Chapter-5

Economic Efficiency of Agriculture in Punjab

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5.1 Introduction

In the developing economics like India, high population growth in the economy and opening of the agriculture sector for export are placing pressure on farmers to produce more. However, the growth in farm production is constraint by accessibility of resources. Therefore, it is considered that production efficiency is a significant factor striving to increase growth of farm production in the economies, where agriculture resources are scarce and opportunities to enhance productivity are dwindling (Ali & Chaudhry, 1990). Such economies can proceeds benefits by improving the efficiency level of neglected resources. They can focus on those areas which have the potential to increase agricultural production without incurring extra costs on inputs and new technology.

A number of studies claim that in less developed economies, the majority of farmers face difficulties in understanding new technologies thereby they failed to reap the benefits of new technologies or make improper allocation of resources (Tadesse & Krishnamoorthy, 1997; Mythili & Shanmugam, 2000; Shanmugam, 2002; Shanmugam & Venkataramani, 2006). For example Kalirajan and Flinn (1983) show that 50 percent inefficiency exists among rice cultivators in Philippines. In the perspective of Pakistan Punjab, Ali and Flinn (1989) show that rice growers can increase their profits by 28 percent through improving farm efficiency. Ali and Chaudhry (1990) follow a similar approach in the same state for different crops and observed that there is an opportunity to enhance farmers' gross income around 13-20 percent without employing any additional resources. Usually, these variations are observed among farmers due to differences in their management abilities, such as farmers who adopt land management and soil conservation practices have relatively higher technical efficiency than their non-adopter counterpart (Solis et al., 2007; Yang et al., 2018; Selejio et al., 2018).

Among India's northern states, Punjab holds a special status in agriculture growth because having healthy mix environmental, institutional and technological factors. The state has a largest contribution to the national pool of food grains such as around 70 percent in wheat and 50 percent in rice production. Currently, wheat and rice become most predominant crops in the state. They covered around 44 percent and 36 percent of the gross cropped area in 2018-19 against with 29.59 percent and 4.8 percent in 1960-61 respectively. However, the several studies (Sidhu, 2002; Sidhu & Jhol, 2002; Singh & Sidhu, 2006; Singh et al., 2013) claims that the recent scenario is not so encouraging; a sluggish growth in the agriculture sector has been noticed in the state. The growth rate of rice yield has declined from 1.27 percent in 1980s to -0.04 percent in the 1990s, in case of wheat it fall down from 3.00 percent to 1.45 percent in 1990s (Kaur & Sekhon, 2005). One important reason for low yield is that agriculture becomes more input intensive, yield almost reached its potential and further productivity growth slowed. In particular, intensive crop production has threatened the long-term sustainability of agricultural. It directly affects the farm production efficiency level due to over-utilization of input resources that are applied to attain higher yield (Sekhon et al., 2010; Singh et al., 2017).

In particular Punjab, several studies have investigated the extent and determinants of farm efficiency in crop production (Sidhu, 1974; Sidhu & Baanante, 1979; Sidhu & Byerlee, 1992; Singh et al., 1998; Singh et al., 2017). However, only a few studies (Kaur et al., 2010; Sekhon et al., 2010) have addressed this issue at districts level or regions level to see the performance of agricultural sector and regional disparities, but no concert attempts of addressing the issue at micro unit level such as tehsil or block has been observed. Moreover, these studies have provided framework for a particular crop (especially wheat), and have used limited approach to examine the technical efficiency across different regions. Being a small and one of the agriculturally rich state, it is important to see the extent of farm efficient and its regional distribution at micro unit. This will lead to identify the micro level problems of farm sector followed by appropriate policy formation. Therefore, present chapter deals with the issue of differences in production efficiency across tehsils in Punjab, India.

In this chapter, using plot-level panel dataset for the three blocks ranging from 2014-15 to 2016-17 different measures of efficiency such as technical efficiency, scale efficiency, cost efficiency, and allocative efficiency are calculated following the well developed and well established non-parametric approach as developed by Charnes et al. (1978). This chapter particularly focuses on: (i) to estimate the economic efficiency of crop production in Punjab; (ii) to determine the effect of crop diversification on economic efficiency.

This present study makes three distinct contributions to the existing literature. First, it contributes to the literature on production efficiency measures at tehsil-level, which provides some ways to understand the causes of regional diversity. It extends the limited but growing literature on different types of farm efficiencies across tehsils within a state. This tehsil level efficiency measures give an ample opportunity to enhance income/output of the farms at given resources by exploring regional diversity on the part of farmers.

Though, several empirical studies have provided a prominent work on technical inefficiency, yet on area that has received very little consideration in the empirical literature is related to the decomposition analysis of production efficiency. From this viewpoint, this study contributes to the literature on decomposition analysis of overall technical inefficiency across regions. This decomposition of efficiency analysis provides the sources of inefficiencies among different farms.

