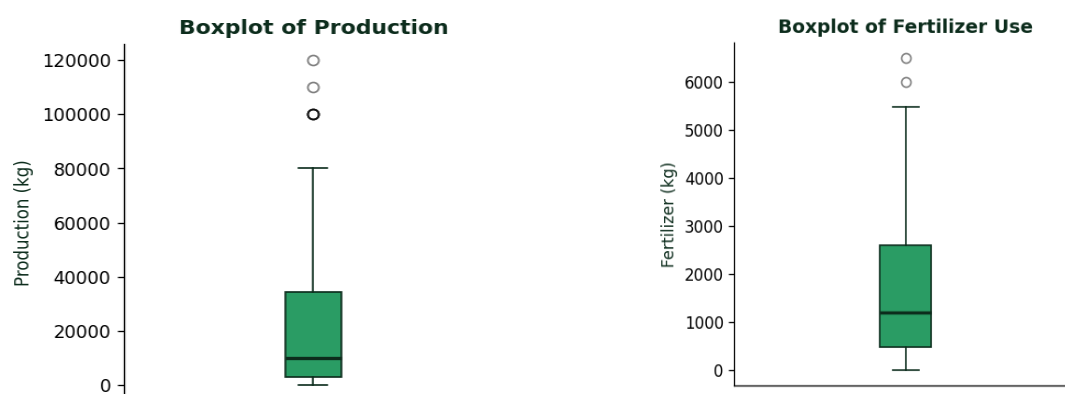


Figure 1 & 2: Boxplot of crop production (kg), Fertilizer (kg) outlier detection

Source: Author's own calculations from survey data (2026)

Figure 1 reveals several extreme observations substantially above the interquartile range. These were individually verified against the original survey responses and either corrected or removed to prevent the formation of an artificial frontier. Figures 1 and 2 identify extreme values in both production and fertilizer use. These were subject to the verification and exclusion procedure described above.

3.4 DEA Model Specification

The present research adopts an input-oriented Data Envelopment Analysis (DEA) model under the assumptions of Constant Returns to Scale (CRS) and Variable Returns to Scale (VRS). Second-stage regression analysis was performed in Stata and Python (statsmodels module) with heteroscedasticity-consistent robust standard errors (HC3) applied to all OLS results. DEA computations were performed using the DEAP 2.1 software package developed by Coelli (1996).

I adopt an input-oriented approach, as farmers in Pakistan have more control over their resource allocation (buying fertilizer, employing labor etc.) than over their final output, which is affected by external weather disruptions. The model finds the potential drop of inputs that will enable the farm to stay on the frontier with the same level of output.

The CRS model (Charnes, Cooper, and Rhodes) posits that a variation in inputs leads to a corresponding variation in outputs. This yields the Overall Technical Efficiency (OTE). Many farms in Pakistan encounter geographical fragmentation or financial limitations, preventing them from functioning at an ideal scale. Consequently, we also utilize the VRS model (Banker, Charnes, & Cooper), which incorporates a convexity constraint ($\sum \lambda = 1$) to differentiate Pure Technical Efficiency (PTE) from scale effects.

The “dimensionality problem”, where the number of inputs/outputs is too large relative to the number of decision-making units (DMUs), is a major concern in DEA, leading to a large number of units being automatically labeled as “efficient.” This study adheres to the “Rule of Thumb” proposed by Cooper et al. (2007) that the number of DMUs should be at least three times the total number of inputs and outputs ($66 > 3 \times (3 + 1)$). The model has a high discriminating power with 66 farmers and 4 production variables.

3.5 Second-Stage Regression Model:

The study used a two-stage methodology to examine the factors contributing to inefficiency, employing PTE scores obtained from the DEA-VRS model as the dependent variable in a Robust OLS analysis.

The model is defined as:

$$\text{Efficiency (y)} = \beta_0 + \beta_1 \text{ Credit} + \beta_2 \text{ Age} + \beta_3 \text{ Experience} + \beta_4 \text{ Extension} + \beta_5 \text{ FarmSize} + \epsilon_i$$

Robust Standard Errors are used to account for probable heteroscedasticity and the bounded character of the DEA scores (between 0 and 1). Some academics recommend that a Tobit model should be used for bounded data. However, a recent study (Simar & Wilson, 2007) shows that in two-stage DEA designs, when the distribution of scores is not too strongly suppressed at the boundaries, OLS with robust errors is often more stable.

