Journal of Agricultural Development and Policy, 2024
Volume 34, No. 2, 245-251
https://doi.org/10.63066/23220457.34.2.008

NAAS - 4.34
UGC CARE List Journal

Determinants of Farm Technical Efficiency in Punjab Agriculture: Findings from a Household Survey

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Abstract

The present study assesses farm technical efficiency in the Punjab state using large household-level data. The results show that the mean farm efficiency is around 80 per cent implying that the farms can raise output by 20 per cent without additional resources through efficient use of existing inputs and technology. The main factors influencing farm efficiency include farm size, as small, semi-medium, and medium holdings exhibit greater efficiency compared to marginal farms. Households primarily dependent on crop cultivation as their main income source also tend to be more efficient, indicating that concentrated investments in farming improve resource allocation. Furthermore, there are clear regional differences, with farms in the central and south-western zones outperforming those in the sub-mountainous areas, where smaller farm sizes, lower productivity, and limited input use hinder efficiency. Targeted interventions focused on improving resource use, irrigation access, and regional support systems are vital for enhancing farm technical efficiency in Punjab. Hence, agricultural policies should promote extension services to educate farmers on optimal cropping practices.

Keywords: Technical efficiency, Stochastic frontier, Tobit model, Punjab, NSSO data

JEL Classification: C67, D24, Q12, Q15

Introduction

For more than thirty years since the start of the green revolution, the economy of Punjab has continued to be a showcase for economic growth and prosperity among Indian states (Singh, 2013). The farmers in Punjab were responsible for guiding the nation from food scarcity to food sustainability, while the state spearheaded the green revolution (Kaur and Singh, 2020). Improved technology along with conducive government policies transformed the agrarian economy of Punjab. Despite making up only 1.5 per cent of India's total land area, the state provides the central government with 31.2 per cent of the country's rice and 46.2 per cent of wheat (Singh et al., 2024).

Strategic focus on rice and wheat production backed by a package of subsidized modern inputs, procurement and price support policies, and extension services led to an unprecedented shift in paddy area relative to other Kharif crops. With the limited scope of agricultural land expansion, Punjab experienced an intensified cropping system with an unprecedented increase in cropping intensity from 133.77 per cent in 1966 to 189.9 per cent in 2021 due to farmers were enticed to increase the acreage devoted to wheat and paddy since their gross returns were consistently higher than those of other crops (Vatta and Budhiraja, 2020). Punjab's agricultural portfolio has shifted away from low-input crops like bajra and maize and toward pulses like mung beans, urad, and gram. This has resulted in an overuse of pesticides and fertilizers as well as an overuse of groundwater resources for irrigation. Such increased use of agricultural inputs with a less than comparable sluggish rise in output leads to falling profitability, ultimately affecting the efficiency of farms.

Several studies on farm efficiency have been conducted in India (Bhat and Bhat, 2014; Kalra et al., 2015; Jain et al., 2016; Bhattacharyya and Mandal, 2016; Murali and Puthira, 2017; Nandy and Singh, 2020), including research specific to Punjab (Kaur et al., 2010; Sekhon et al., 2010; Singh, 2012; Bhoi et al., 2017). However, no study in Punjab has utilized household-level data from the National Sample Survey Office (NSSO), which is among the most comprehensive datasets for agricultural households in India. This paper addresses this gap by using the latest NSSO data to analyze farm technical efficiency in Punjab and identify the socio-economic factors influencing it.

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Data Sources and Methodology

The study utilizes household-level data from the latest round of the 'Situation Assessment Survey of Agricultural Households,' conducted by the National Sample Survey Office (NSSO), Government of India. The data were collected for the agricultural year 2018-19 in two visits (visit-1: July-December 2018 and visit-2: January-June 2019), covering a total of 58,035 households across India. For Punjab state, the dataset includes information from 1,187 households, of which 889 are classified as agricultural households. After a thorough data-cleaning process and the removal of outliers, 746 agricultural households were retained for further analysis in this study.

Analytical Framework

Estimation of technical efficiency:

The stochastic frontier production approach was used to analyze farm technical efficiency in Punjab. The technical inefficiency of an individual farm was estimated using the stochastic frontier production function proposed by Aigner et al. (1977) and Meeusen and Van den Brock (1977).