In the context of scarce agricultural resources, several studies have provided evidences on inadequate use of input resources. However, no study is found that has recommended the amount of each input reduction in order to increase output across regions. In this backdrop, this analysis shed some light on slacks and targets setting appliance to evaluate the way for improvement in the context of inefficient tehsils. For example, if an inefficient tehsil cannot reach their target after proportional addition in output or potential reduction in input, the slacks help to push the inefficient tehsils to reach their target. Thereby, this analysis explains how much proportion of each input has to be reduced for each inefficient tehsil to attain same outcomes. This analysis also assists to limit those inputs which are used in excessively. To carry out this analysis, input output slacks that have been derived from CCR input-oriented DEA based model. Moreover, this study also reveals the ranking of efficient tehsils in Punjab. This information is vital for policy makers to look toward a more suitable direction for production.

The remaining part of the chapter is structured as: - Section 5.2 presents the conceptual and theoretical framework. Section 5.3 represents the efficiency score and scale operations in crops production across tehsils. Section 5.4 presents the efficiency improvement: slacks and targets setting analysis for each tehsil. Section 5.5 presents the performance of farmers' in allocating their agricultural resources across tehsil; the last Section 5.6 represents conclusions and policy implications.

5.2 Methodological Frameworks

There are many parametric and non-parametric techniques, which researchers have applied to measure efficiency in the development economics. However, the most popular techniques used to measure farm efficiency are data envelopment analysis (DEA) and stochastic frontier analysis (SFA). SFA is a parametric technique that requires the functional form of the model under consideration and explicitly measures the technical efficiency (Forsund et al., 1980;

Bauer, 1990; Coelli & Battese, 1996). DEA is a non-parametric deterministic technique for measuring the frontier to measure efficiency (Varian, 1984; Chavas & Aliber, 1993; Coelli, 1995).

DEA technique has been used that originally developed by Charnes et al. (1978). DEA method has been preferred over other competing techniques because it can readily produce rich information on technical efficiency and scale efficiency. For crop production efficiency, two most popular DEA models namely CCR[1] and BCC[2] models are used. However, CCR model does not provide any scale effect due to some constraints. Therefore, BCC model is followed, which allows computing the pure technical efficiency and scale efficiency effects, and it is more flexible than the CRS-DEA model.

As it is difficult to give rank or differentiate the most efficient tehsil among the fully efficient tehsils in Punjab with CCR model, therefore the super-efficiency slacks based measurements (SBM) model has been employed. The SBM model has the ability to give ranking to those fully efficient tehsils, which have overall technical efficiency (OTE) score equal to unity.

5.2.1 Measurement of farm efficiency: CCR and BCC DEA models

By exploring regional variations in production efficiency across different tehsil, it finds the overall farm efficiency scores in crop production for each tehsil. Here, technical efficiency (TE) refers to *"the ability of a farm to either produce the maximum feasible output from a given bundle of inputs or to produce the given level of output using minimum amount of inputs" (Coelli et al., 2002).* Overall technical efficiency composes of pure technical efficiency and scale efficiency[3]. Where, pure technical efficiency refers to managerial

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[1] CCR model is given by Charnes et al. (1978), and is based on the assumption of constant returns-to-scale.

[2] BCC model is given by Banker et al. (1984), and is based on the assumption of variable returns-to-scale.

[3] The rationing of overall technical efficiency (OTE) to pure technical efficiency (PTE) provides scale efficiency (SE) as shown in the following specification: $SE_k = \frac{TE_{CRS_k}}{TE_{VRS_k}} = \frac{OTE_k}{PTE_k}$; when OTE=PTE than farm unit is said to be scale-efficient. Scale efficiency is described as whether a farm is working at its optimal size or not.

efficiency (application of input utilization) and scale efficiency refers to scale operations of the tehsils. Farm efficiencies scores across tehsils are measured by using the following specification:

i) $\min\limits_{\theta_k, \lambda_1, \lambda_{2,\dots\dots,}\lambda_n, s_i^-, s_r^+}$

$$TE_k = \theta_k - \in \left(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+ \right)$$

Subject to:

$$ii) \sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = \theta_k X_{ik}$$

$$iii) \sum_{j=1}^{n} \lambda_j y_{rj} - s_r^+ = Y_{rk}$$

iv) $s_i^-, s_r^+ \geq 0$

v) $\lambda_j \geq 0, if\ constant\ return\ to\ scale$

$$vi) \sum_{j=1}^{n} \lambda_j = 1, if\ variable\ return\ to\ scale$$

(i=1,2…m; r =1, 2…s; j=1, 2 …n) *(5.1)*

In the above specification, *(i=1, 2…m)* and *(r=1, 2…s)* are sets of inputs and output for the farm; *n* is the number of tehsils; X_{ik} is amount of input *i* used by tehsil *k;* Y_{rk} is amount of output *r* produced by tehsil *k*; ∈ is a small positive number, (s_i^-) = input slack, (s_r^+) = output slack; λ_j is non-negative weights for tehsil *j*; θ_k refers to technical efficiency score of tehsil *k* (within a range from $0<\theta_k<1$). Given the above specification if $\theta_k = 1$ and $s_i^- = s_r^+ = 0$, then tehsil *k* is Pareto-efficient tehsil, implying that no input excesses and no output shortfalls exist in any optimal solution for that tehsil.