The endogeneity of credit access is a basic theoretical issue considered here. More productive farmers may be predisposed to seek and secure finance rather than credit providing the spur to efficiency. To deal with this, the data are treated as correlations and not as a clear causal relationship. Moreover, the regression also evaluates the "Productivity-Welfare Gap" through a secondary regression in which Log (Income) is the dependent variable, allowing an investigation of the association between efficiency ratings and real economic growth at the farm level.

Methodological Limitations:

In contrast to Stochastic Frontier Analysis (SFA), Data Envelopment Analysis (DEA) does not distinguish random noise, such as the 2022 floods, from genuine managerial failure. Thus, the reported efficiency disparities may be somewhat exaggerated in the presence of environmental shocks. The use of cross-sectional data indicates that the findings represent a particular moment and are incapable of capturing long-term "learning-by-doing" impacts or seasonal variations. Although 66 observations meet the mathematical criteria for DEA, the findings should be interpreted as "representative of the sampled area" rather than a conclusive national average for all of Pakistan.

4. EMPIRICAL RESULTS AND DISCUSSION

The study is organized in a manner that a full description of the characteristics of the sample is given first followed by the non-parametric evaluation of technical efficiency scores. The paper also analyses the socio-economic and institutional determinants of these efficiency levels, and finishes with an analysis of the relationship between technical performance and farm income.

In this analysis, an obvious distinction is maintained between technical efficiency (the ability to produce at the frontier) and productivity growth (the movement of the frontier itself). The combination of both of these concepts can lead to misleading policy conclusions (Coelli et al., 2005; Silva & Pereira, 2022).

4.1 Descriptive Statistics and Farm Heterogeneity

First, the analysis includes an assessment of the descriptive statistics of the variables used in the Data Envelopment Analysis (DEA) and subsequent regression models. The Table 4.1 (extracted from “Descriptive Statistics – Farmers Survey Dataset” in the Excel results) shows some heterogeneity in resource endowments, output performance and human capital within the sample.

Table 4.1

Descriptive Statistics of Key Variables (n=66)

Variable	Mean	Std. Dev.	Min	Max
Age (years)	37.08	11.21	20	65
Experience (years)	14.15	9.03	1	37
Farm Size (acres)	23.07	17.35	1	65
Labor (workers)	2.33	1.46	0	8
Fertilizer (kg)	1,770.94	1,710.34	3	6,500
Production (kg)	24,027.32	31,834.16	80	120,000
Income (PKR)	3,752,442.42	3,685,651.66	3,200	15,000,000

Source: Author's own calculations from survey data (2026)

The descriptive data suggests a big difference in the level of output. The average is 24,027kg with a standard deviation of 31,834 which is larger than the mean. The distribution is highly skewed.

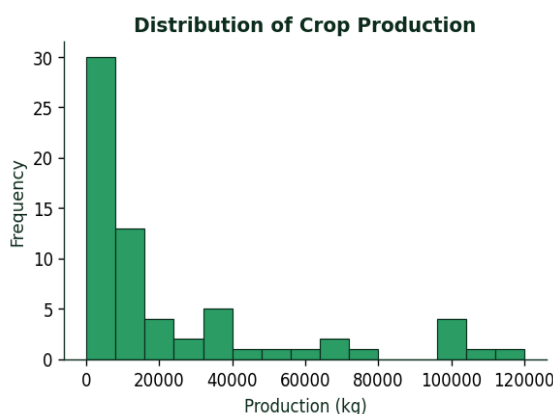


Figure 3: Distribution of crop production (kg), n = 66 farmers

Source: Author's own calculations from survey data (2026)

This is visually supported by the skewness of the "Distribution of Crop Production" histogram, which shows a significant concentration of low-yield subsistence farming

operations and a small tail of high-performing commercial units. This distribution confirms the use of DEA, which is a non-parametric method that does not require the normalcy assumption and is designed to deal with such heterogeneity by choosing “best-practice” peers (Silva & Pereira, 2022; Fatima et al., 2020).