The actual production function can be written as:

$Y_i = f(X_i; \beta) \exp(-u_i)$

where,

Y_i = The actual output for the i^{th} production unit

X_i = Vector of inputs

β = Vector of parameters that describe the transformation process

f(.) = The frontier production function

u_i = One-sided (non-negative) residual term

A random noise variable v_i which is independently and identically distributed normally with mean 0 and variance σ^2_v can be included in the equation to capture the effect of omitted variables that can influence the output, i.e., exogenous production shocks, as:

$Y_i = f(X_i; \beta) \exp(v_i - u_i)$

The likelihood function for the model is:

$L = -N \ln \sigma - \text{constant} + \sum [\ln \Phi(-\varepsilon_i \lambda / \sigma) - 1/2 (\varepsilon_i / \sigma)^2]$

Where,

$\lambda = \sigma_u / \sigma_v$

$\sigma^2 = \sigma_u^2 + \sigma_v^2$

Φ = Cumulative standard normal distribution function

$\varepsilon_i = (v_i - u_i)$

σ_u & σ_v = Standard deviations of the residuals u and v, respectively

The specific form of the production function employed to estimate the stochastic model is a Cobb-Douglas production framework given as:

$Y = a \prod_{i=1}^{n} X_i^{b_i} e^{(v_i + u_i)}$

In log-linear form, it is written as:

$$\ln Y = b_0 + \sum_{i=1}^{8} b_i \ln X_i + v_i - u_i$$

The variables, Y and X's, used in technical efficiency estimation and its description is given in Table 2.

Determinants of Technical efficiency:

The sources of efficiency differentials among farmers were identified by estimating a second-stage relationship between the efficiency measures and the assumed correlates of efficiency. Since the dependent variable of efficiency parameters varied between 0 and 1, the ordinary least square would produce biased and inconsistent estimates (Greene 2003). Therefore, the Tobit regression was used to analyze the data which is given by an index function:

$y_i^* = \beta_i Z_i + u_i$

$yi = y_i^*$ if $0 < y_i^* < 1$

$y_i = 0$ if $y_i^* \leq 0$

$y_i = 1$ if $y_i^* \geq 1$

Where, y_i^* and y_i are latent and the observed levels of technical efficiency respectively, Z_i is a vector of variables influencing technical efficiency and β is a vector of parameters to be estimated.

Based on the literature and conceptual model, a set of explanatory factors were identified to see their influence on the farm technical efficiency (Table 1).

Results and Discussion

The descriptive statistics of variables employed in the estimation of farm technical efficiency through the stochastic frontier approach are presented in Table 2. The mean value of production, i.e., the value of total crop produced by the household in a year is around Rs. 93820. The average land possessed by a household is about 3.48 ha. The average annual expenditure on various farm inputs like seeds, fertilizer and manure, plant protection chemical, labour is approximately Rs. 3270, Rs. 8070, Rs. 3540, and Rs. 15200 respectively. Miscellaneous expenses which include expenditure on diesel, electricity, irrigation, interest and other expenses averaged at Rs 15600 per ha. The high standard deviation values of the variables indicate the wide variation in its values among the households considered for the study.

The maximum likelihood estimates of the double-log production function are given in Table 3. It reveals that expenditures on fertilizer and manure, labour and miscellaneous expenditure contributed positively and

Table 1. Summary statistics of variables for identifying factors influencing farm technical efficiency

Variable	Descriptive	Mean	SD
Socio-economic variables			
Age	Age of household head (years)	54.74	13.20
Age15-65	Number of family members in the working age group of 15 to 65 years	3.82	1.45
Education	Education level of household head	2.53	2.02
Cultivation as principal income source	Dummy = 1 if cultivation is the principal income source, 0 otherwise	0.76	0.43
Non-farm business income	Dummy = 1 if household head derives income from non-farm business, 0 otherwise	0.06	0.24
Crop loss	Dummy = 1 if household had experienced any crop loss, 0 otherwise	0.12	0.33
Proportion of irrigated area	Proportion of Irrigated area out of net cropped area	0.99	0.10
Land holding category			
Marginal	Dummy = 1 if household belongs to marginal category (< 1 ha), 0 otherwise	0.49	0.50
Small	Dummy = 1 if household belongs to small category (1-2 ha), 0 otherwise	0.19	0.40
Semi-medium	Dummy = 1 if household belongs to semi-medium category (2-4 ha), 0 otherwise	0.18	0.38
Medium	Dummy = 1 if household belongs to medium category (4-10 ha), 0 otherwise	0.12	0.33
Large	Dummy = 1 if household belongs to large category (> 10 ha), 0 otherwise	0.02	0.14
Agro-climatic zones*			
Sub-mountainous zone	Dummy = 1 if household belongs to sub-mountainous zone, 0 otherwise	0.35	0.48
Central zone	Dummy = 1 if household belongs to central zone, 0 otherwise	0.49	0.50
South-western zone	Dummy = 1 if household belongs to south-western zone, 0 otherwise	0.16	0.37