The model comprising *(i–v)* is an identified form of CCR model. It gives Farrell's input-oriented technical efficiency estimation based on the assumption of constant return to scale.

The objective of equation *(i)* is to minimize the inputs, while keeping the output level constant. The model containing *(i–iv)* and *(vi)* is recognized as BCC model that is based on variable return to scale assumption. The main purpose of adding convexity constraint ($\sum_{j=1}^{n} \lambda_j = 1$) is to the CCR model by Banker et al. (1984). Because of this convexity, constraint authorizes that an inefficient DMU is only 'benchmarked' in contrast of similar size DMUs.

5.2.2 Super-efficiency model

The Andersen and Petersen's super-efficiency model under CRS assumption is used to resolve ranking issues among the efficient tehsils. In this model efficient tehsils contain any value greater than or equal to unity. This exercise makes it possible to rank the efficient tehsils (i.e., upper super-efficiency scores infers higher rank). To measure super-efficiency scores following specification is used:

$$i)\ \underset{\theta_k^{super}, \lambda_1, \lambda_{2,\dots\dots,} \lambda_n, s_j^-, s_r^+}{\min}$$

$$TE_{CRS}^{k,super} = \theta_k^{super} - \in \left(\sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+ \right)$$

Subject to:

$$ii) \sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = \theta_k^{super} X_{ik}$$

$$iii) \sum_{j=1}^{n} \lambda_j y_{rj} - s_r^+ = Y_{rk}$$

iv) $s_i^-, s_r^+ \geq 0$ (r =1, 2,….s)

v) $\lambda_j (j \neq k) \geq 0$ (i=1, 2…m);(j=1, 2…n) *(5.2)*

Here, all the notations are same as presented in the above section. However, θ_k^{super} gives ranks to the different tehsils based on their efficiency scores. The higher rank values of θ shows the most efficient tehsil among the fully efficient tehsils.

5.2.3 Cost efficiency and allocative efficiency

(i) Cost efficiency: Cost efficiency defines the capability of a firm to obtain a given level of output spending cost-minimizing input prices (Coelli et al., 2002). Fare et al. (1994) explained that the input cost inefficiency is due to wrong selection of the input mix, adoption of inappropriate scale size, input congestion, or to purely technical inefficient. The cost efficiency scores have measures for each tehsil by using the following specification:

$$\underset{\lambda_j x_i}{\mathit{Minimize}} \{CE_k = \sum_{i=1}^{m} p_{ik} x_{ik} \mid \sum_{j=1}^{n} \lambda_j x_{ij} \leq x_{ik}, i = 1, \ldots\ldots, m, \sum_{j=1}^{n} \lambda_j y_{rj} \geq y_{rk}\ , r = 1, \ldots\ldots, s, \lambda_j, x_i \geq 0\}$$

(5.3)

In the above model, $CE_k = \sum_{i=1}^{m} p_{ik} x_{ik}$ is the observed aggregate cost of inputs for tehsil *k*; p_{ik} is the price of input *i* for the tehsil *k*. The above specification assumes that for each tehsil inputs prices *(*p_{ik}*, i=1,…,m)* are known and fixed, however they can vary across tehsils. Consider for each tehsil *j (j=1, 2,…,n)* a vector x_j*=(* x_{1j}, x_{2j} …… x_{mj}*)* showing *m* inputs used for producing a vector of *s* outputs $y_j = (y_{1j,} y_{2j,\ldots\ldots} y_{sj})$; implying that x_{ik} is the observed amount of input *i* to be used by tehsil *k*; and y_{rk} is the amount of output *r* produced by tehsil *k*.

Using the above specifications, cost efficiency is ratio of minimum cost to the observed cost defined as below:

$$CE_k = \sum\nolimits_{i=1}^{m} p_{ik} x_{ik}^{*} / \sum\nolimits_{i=1}^{m} p_{ik} x_{ik}$$

(5.4)

(ii) Allocative efficiency: Allocative efficiency or price efficiency defines the capacity of the farmers to select appropriate mixture of inputs at specified input prices (Farrell, 1957). According to (Yotopoulos & Lau, 1973) a farm is allocatively efficient if it equates the value of the marginal product of each resources employed to the unit cost of that resource.

Therefore, it is examined whether any distinct pattern exists with different regions in Punjab allocative efficiency is measured by using the following equation:

$$AE_k = \frac{CE_k}{TE_k}$$

(5.5)

where, CE_k = cost efficiency calculated for tehsil *k; TE_k* = technical efficiency for tehsil *k*

5.2.4 Impact of crop diversification on economic efficiency

In order to estimate the link between crop diversification and economic efficiency, very popular and well established ordinary least square (OLS) regression model is used in this chapter. The specification of the model is follows as:

$$TE_i = \alpha_{0i} + \alpha_{1i}SID + \alpha'_{ji}Z + e_i$$

(5.6)

where, *TE* is “technical efficiency”, *Z* is a vector which includes farm household characteristics such as age, education, gender and major occupation. The coefficient of interest is α_{1i}.