Input usage follows a similar trend. The farm sizes are from 1 acre to 65 acres that highlight the present land fragmentation problems in Pakistan (Fatima et al., 2020). The large range of fertilizer use (3 kg to 6,500 kg) suggests that some farmers are not applying enough nutrients because they cannot afford it, and some are over-applying and wasting resources, which is a common observation in the Punjab “rice-wheat” systems (Shafiq & Rehman, 2000; Aslam et al., 2023).

The sample comprises a middle-aged workforce, with a mean age of 37 years and an average experience of 14 years. Nevertheless, the "Credit Access Distribution" chart indicates that hardly a minority of the surveyed farmers (17 out of 66) had access to institutional or formal loans.

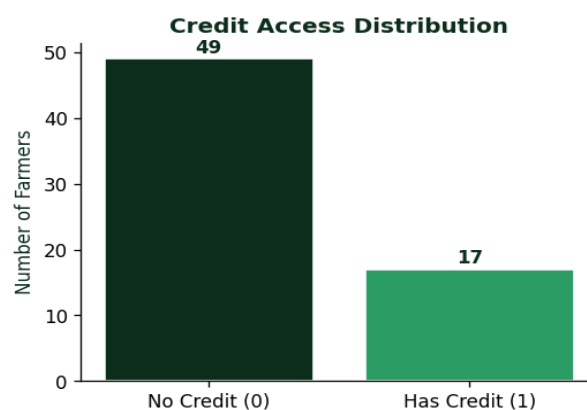


Figure 4: Credit access distribution among sampled farmers, n = 66

Source: Author's own calculations from survey data (2026)

Figure 4 illustrates the severe financial exclusion in the sample — only 25.8% of farmers had any access to credit, which partly explains the wide efficiency gap documented in Section 4.2. The deficiency in financial liquidity constitutes a significant impediment that likely hinders numerous farmers from attaining the output frontier (Iqbal et al., 2018; Fatima et al., 2020).

4.2 DEA Efficiency Results: CRS and VRS

Technical efficiency was assessed utilizing an input-oriented DEA model based on both Constant Returns to Scale (CRS) and Variable Returns to Scale (VRS) assumptions. The selection of input-orientation illustrates the conditions of the Pakistani agricultural industry, wherein farmers possess greater control over resource allocation (land, labor, fertilizer) than

over their end production, which is frequently influenced by external environmental factors (Murtaza & Thapa, 2017).

Table 4.2

Summary of Efficiency Scores

Efficiency Measure	Mean Score	Std. Dev	Min	Max
Overall Technical Efficiency (CRS)	0.3852	0.3422	0.0015	1.000
Pure Technical Efficiency (VRS)	0.5255	0.3249	0.0748	1.000
Scale Efficiency (SE)	0.6299	0.3366	0.0090	1.000

Source: Author's own calculations using DEAP 2.1.

The data indicate that Pakistani farmers are operating well below their potential. The average CRS efficiency score of 0.3852 implies that the farmers are working at 38.5% efficiency on average, compared to the most efficient units in the sample. This is a considerable “efficiency gap” implying that potentially the same level of production could be achieved with just 38.5% of the current number of inputs if all farmers were to operate at the frontier (Shafiq & Rehman, 2000).

The average efficiency under the Variable Returns to Scale (VRS) assumption that isolates the managerial performance from the scale effects is 0.5255 (Pure Technical Efficiency). Even with the CRS score being exceeded, it still implies that 47.5% of the input resources are wasted owing to managerial or technical incompetence. Only 19.7% of the farmers surveyed were found to be fully efficient (score = 1.000) based on the VRS criteria. (Fatima et al., 2020).

The average Scale Efficiency (SE) of 0.6299 implies that about 37% of the total observed inefficiency is related to farmers operating at an inappropriate scale rather than poor management. Empirical evidence shows that only 28.8% of farmers are scale efficient and the remaining are either operating under Increasing Returns to Scale (IRS) or Decreasing Returns to Scale (DRS), usually due to land fragmentation (Javed et al., 2011; Fatima et al., 2020).

As confirmed by the dimensionality check in Section 3.4.3, the sample satisfies the Cooper et al. (2007) rule of thumb, ensuring the observed inefficiency reflects genuine performance rather than a mathematical artefact.