**The sub-mountainous zone comprises Gurdaspur, Hoshiarpur, Pathankot, SAS Nagar, SBS Nagar, Roopnagar districts while the central zone consists Amritsar, Taran Taran, Kapurthala, Jalandhar, Ludhiana, Moga, Fatehgarh Sahib, Sangrur, Barnala, Patiala districts and Ferozpur, Faridkot, Fazilka, Bathinda, Mansa and Mukatsar fall under the south-western zone.*

Table 2. Descriptive statistics of variables used in the stochastic frontier estimation

Variable	Mean	SD
Value of production (Rs/ha)	93819.55	34858.84
Landholding (ha)	3.48	4.32
Expenditure on seeds (Rs/ha)	3271.67	3021.49
Expenditure on fertilizer and manure (Rs/ha)	8074.55	9742.21
Expenditure on plant protection chemical (Rs/ha)	3545.78	2368.33
Expenditure on labour (Rs/ha)	15255.21	13559.52
Miscellaneous expenditure (Rs/ha)	15544.15	26509.63

Table 3. Estimates of the stochastic frontier production function

Variable	Coeff. (Std. Err.)
Landholding	0.017 (0.012)
Seeds	0.036 (0.022)
Fertilizer and manure	0.069*** (0.022)
Plant protection chemical	0.026 (0.017)
Labour	0.125*** (0.02)
Miscellaneous expenditure	0.022** (0.011)
Constant	9.138 (0.26)
Sigma (u) constant	-2.684*** (0.127)
Sigma (v) constant	-2.952*** (.088)
Sigma (u):	0.261*** (0.016)
Sigma (v):	0.228*** (0.010)
Gamma:	0.537*** (0.022)
Log-likelihood function	-240.96
No. of observations	746

*Significance level: * p < .10, ** p < .05, *** p < .01*

significantly towards the total crop production in the state implying that there is scope for increasing the value of production by enhancing the level of these inputs. The elasticity of frontier production with respect to labour under total crop production was estimated to be 0.12 which is the highest elasticity followed by fertilizer and manure (0.06) and miscellaneous expenditure (0.02). The parameter gamma (γ), shows the proportion of overall variance that can be attributed to inefficiency and is around 54 per cent.

The estimates of technical efficiency categorized by landholding size across the three agro-climatic zones of Punjab are given in Table 4. Zone I, characterized as the sub-mountainous region, exhibits the lowest technical efficiency values across all land categories compared to Zone II (Central zone) and Zone III (Southwestern zone). The overall efficiency in Zone I is 76.97 per cent, significantly lower than Zone III at 84.03 per cent. This trend can be attributed to the challenging topographical and agro-climatic conditions in Zone I, which hinder the optimal utilization of agricultural inputs and technology. Factors such as uneven terrain, limited irrigation facilities, and higher susceptibility to soil erosion in the sub-mountainous zone likely contribute to the lower efficiency levels observed. Conversely, Zones II and III benefit from relatively favorable farming conditions, leading to higher technical efficiency across all land categories.

The table further reveals a trend of increasing technical efficiency as farm size increases within each zone. At the overall level, the efficiency rises from 76.85 per cent for marginal farms to 82.49 per cent for large farms. This pattern is consistent across all zones and can be attributed to economies of scale, better access to resources, and improved capacity to adopt modern agricultural practices on larger farms (Singh et al., 2027). The overall value of technical efficiency is 79.72 per cent implying that Punjab farms can increase their productivity by around 20 per cent without acquiring new resources by making appropriate (i.e., more effective) use of existing inputs and technology. Kaur et al., (2010) found the value of technical efficiency to be around 88 per cent in Punjab in wheat production whereas, Bhoi et al., (2017) found that the average technical efficiency level in paddy farming ranged between 83 to 86 per cent. Sekhon et al. (2010) however reported a lower efficiency value of about 76 per cent in Punjab farms.

The distribution of households across various technical efficiency ranges is presented in Table 5. A majority of households (59.79%) achieve technical efficiency levels between 80–90 per cent, indicating that most farmers operate relatively close to optimal efficiency. Meanwhile, 18.23 per cent of households fall within the 70–80 per cent range, and only a small proportion of households (5.23 per cent) exhibit technical efficiency below 50 per cent.