5.3 Data and Specification of Variables

The data used in this study are retrieved form Comprehensive Scheme for Cost of Cultivation (CCS) of Principal Crops administered by Directorate of Economics and Statistics, Ministry of Agriculture Government of India. In this survey, the data set provides various features of farming across regions of the country since 1970-71. In this dataset, each sample household is surveyed consecutively for three years. However, this study particularly focuses on the recent available data pertaining to the block period 2014-15, 2015-16 and 2016-17 for the Punjab state. For Punjab, plot-level data has been collected from 300 households of 30 tehsils. In CCS data, the sample of households has been divided into five different land-holding size groups. This dataset provides a comprehensive view of the cropping patterns and inputs used by agricultural households. The focus of this study is on two crops: wheat and paddy, which together cover about 89 percent of the sample. However, cotton and maize are also cultivated but they cover only a smaller proportion (13 percent).

To analyze farm-level efficiency in crop production across tehsils in Punjab, the plot-level input-output information at aggregate level are retrieved to show the combined picture of the three block period. Only those cultivators are included who grow selected crops in all the three years. Each tehsil is considered as a DMU has the availability of complete inputs-output information at that level. The tehsils are mainly considered Gurdaspur (T1), Batala (T2), Ajnala (T3), Patti (T4), Dasua (T5), Hoshiarpur 1(T6), Balachaur (T7), Anandpur Sahib (T8), Patiala (T9), Fatehgarh Sahib (T10), Ferozepur (T11), Guruharsahai (T12), Moga (T13), Samrala (T14), Jalandhar (T15), Sultanpurlodhi (T16), Payal (T17), Jagraon (T18), Sangrur (T19), Jalandhar (T20), Malerkotla (T21), Sardulgarh (T22), Mansa (T23), Budhlada (T24), Bathinda (T25), Talwandi Sabo (T26), Malout (Singhewala) (T27), Malout (Shamkot) (T28), Fazilka (T29), Abohar (T30).

For analysis purposes, the physical output of the crops is measured in terms of quintals per hectare including by-products. The by-products are converted into quintals of crops by dividing total value of by-products by crop price (followed Sidhu, 1974). While inputs consists of human labour, machine, seeds, fertilizer, and irrigation machine. Moreover, farmers face different input prices across tehsils, such price variations may be relatively small but it cannot be ruled out. Therefore, price information on inputs is also considered. The description and selection of input-output variables are reported in Table C1 in Appendix C.

Additional variables that could not be considered in the analysis are manure, insecticides, and miscellaneous cost, due to insufficient information availability.

5.3.1 Descriptive statistics

Table 5.1 presents the descriptive statistics for variables output, inputs, and input-prices that are used in the estimation. It is noticed that in case of wheat, production varies from 32.4 to 52.4 quintals per-hectare with mean and standard deviation 45.84 and 4.01 respectively. While, in case of paddy, production varies from 36.6 to 84.2 quintals per-hectare, and its mean is 64.9 and standard deviation is 12.4, respectively. The use of all other inputs such as human labour, seed, fertilizers, and irrigation have increased more than double in both crops.

Table 5.1: Summary statistics

Variables	Wheat						Paddy					
	Obs	Units	Mean	SD*	Min	Max	Obs	Units	Mean	SD*	Min	Max
Output												
Production and by-product#	30	Qtls/Ha	45.8	4.01	32.4	52.4	29	Qtls/Ha	64.9	12.4	36.6	84.2
Inputs												
Labour@	30	Hrs/Ha	139	56.1	89.9	367	29	Hrs/Ha	366	62.8	311	541
Machine$	30	Hrs/Ha	16.5	2.29	12.5	23.9	29	Hrs/Ha	14.5	2.17	10.6	19.2
Seeds	30	Kg/Ha	108	6.4	99	122	29	-	-	-	-	-
NPK	30	Kg/Ha	234	38.4	119	294	29	Kg/Ha	187	24.6	143	232
Irrigation#	30	Hrs/Ha	39	16.9	2.63	69.1	29	Hrs/Ha	233	50.3	95.3	306
Inputs-Prices												
Labour	30	Rs/ha	6424	2608	3824	17049	29	Rs/ha	16456	2754	13491	25051
Machine	30	Rs/ha	9054	1154	6783	11603	29	Rs/ha	6557	1260	3988.4	9523
Seed value	30	Rs/ha	2150	244	1766	2631	29	Rs/ha	1768	368	1372.3	2917
Fertilizer	30	Rs/ha	4985	893	2488	6755	29	Rs/ha	3581	895	2253.5	5531
Irrigation machine	30	Rs/ha	647	383	31.2	1753	29	Rs/ha	2956	1155	1370.8	7324

Note:***** Standard Deviation**; @** Human Labour =Family Labour + Attached Labour + Casual Labour; $ Machine = Hired + Own; # Irrigation = Hired Irrigation Machine + Own.

It implies that farmers are using additional amount of inputs i.e. fertilizer, pesticides, labour, and irrigation to obtain higher yield on fixed land. As results diminishing marginal returns occurred, and an increasing input after optimal capacity has been reached leading to smaller increases in output. If this over-utilization input trend continues, it would be difficult to have increasing productivity in the sector. This results is found to be similar as reported in Swarup and Singh, (1989); Kumar and Yadav, (1993); Lal et al. (2004).