The "Distribution of Pure Technical Efficiency (VRS)" (shown in Figure 4.1) demonstrates a bimodal-leaning distribution:

< 0.50 (Very Low Efficiency): 48.5% of farmers.

0.50 – 0.89 (Low to Moderate): 31.8% of farmers.

≥ 0.95 (Fully Efficient): 19.7% of farmers.

Approximately 50% of the sample functions at an efficiency level under 50%. This pronounced disparity indicates a "dual economy" in the agricultural sector: a limited elite of farmers establishing the technological frontier, alongside a substantial contingent of subsistence farmers ensnared in low-efficiency production cycles (Aslam et al., 2023).

4.3 Determinants of Technical Efficiency

The study employed a **Second-Stage Robust OLS Regression** to analyze the determinants of the significant variance in efficiency, regressing the VRS efficiency scores against socioeconomic and institutional characteristics.

Table 4.3

Determinants of Technical Efficiency (DEA-VRS), Robust OLS

Variable	Coefficient	Robust Std. Error	t-Statistic	p-Value	Significance
Constant	0.3364	0.2022	1.6639	0.0961	*
Farm Size (acres)	-0.0031	0.0031	-1.0083	0.3133	n.s.
Credit Access (1 = Yes)	0.2362	0.0976	2.4192	0.0156	**
Labor (workers)	0.0015	0.0455	0.0337	0.9731	n.s.
Age (years)	0.0197	0.0085	2.3193	0.0204	**
Farming Experience (years)	-0.0291	0.0100	-2.9068	0.0037	***
Extension Services (1 = Yes)	-0.2091	0.0873	-2.3940	0.0167	**

Source: author's calculations

$R^2 = 0.3715$ / $Adjusted R^2 = 0.3075$ / F -statistic = 6.6025 / $Prob(F) = 0.000$ / $n = 66$.

Note. Robust standard errors (HC3). Dependent variable: VRS Technical Efficiency. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$; n.s. = not significant.

The Role of Credit Access and Endogeneity Credit Access are a positive and statistically significant factor that influences efficiency ($p=0.0156$). A farmer with access to funding will have an efficiency score 0.236 greater than a farmer without access to financing. This suggests that liquidity allows for "timely use" of inputs to purchase seeds and fertilizer just when the crop requires them, critical for keeping output at the frontier (Iqbal et al., 2018; Burki & Shah, 1998).

This suggests reverse causality in that more efficient farmers are more likely to seek and secure loans. The study uses cross-sectional data, and hence this conclusion should be

interpreted as a robust positive association, but not conclusively causality. Whatever the direction of causality, the association highlights the importance of financial systems to agricultural prosperity.

An interesting finding is that the determinants of human capital impact differently. The age of farmers is positively connected to efficiency ($p=0.0204$), presumably suggesting managerial maturity and the cognitive aptitude needed to manage environmental risks (Aslam et al., 2023).

On the other hand, Farming Experience has a very negative effect ($p=0.0037$). The contradiction that age promotes efficiency while accumulated experience reduces it is known as the “traditionalist trap” and is discussed in Section 5.1.3.

Before continue, a word about multicollinearity is in order. Farmer Age and Farming Experience are strongly correlated ($r = 0.88$). The calculated Variance Inflation Factor (VIF ≈ 4.43 (calculated from $1/(1 - 0.88^2)$) is less than the traditional criterion of 10, indicating that multicollinearity is present but its effect is not severe enough to undermine the conclusions. Both variables are retained because they represent theoretically distinct constructs: Age represents cognitive maturity and risk management capacity, whereas Experience represents years of accumulated practice that may or may not include contemporary approaches. The diverging indications are statistically significant, logically interpretable and not artifacts of collinearity.

A disturbing conclusion is the negative and statistically significant association between Extension Services and efficiency ($p=0.0167$). In principle, contact with extension agents should move farmers towards the frontier. The negative sign implies that the existing extension services in the sampled areas are either not reaching the most productive farmers or providing outdated, irrelevant advice (Ullah et al., 2016; Ali et al., 2020). The “extension gap” is a reminder of the need to modernize the advising system, possibly using ICT-based platforms (Aslam et al., 2023).