Determinants of technical efficiency

The factors influencing farm technical efficiency in Punjab is given in Table 6. The Tobit regression findings showed that experiences of crop loss led to farm inefficiency. On the other hand, if the principal income source of the household is crop cultivation, then it is more efficient compared to households with other sources of principal income. The proportion of irrigated land has a positive coefficient validating the anticipated positive correlation between the proportion of irrigated land and the overall output value. Morais et al. (2021) found that irrigation positively affects farm efficiency. Similarly, Bhoi et al. (2017) also reported that an investment in irrigation, one of the most important aspects of paddy cultivation, had a favourable and significant impact on technical efficiency at the farm level. Ahmad et al. (2002) observed similar results on wheat productivity, which was found substantially higher on farms with access to more dependable irrigation systems than on farms without irrigation or that only used one comparatively

Table 4. Land category-wise values of farm technical efficiency across agro-climatic zones

(per cent)

Land category	Zone I	Zone II	Zone III	Overall
Marginal	75.50	76.50	84.32	76.85
Small	78.41	82.86	84.15	81.51
Semi-Medium	77.79	83.44	84.05	81.62
Medium	78.41	84.25	83.46	82.38
Large	79.40	84.28	82.57	82.49
Overall	76.97	80.54	84.03	79.72

Table 5. Distribution of households by the level of technical efficiency

Technical efficiency range (%)	Technical Efficiency (%)	f (%)
< 50	35.28	39 (5.23)
50-60	54.85	20 (2.68)
60-70	65.34	41 (5.5)
70-80	76.44	136 (18.23)
80-90	85.23	446 (59.79)
>90	92.27	64 (8.58)
Mean	79.72	
N	746	

less dependable source of irrigation. The Tobit estimates further reveal that small, semi-medium, and medium land holdings have higher farm efficiency as compared to the marginal land holding category. Several studies such as that of Singh (2012), Ren et al. (2019) and Chakraborty and Pal (2020) also reported that larger farm size leads to increased farm efficiency. We further find that compared to the sub-mountainous zone, farm households in the central and south-western zone show higher farm technical efficiency. This is in collaboration with the findings of Sekhon et al. (2010) who found that the technical efficiency of farms in the sub-mountainous zone is lower than the other two zones. This may be probably due to low crop productivity, low use of farm inputs, and small farm size in the region resulting to lower returns (Kaur et al., 2021).

Conclusion and Policy Implications

The study on farm technical efficiency in Punjab's agriculture highlights the potential for productivity gains in Punjab farms, as farms currently operate at an average efficiency of around 80 per cent, leaving a 20 per cent margin for improvement through optimized resource use. Technical efficiency increases with farm size across all zones, reflecting economies of scale and better resource utilization. Key determinants of efficiency include access to irrigation, with farms that have a higher proportion of irrigated land showing greater productivity. Small, semi-medium, and medium holdings demonstrate significantly higher efficiency compared to marginal farms. Additionally, households that rely primarily on crop cultivation as their main source of income tend to be more efficient, suggesting that focused investment in farming enhances resource allocation. Regional disparities are also evident, with farms in the central and south-western zones outperforming those in the sub-mountainous zone, where smaller farms, lower productivity, and reduced input use contribute to inefficiency.

These findings point to important policy implications. Expanding access to efficient and reliable irrigation systems, especially for small and marginal farmers, would greatly boost productivity, especially in the sub-mountainous zone. Additionally, policies that provide better access to credit, input subsidies, and promote cooperative farming could help improve efficiency for smaller landholders. Strengthening agricultural extension services is crucial for disseminating modern farming practices and technologies, particularly in the sub-mountainous regions where challenges are more pronounced. Development policies tailored to specific regional needs should aim to improve crop productivity, optimize landholding patterns, and enhance access to farm inputs. Encouraging farmers to prioritize agriculture as their primary income source through incentives for crop diversification and complementary non-farm activities could further increase efficiency. Overall, targeted interventions focused on improving resource use, irrigation access, and regional support systems are vital for enhancing farm technical efficiency in Punjab.

Table 6. Determinants of technical efficiency: Tobit model

Variables	Coeff. (Std. err.)
Socio-economic characteristics	
Age	0.001 (0.001)
Age15-65	-0.001 (0.003)
Education	0.003 (0.002)
Cultivation as principal income source	0.084*** (0.012)
Non-farm business income	0.018 (0.021)
Crop loss	-0.062*** (0.012)
Proportion of irrigated area	0.135** (0.055)
Landholding category	
Small	0.024** (0.012)
Semi-medium	0.023* (0.014)
Medium	0.029* (0.016)
Large	0.034 (0.037)
Agro-climatic zones	
Central	0.018* (0.01)
South-western	0.037** (0.015)
Constant	0.585*** (0.06)
Sigma	0.015 (0.001)
Log likelihood	509.764
LR chi2 (14)	127.86
Prob Chi2	0
No. of observations	746

*Significance level: *P<.10, **P<.05, ***P<0.01*

Declaration: The authors declare that they do not have any conflict of interest.

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Received: October 23, 2024 Accepted: November 30, 2024