5.4 Empirical Results of Crops Cultivation

The outcomes of input-oriented CCR and BCC model define by how much can input quantities be proportionally reduced without altering the output quantities produced? Therefore, the tehsils that has a need to reduce their level of inputs usage, are discriminated by using frequency method suggested by Chen and Yeh (1998). To discriminate inefficient tehsils, the efficient tehsils are presented in the reference sets. The higher frequency count tehsils implies that these tehsils are probably good example of "well-rounded performer" with high robustness. Whereas, the lower frequency count tehsils show those tehsils that should not be followed by other inefficient tehsils as their benchmark. Here, the best performer tehsils are identified among the fully efficient tehsils following the Andersen and Petersen (1993) methodology.

5.4.1 Efficiency score and scale operations in crops production

Table 5.2 and Table 5.3 present the estimation of the Equation (5.1). It is found that in case of wheat only 23 (7 out of 30 tehsils) percent tehsils are performing at fully efficient level. It could be inferred that remaining 77 percent tehsils which do not operate at efficiency level need to reduce their input usage by approximately 6.1 percent, to maintain the same level of wheat production as achieved by the other 23 percent of the tehsils. As expected, on an average these tehsils have substantial scope to produce 1.06 times additional output by properly organizing inputs level. While, in case of paddy around 24 percent (7 out of 29) tehsils are operating at frontier level and remaining 76 percent tehsils are producing at an inefficient level. These tehsils are over-utilizing their inputs to the extent of 16.4 percent than required. They have substantial scope to produce 1.19 times more output by applying the same inputs amount.

Table 5.2 and Table 5.3 also present the optimal scale of operation which infers that around 74 percent tehsils in case of wheat and 72.42 percent tehsils in case of paddy are operating under increasing returns-to-scale. As these tehsils are performing below the optimum production scale. It indicates that the production scale could be improved by decreasing the costs of these tehsils.

Table 5.2: Estimated efficiency scores of wheat across tehsil from Equation (5.1)

Tehsil Code	Tehsils	OTE	OTIE	PTE	PTIE	SE	SEI	RTS
T1	Gurdaspur	0.752	0.248	1.000	0.000	0.752	0.248	IRS
T2	Batala	0.924	0.076	0.982	0.018	0.941	0.059	IRS
T3	Ajnala	0.935	0.065	1.000	0.000	0.935	0.065	IRS
T4	Patti	0.929	0.071	1.000	0.000	0.929	0.071	IRS
T5	Dasua	0.849	0.151	1.000	0.000	0.849	0.151	IRS
T6	Hoshiarpur 1	1.000	0.000	1.000	0.000	1.000	0.000	CRS
T7	Balachaur	0.825	0.175	0.888	0.112	0.929	0.071	IRS
T8	Anandpur Sahib	0.885	0.115	0.955	0.045	0.926	0.074	IRS
T9	Patiala	0.920	0.080	0.938	0.062	0.981	0.019	IRS
T10	Fatehgarh Sahib	0.922	0.078	0.944	0.056	0.977	0.023	IRS
T11	Ferozepur	0.971	0.029	1.000	0.000	0.971	0.029	IRS
T12	Guruharsahai	0.991	0.009	1.000	0.000	0.991	0.009	IRS
T13	Moga	0.945	0.055	0.983	0.017	0.961	0.039	IRS
T14	Samrala	0.979	0.021	0.983	0.017	0.996	0.004	IRS
T15	Jalandhar	0.912	0.088	0.987	0.013	0.924	0.076	IRS
T16	Sultanpurlodhi	1.000	0.000	1.000	0.000	1.000	0.000	CRS
T17	Payal	1.000	0.000	1.000	0.000	1.000	0.000	CRS
T18	Jagraon	0.983	0.017	1.000	0.000	0.983	0.017	IRS
T19	Sangrur	0.987	0.013	0.988	0.012	0.999	0.001	IRS
T20	Jalandhar	1.000	0.000	1.000	0.000	1.000	0.000	CRS
T21	Malerkotla	0.938	0.062	0.953	0.047	0.983	0.017	IRS
T22	Sardulgarh	0.959	0.041	0.969	0.031	0.989	0.011	IRS
T23	Mansa	0.985	0.015	1.000	0.000	0.985	0.015	IRS
T24	Budhlada	1.000	0.000	1.000	0.000	1.000	0.000	CRS
T25	Bathinda	0.944	0.056	0.978	0.022	0.965	0.035	IRS
T26	Talwandi Sabo	1.000	0.000	1.000	0.000	1.000	0.000	CRS
T27	Malout(Singhewala)	0.930	0.070	0.965	0.035	0.963	0.037	DRS
T28	Malout(Shamkot)	1.000	0.000	1.000	0.000	1.000	0.000	CRS
T29	Fazilka	0.890	0.110	1.000	0.000	0.890	0.110	IRS
T30	Abohar	0.823	0.177	0.998	0.002	0.825	0.175	IRS
Mean	-	0.939	-	0.984	-	0.955	-	-

Notes: OTIE=Overall technical inefficiency=(1-OTE), PTIE=Pure technical inefficiency=(1-PTE), SIE=Scale inefficiency=(1-SE), IRS= increasing returns-to-scale, CRS=constant returns to-scale; and DRS=decreasing returns-to-scale

In particular, these tehsils are not efficiently using their production resources. While, 3 percent of the tehsils in case of wheat and 3.44 percent in case of paddy are working under decreasing returns-to-scale i.e., these tehsils are performing above the optimum scale of production. It reflects that the farmers of these tehsils are over utilizing their inputs in production process.