4.4 Efficiency and Farm Income Analysis

A second regression was conducted with Household Income as the dependent variable to assess the impact of technical performance on overall economic welfare.

Table 4.4

Income Regression: Effect of Technical Efficiency on Farm Income

Variable	Coefficient	Robust Std. Error	t-Statistic	p-Value	Significance
Constant	13.6679	0.9699	14.0922	0.0000	***

DEA Technical Efficiency (VRS)	-0.6363	0.9706	-0.6556	0.5121	n.s.
Farm Size (acres)	0.0440	0.0104	4.2274	0.0000	***
Credit Access (1 = Yes)	1.1430	0.4018	2.8450	0.0044	***
Farming Experience (years)	-0.0160	0.0317	-0.5062	0.6127	n.s.

Source: author's calculations

$R^2 = 0.3455$ / $Adjusted R^2 = 0.3026$ / F -statistic = 29.9434 / $Prob(F) = 0.000$ / $n = 66$.

Note. Robust standard errors (HC3). Dependent variable: $\text{Log}(\text{Income})$. *** $p < 0.01$; n.s. = not significant.

The major finding of this research is that there is no statistically significant effect of Technical Efficiency on household income ($p=0.5121$). This points to a large scale “decoupling” of technical skill from economic well-being. Technical efficiency of a farmer shows the optimal use of limited resources; however, the farmer can be inefficient in terms of revenue due to operating on a small scale or facing severe market constraints (Fatima et al., 2020; Murtaza & Thapa, 2017).

On the other hand, Farm Size and Credit Access are shown highly important in determining income ($p<0.01$). This suggests that in the present Pakistani agricultural setting, wealth is related more with land assets and financial capital than with the technical management of resources (Burki & Shah, 1998; Murtaza et al., 2026). To turn technical efficiency into income growth, institutional reforms are needed to improve market access and price stability.

4.5 Robustness Discussion

The results should be analyzed judiciously due to the sample size and methods employed. Traditional OLS can sometimes give skewed estimates because the DEA scores are confined between 0 and 1. To remedy this we use Robust Standard Errors which allows for any heteroscedasticity and ensures p-values are not too inflated. Moreover, the second-stage interpretations are taken to be correlational rather than causative, acknowledging the inherent limitations of cross-sectional micro-data (Oumer et al., 2022).

The sample of 66 farmers is statistically enough for DEA but it is a micro level representation. Hence policy ideas are couched in cautious terms. The findings reveal that the existence of institutional bottlenecks in lending and extension is common but generalizations at the national level should be made only in conjunction with larger panel datasets (Fatima et al., 2020).

4.6 Summary of Findings

The empirical analysis produces three main conclusions, accompanied by clear assessments of the study's predetermined hypotheses.

Results of the paper:

H1 (Access to credit significantly influences technological efficiency): Affirmed. Access to credit is positively correlated and statistically significant ($\beta = 0.2362$, $p = 0.0156$), indicating that financial liquidity facilitates prompt input use and is a crucial determinant of agricultural success.

H2 (The correlation between technical efficiency and household income is positive): Rejected. The income regression indicates that technical efficiency exhibits no statistically significant correlation with log household income ($\beta = -0.6363$, $p = 0.5121$). This validates the "productivity-welfare gap" recognized in the literature.

H3 (A greater level of farming expertise correlates positively with efficiency): Rejected. Farming experience exhibits a negative and statistically significant correlation with efficiency ($\beta = -0.0291$, $p = 0.0037$), indicating that accrued experience devoid of contemporary instruction results in a "traditionalist trap" rather than improved performance.

Table 4.5

summarizes the key quantitative outcomes of this chapter.

Finding	Value
Mean VRS Technical Efficiency	0.5255
Mean CRS Technical Efficiency	0.3852
Mean Scale Efficiency	0.6299
Farms below 50% efficiency (VRS)	48.5% (32 farms)
Fully efficient farms — VRS (≥ 0.95)	19.7% (13 farms)
Fully efficient farms — Scale (≥ 0.95)	28.8% (19 farms)
Credit access effect on efficiency (β)	+0.2362 ($p = 0.0156$)
Age effect on efficiency (β)	+0.0197 ($p = 0.0204$)
Farming experience effect on efficiency (β)	-0.0291 ($p = 0.0037$)
Extension services effect on efficiency (β)	-0.2091 ($p = 0.0167$)
Technical efficiency effect on income (β)	-0.6363 ($p = 0.5121$)
Farm size effect on income (β)	+0.0440 ($p = 0.000$)
Credit access effect on income (β)	+1.1430 ($p = 0.0044$)

Source: author's calculations

Note. All efficiency scores are bounded between 0 and 1. Regression coefficients are from robust OLS with HC3 standard errors. Dependent variable for efficiency model: VRS technical efficiency score. Dependent variable for income model: Log(household income in PKR). $n = 66$.

The mean VRS efficiency is 0.5255 (CRS: 0.3852). Credit access increases efficiency by 0.236 units ($p = 0.0156$) and farming experience reduces it by 0.029 units per year ($p = 0.0037$). Technical efficiency shows no significant association with log household income ($p = 0.5121$), while farm size ($p = 0.000$) and credit access ($p = 0.004$) are the primary income drivers. Full interpretation of these findings is provided in Chapter 5.

5. DISCUSSION AND POLICY IMPLICATIONS

5.1 Interpretation of Findings

The empirical results of this study evaluate the technological status of the agriculture sector of Pakistan at micro level critically and challenge some of the conventional assumptions. The examination of these findings is structured around three main themes: the size of the “efficiency gap”, the institutional factors of managerial success, and the large “productivity-welfare gap” that occurs when technological achievement does not lead to economic gain.

The Efficiency Gap and Managerial Heterogeneity: The mean Pure Technical Efficiency (VRS) is 0.5255 and the Constant Returns to Scale (CRS) efficiency is 0.3852. This implies that the sampled farmers are operating at about fifty percent of their optimal capacity. This suggests a large “yield gap” that is not due to a lack of physical resources but an inadequacy in the administrative translation of inputs into outputs. It means that, theoretically, about 47.5% of the input resources land, labor and fertilizer are effectively squandered.

The bimodal distribution of the efficiency ratings indicates a “dualistic” agricultural economy within the sample. A small elite of farmers (19.7%) is working at the ‘best-practice’ frontier, presumably with the latest agronomic knowledge and optimally planned resource allocations. Conversely, some 48.5% of the sample is below the 0.50 efficiency level. This distribution shows that the biggest hurdle to the growth of agriculture in Pakistan is not the dearth of “new” technology, but the wide gulf between the use of existing technology by various classes of farmers.

Institutional Drivers and the Endogeneity of Credit: The regression analysis reveals that Credit Access is a significant determinant of efficiency ($p=0.0156$). As established in chapter 4, credit provides the liquidity required for timely input application a critical factor in Pakistan's time-sensitive cropping systems where delayed fertilizer application causes irreversible yield losses.

There may be a “virtuous cycle” whereby more efficient and productive farmers are perceived as less risky borrowers by official and informal lenders, resulting in increasing access to finance. If this is true, access to credit may be both a consequence of efficiency as

well as a generator of it. The strong correlation suggests a basic relation between the financial system and the production frontier independent of the causal direction. This virtuous cycle is not directly tested in the present study, as the cross-sectional design does not permit causal identification; the association between credit and efficiency should therefore be interpreted as correlational.

The Paradox of Human Capital: The contrasting effects of Age (+) and Experience (-) give a clear picture of the individual farmer's engagement. The positive effect of age probably reflects cognitive knowledge and the maturation of risk management needed to deal with the biological uncertainties inherent in agriculture. The negative effect of farming knowledge ($p=0.0037$) suggests a "traditionalist trap." Experienced farmers who have not had a modern education may continue to use traditional practices that were effective during the Green Revolution but are no longer appropriate for today's depleted soils and changing environment.

The Productivity-Welfare Gap: The Income Decoupling; The most important finding for national development is that there is no statistically significant effect of Technical Efficiency on household income ($p=0.5121$). This confirms a "decoupling" between technical success and economic well-being. Efficiency helps a farmer to make the best use of resources, but actual incomes are controlled by Farm Size ($p=0.000$) and Credit ($p=0.004$). This suggests that in the current institutional scenario of Pakistan, the increase in the economy to the rural households is due to ownership of land and the availability of liquid financial assets rather than technical management of crops. A farmer can be "perfectly efficient" on an acre of land and still be poor. This means that just improving technology is not enough to drive economic growth unless structural challenges such as land scale and market integration are addressed.