Table 5.3: Estimated efficiency scores of paddy across tehsil from Equation (5.1)

Tehsil Code	Tehsil	OTE	OTIE	PTE	PTIE	SE	SEI	RTS
T1	Gurdaspur	0.642	0.358	1.000	0.000	0.642	0.358	IRS
T2	Batala	0.683	0.317	0.851	0.149	0.803	0.197	IRS
T3	Ajnala	0.516	0.484	0.896	0.104	0.576	0.424	IRS
T4	Patti	0.681	0.319	1.000	0.000	0.681	0.319	IRS
T5	Dasua	0.691	0.309	0.916	0.084	0.754	0.246	IRS
T6	Hoshiarpur 1	0.701	0.299	0.948	0.052	0.740	0.260	IRS
T7	Balachaur	0.715	0.285	0.969	0.031	0.738	0.262	IRS
T8	Anandpur Sahib	0.675	0.325	0.818	0.182	0.826	0.174	IRS
T9	Patiala	0.951	0.049	1.000	0.000	0.951	0.049	IRS
T10	Fatehgarh Sahib	0.909	0.091	1.000	0.000	0.909	0.091	IRS
T11	Ferozepur	0.840	0.160	0.999	0.001	0.841	0.159	IRS
T12	Guruharsahai	1.000	0.000	1.000	0.000	1.000	0.000	CRS
T13	Moga	1.000	0.000	1.000	0.000	1.000	0.000	CRS
T14	Samrala	0.985	0.015	1.000	0.000	0.985	0.015	IRS
T15	Jalandhar	0.674	0.326	0.934	0.066	0.722	0.278	IRS
T16	Sultanpurlodhi	0.966	0.034	0.984	0.016	0.981	0.019	IRS
T17	Payal	0.973	0.027	0.991	0.009	0.981	0.019	IRS
T18	Jagraon	0.947	0.053	0.965	0.035	0.981	0.019	IRS
T19	Sangrur	1.000	0.000	1.000	0.000	1.000	0.000	CRS
T20	Jalandhar	1.000	0.000	1.000	0.000	1.000	0.000	CRS
T21	Malerkotla	1.000	0.000	1.000	0.000	1.000	0.000	CRS
T22	Sardulgarh	0.767	0.233	0.932	0.068	0.823	0.177	IRS
T23	Mansa	1.000	0.000	1.000	0.000	1.000	0.000	CRS
T24	Budhlada	0.968	0.032	0.976	0.024	0.991	0.009	DRS
T25	Bathinda	0.881	0.119	0.952	0.048	0.926	0.074	IRS
T26	Talwandi Sabo	0.683	0.317	0.829	0.171	0.824	0.176	IRS
T27	Malout(Singhewala)	0.655	0.345	0.867	0.133	0.755	0.245	IRS
T28	Malout(Shamkot)	0.755	0.245	0.994	0.006	0.760	0.240	IRS
T29	Fazilka	1.000	0.000	1.000	0.000	1.000	0.000	CRS
Mean	-	0.836	-	0.959	-	0.869	-	-

Notes: OTIE = Overall technical inefficiency = (1-OTE), PTIE=Pure technical inefficiency = (1-PTE), SIE=Scale inefficiency = (1-SE), IRS= increasing returns-to-scale, CRS=constant returns to-scale; and DRS=decreasing returns-to-scale

So, the farmers can downsize their scale of operations to increase their production level. Further, it has been examined that seven tehsils have shown constant returns to scale each for wheat[4] and paddy[5]. This implies that these tehsils are operating at most productive scale

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[4] Hoshiarpur 1, Sultanpurlodhi, Payal, Jalandhar, Budhlada, Talwandi Sabo and Malout

operation or lies on flatter portion of the long-run average cost curve. Overall, it implies that only 23 percent in case of wheat and around 24 percent in case of paddy tehsils are operating under correct scale of operations.

According to DEA terminology, these 23 percent tehsils in case of wheat and 24 percent tehsils in case of paddy are called best producer tehsils. The input resources utilization experiences in these tehsils are better. But, remaining 77 percent inefficient tehsils in case of wheat and 76 percent in case of paddy are producing under inappropriate scale size (i.e., too large too small) or performing under poor utilization of inputs. There is a wide difference in technical efficiency across tehsils. Each tehsil performs differently in utilizing the given resources. Thus, higher efficiency gap that exists in across the tehsils can be explained by relatively better use of inputs resources or best practices farmers. These results are consistent with the findings of the earlier (Llewelyn & Williams, 1996; Okello et al., 2019).

5.4.2 Decomposition of OTE: PTE and SE

Table 5.2 and Table 5.3 also present the estimation of the decomposition of overall technical efficiency scores. It is found that in case of wheat, nine tehsils namely Gurdaspur, Ajnala, Patti, Dasua, Ferozepur, Guruharsahai, Jagraon, Mansa, and Fazilka are lie on the efficient edge under variable return to scale (VRS) assumption. However, these nine tehsils have been found to be inefficient under constant return to scale (CRS) as their OTE score is less than unity. It indicates that the overall technical inefficiency of these tehsils is due to inappropriate scale size. Furthermore, another 14 tehsils have PTE<1. Out of these 14 tehsils, seven tehsils have PTE score less than the SE score implying that inefficiency of these seven tehsils are due to poor inputs utilization. While, in case of paddy, five tehsils namely Gurdaspur, Patti, Patiala, Fatehgarh Sahib and Samrala are lie on the efficient target under variable return to

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[5] Guruharsahai, Moga, Sangrur, Jalandhar, Malerkotla, Mansa, and Fazilka

scale supposition, but these tehsils are inefficient under CRS supposition. From this, it can be concluded that the inefficiency of these five tehsils is resulted by operating on the wrong scale size. The remaining 17 tehsils having PTE score less than unity infer that there exists managerial inefficiency. Out of these 17 tehsils, three tehsils with PTE score less than SE score implies that inefficiency of these tehsils is due to poor input utilization rather than scale size.

Overall, it is observed that inefficiency is resulted from both poor utilization of input mix and inappropriate scale size. When the PTE scores are compare with SE scores, it is found that a greater proportion of overall technical inefficiency is owing to scale inefficiency in case of both crops wheat and rice (see Table C3 and Table C4 in Appendix C). The farmers of these tehsils are not ensuing suitable managing practices and performing under improper scale operations. These findings are consistent with previous literature that says the inefficiency in crop production is caused by inappropriate farming practices viz., pure technical inefficiency and scale inefficiency (Paul et al., 2004; Latruffe et al., 2005; Chen et al., 2011; Ngwira et al., 2012; Hassen et al., 2017).

5.4.3 Discrimination of efficient tehsils

Table 5.4 and Table 5.5 present the frequency or peer count scores of each efficient tehsil. In case of wheat, the tehsils such as Talwandi Sabo and Payal are seemed to have higher frequency scores as compare to other efficient tehsils. They obtained 18 and 17 frequency scores respectively. In the second category, Jalandhar, Budhlada and Hoshiarpur1 are accounted for 8, 6, and 5 frequency counts respectively. And in the third category, two tehsils namely Malout and Sultanpurlodhi are exemplified which have frequency count 3 for each. However, in case of paddy, Sangrur tehsil is more efficient as compared to other efficient tehsils with 12 frequency count followed by Malerkotla and Guruharsahai. In the third category, two tehsils i.e. Moga and Fazilka are efficient tehsils with 3 and 1 frequency count respectively. On the basis of peer count, the higher frequency count tehsils are characterized as efficient producer (or highly robust tehsils).

Table 5.4: Peer-weights for inefficient tehsil and peer counts (Wheat)

Inefficient-tehsils	OTE	Reference Set						
		T6	T16	T17	T20	T24	T26	T28
T1	0.752	0.124	-	-	-	0.186	0.338	-
T2	0.924	-	-	0.166	-	-	0.697	-
T3	0.935	-	-	0.238	0.073	-	0.556	-
T4	0.929	-	0.106	0.061	-	0.160	0.528	-
T5	0.849	0.195	-	-	0.652	-	-	-
T7	0.825	0.230	-	-	0.420	0.242	-	-
T8	0.885	-	-	0.028	-	-	0.815	-
T9	0.920	-	0.497	0.246	0.093	-	-	0.144
T10	0.922	-	0.233	0.298	-	-	-	0.445
T11	0.971	-	-	0.507	-	-	0.414	-
T12	0.991	-	-	0.664	0.162	-	0.148	-
T13	0.945	-	-	0.697	-	0.040	0.197	-
T14	0.979	-	-	0.516	-	-	0.446	-
T15	0.912	0.031	-	-	0.482	0.364	-	-
T18	0.983	-	-	0.882	-	-	0.081	-
T19	0.987	-	-	0.891	-	-	0.102	-
T21	0.938	-	-	0.946	-	-	0.032	-
T22	0.959	-	-	0.127	-	0.235	0.586	-
T23	0.985	-	-	0.102	-	-	0.831	-
T25	0.944	-	-	0.040	-	-	0.876	-
T27	0.930	-	-	0.039	0.424	-	0.499	0.073
T29	0.890	-	-	-	0.060	-	0.792	-
T30	0.823	0.064	-	-	-	-	0.760	-
Frequency count		5	3	17	8	6	18	3

Note: values are obtained from solution of CCR model for individual inefficient tehsil.