5.2 Comparison with Previous Literature

A comparison of these findings with earlier research on Pakistani agriculture underscores the influence of methodological rigor and evolving institutional dynamics.

The average efficiency scores of this study are lower than those of prior major studies. Aslam et al., (2023) reported average efficiencies of 0.87 for rice and 0.85 for wheat in Punjab however Khajjak et al., (2024) showed efficiency of 87% for wheat in Sindh. The substantially lower scores we have found (VRS 0.5255) are the result of aggressive data cleansing and unit standardization processes. This study sets a more realistic and conservative norm by carefully converting all local "maunds" into kilograms and removing outliers that could lead to an "artificial" or unreachable barrier. Given the alerts highlighted by Silva and

Pereira (2022), it seems that various previous research could have overestimated efficiency by ignoring the differences in measurement units.

The negative impact of Extension Services This study has found a contrary result ($p=0.0167$) as compared to Murtaza and Thapa (2017) who found extension interaction as advantageous for apple growers. However, our results support the claims of Ali et al. (2020) and Ullah et al. (2016) who argue that the quality of information is often insufficient, making interactions with agents unproductive for better management. This discrepancy is a reflection of the highly regional and crop-specific nature of the efficacy of the Pakistani extension system. The advising services in the examined areas are not providing the required “frontier-shifting” advice for modernization.

This analysis finds little association between **farm size** and technical efficiency, in contrast to the “inverse size-efficiency” relationship highlighted in earlier work by Burki and Shah (1998). The importance of farm size in the revenue model (Table 4.4) is in line with the results of Fatima et al., (2020) and Murtaza and Thapa (2017). This means a change in Pakistani agriculture where small farms could have administrative competence similar to large farms but are losing the economic competition due to low Scale Efficiency (mean=0.6299).

5.3 Policy Implications

Several specific policy initiatives are offered based on empirical evidence.

Modernizing Extension through ICT-Based Platforms: The negative relationship of present extension contacts and efficiency shows that the traditional method of door-to-door advising is not effective. The results suggest the need for a change to an Information and Communication Technology (ICT) based extension. Mobile applications that provide real-time, location-specific advice on fertilizer and pest management could bypass the bureaucratic inefficiency of the current system and appeal to a younger generation of farmers more willing to accept modern technology.

Financial Reform and Credit Liquidity: Since credit plays an important role in promoting efficiency and increasing income, the results suggest that the government should focus on the expansion of official micro-credit programs. Interest-free or subsidized loans with less collateral would help smallholders to avoid the current dependence on informal lenders that charge high interest rates and would diminish the reinvestment potential of the rural economy. Such steps are crucial to ensure that the “virtuous cycle” of loans and efficiency is available to all farmers, not only the rich landowners.

Addressing Scale Inefficiency and Land Consolidation: The main reason for technical loss is the split of land into inefficient plots. This is evidenced by the largescale inefficiency (loss of 37%). The results may imply a need for initiatives that promote cooperative farming or land consolidation. When smallholders are able to operate at an appropriate size of production, they can take advantage of automation and access the scale efficiencies that are currently available exclusively to huge commercial firms.

Closing the Productivity-Welfare Gap: The independence of efficiency and income implies that economic improvement cannot be made by technological direction alone. The results imply that structural adjustments in the market are necessary for technical progress to result in welfare gains. That means better market infrastructure, such as cold storage and transportation networks, and formalizing agricultural contracts that guarantee farmers get fair farm-gate pricing for their increased output.

Robustness and Methodological Caveats: It is important that these policy implications are derived from a DEA-based analysis which suffers from the “dimensionality problem”. But the sample size of 66 units is well beyond the threshold for our four-variable model and the reported inefficiency is statistically solid. In addition, because of its deterministic nature, DEA cannot distinguish between random noise and inefficiency. The observed ‘efficiency gap’ should be taken as a conservative upper bound of managerial potential, recognizing that environmental shocks also affect the measured yields.

The statistics imply that technical efficiency in Pakistan is not only an agronomic problem but an institutional and systemic one. But the benefits of improved technical performance can only be achieved if the government removes the basic constraints on loan markets, extension services and market integration which are critical for growth.

6. CONCLUSION

The purpose of this paper is to provide a detailed review of the technological efficiency and its economic implications in the agriculture sector of Pakistan. The study used a carefully constructed micro-level dataset of 66 farmers to go beyond the aggregate data normally used in regional studies to explore the individual managerial activities that define the production frontier. The main purpose was to test whether technical efficiency defined as the ability of a producer to obtain maximum output from a given set of inputs was a significant factor of economic welfare of rural people.

The analytical procedure, based on the two-stage DEA and robust regression framework, reveals a sector with significant technology and scale inefficiencies. The key result of this study is the observation of a ‘productivity-welfare gap’. Theoretically, technical

efficiency is a necessary condition for growth, although the empirical evidence shows a clear distinction between technological success and household income, which suggests that institutional and structural constraints have prevented production from translating into wealth.

The research findings indicate that for technical efficiency to significantly enhance economic growth in Pakistan, the findings suggest it may be beneficial for policymakers to move beyond fundamental agronomic guidance to implement structural and institutional reforms. Priority areas could include the expansion of formal loan access to enhance liquidity and the reform of the extension system potentially transitioning to ICT-based delivery to circumvent conventional bureaucratic inefficiencies and engage a younger demographic of farmers. By tackling the fundamental "productivity-welfare gap," these reforms could help farmers contribute more meaningfully to national economic growth.

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APPENDIX

1. Farmers Survey Questionnaire (Responses).xlsx

<https://docs.google.com/spreadsheets/d/1aCvrOKvZWfHToUI0KGNYQzMFVIA7Gddc/edit?usp=sharing&ouid=106836018506466318246&rtpof=true&sd=true>

KOKKUVÕTE

Tehniline efektiivsus ja põllumajandustulu Pakistanis: DEA-põhine analüüs

Käesolev uurimistöo hindab 66 Pakistani põllumajandustootja tehnilist efektiivsust ning uurib selle seost kodumajapidamiste sissetulekuga. Kasutades sisendisuunalist mitteparameetrilise andmerajaanalüüsi meetodit (Data Envelopment Analysis, DEA) DEA on mitteparameetriline efektiivsuse hindamise meetod, mida kasutatakse otsustusüksuste suhtelise tehnilise efektiivsuse mõõtmiseks.

Meetod võimaldab võrrelda sisendite ja väljundite vahelist seost ning hinnata tootjate efektiivsust parimate praktikate suhtes. nii konstantse (CRS) kui ka muutuva (VRS) mastaabiefektiivsuse eelduse alusel — maa, tööjõud ja väetised sisenditena ning põllumajandustoodang väljundina — tuvastas uuring märkimisväärsed efektiivsuslõhed. Keskmine VRS põhine tehniline efektiivsus on 0,5255 ja keskmine CRS põhine efektiivsus 0,3852, mis tähendab, et enamik põllumehi tegutseb oluliselt allpool oma potentsiaalset tootlikkuse taset.

Teises etapis läbi viidud robustne lihtne vähimruutude regressioon näitab, et ligipääs laenudele ja põllumajandustootja vanus on seotud efektiivsusega positiivselt, samas kui töökogemus ja nõuandeteenuste kasutamine on efektiivsusega negatiivselt seotud. Kõige olulisem leid on see, et tehniline efektiivsus ei avalda kodumajapidamise sissetulekule statistiliselt olulist mõju ($p = 0,5121$). Sissetulekut määravad peamiselt talumajapidamise suurus ja ligipääs laenudele, mitte ressursside tehnilise juhtimise kvaliteet.

Need tulemused paljastavad olulise tootlikkuse ja heaolu vahelise lõhe ning viitavad sellele, et ainult agronoomilised parendused ei ole piisavad põllumajandustootjate majandusliku heaolu tõstmiseks. Tehnilise arengu muutmiseks sissetulekute kasvuks on vaja samaaegselt reformida laenuturge ning ajakohastada nõuandeteenuseid.

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