For better illustrations, the super-efficiency scores for fully efficient tehsils are also estimate (see Table C7 and Table C8 in Appendix C). The super-efficiency scores shows that in case of wheat, Talwandi Sabo is most efficient tehsil with super-efficiency score equal to 2.68. Hoshiarpur1 has occupied the second place having super-efficiency score of 1.30. And in case of paddy, Sangrur tehsil is ranked at the top position with 1.16 super efficiency score, and Mansa has the second place with 1.11 score.

Table 5.5: Peer-weights for inefficient tehsil and peer counts (Paddy)

Inefficient Tehsil	OTE	Reference Set						
		T12	T13	T19	T20	T21	T23	T29
T1	0.642	-	-	-	-	-	0.462	0.022
T2	0.683	0.742	-	-	-	-	-	-
T3	0.516	-	-	-	0.567	-	-	-
T4	0.681	0.596	-	-	-	-	-	-
T5	0.691	0.722	-	0.030	-	-	-	-
T6	0.701	0.478	-	0.258	-	-	-	-
T7	0.715	0.108	-	0.507	-	0.118	-	-
T8	0.675	0.803	-	-	-	-	-	-
T9	0.951	-	-	0.504	0.426	-	-	-
T10	0.909	-	-	0.722	-	0.183	-	-
T11	0.840	-	0.185	-	0.505	-	0.111	-
T14	0.985	-	-	0.439	0.527	-	-	-
T15	0.674	0.382	-	0.190	-	0.130	-	-
T16	0.966	-	-	0.376	0.603	-	-	-
T17	0.973	-	0.524	-	-	0.306	0.130	-
T18	0.947	-	-	-	-	0.646	0.325	-
T22	0.767	-	-	0.115	-	0.668	-	-
T24	0.968	-	-	-	0.863	-	0.179	-
T25	0.881	-	-	0.113	0.580	-	0.223	-
T26	0.683	0.776	-	-	-	-	-	-
T27	0.655	-	-	0.094	-	0.630	-	-
T28	0.755	-	0.226	0.087	-	0.424	-	-
Frequency count		8	3	12	7	8	6	1

Note: values are obtained from solution of CCR model for individual inefficient tehsil.

5.4.4 Discrimination of inefficient tehsils

Table 5.6 and Table 5.7, presents the classification results of inefficient tehsils. The most inefficient tehsils are Gurdaspur, Abohar, Balachaur, Dasua, and Anandpur Sahib in case of wheat, while Ajnala, Gurdaspur, Malout, Jalandhar and Anandpur Sahib are found to be inefficient in case of paddy. The cultivators of these tehsils are worst performers therefore; these tehsils are termed as ‘target tehsils’. The inefficient tehsils that have attained Q3<OTE<1 are included in “marginally inefficient” category. The tehsils included in this category are Ferozepur, Samrala, Jagraon, Mansa, Sangrur, and Guruharsahai in case of wheat, while Patiala, Sultanpur, Budhlada, Payal, Samrala are included in case of paddy. It is important to know that these tehsils are marginally inefficient because these tehsils are operating close to the frontier, but they are not producing on the frontier level. These tehsils can enhance their efficiency level in production, and can obtain the status of efficient tehsils by slightly improving their resources utilization process.

Table 5.6: Classification of inefficient tehsils (Wheat)

Category I (OTE<Q1) (Most Inefficient)	Category II (Q1<OTE<Median) (Below Average)	Category III (Median<OTE<Q3) (Above Average)	Category IV (Q3<OTE<1) (Marginally Inefficient)
Gurdaspur (30)	Patiala (25)	Malout (19)	Ferozepur (13)
Abohar (29)	Fazilka (24)	Ajnala (18)	Samrala (12)
Balachaur (28)	Jalandhar (23)	Malerkotla (17)	Jagraon (11)
Dasua (27)	Fatehgarh Sahib (22)	Bathinda (16)	Mansa (10)
Anandpur Sahib (26)	Batala (21)	Moga (15)	Sangrur (9)
	Patti (20)	Sardulgarh (14)	Guruharsahai (8)

Notes: 1) The 'Most Inefficient' category includes those tehsils which have OTE score below the first quartile; 2) Those tehsils are included in the 'Below Average' category whose OTE score lies between first and second quartile; 3) The 'Above Average' category consists of the tehsils wherein OTE score lies between median and third quartile; 4) The tehsils with OTE scores above the third quartile are included in the 'Marginally Inefficient' category; 5) Figures in brackets are ranks; and 6) Q1= 0.890, Q3=0.971, Median=930.

Table 5.7: Classification of inefficient tehsils (Paddy)

Category I (Most Inefficient)	Category II (Below Average)	Category III (Above Average)	Category IV (Marginally Inefficient)
Ajnala (29)	Patti (24)	Malout (18)	Patiala (12)
Gurdaspur (28)	Talwandi Sabo (23)	Sardulgarh (17)	Sultanpurlodhi (11)
Malout (27)	Batala (22)	Ferozepur (16)	Budhlada (10)
Jalandhar (26)	Dasua (21)	Bathinda (15)	Payal (9)
Anandpur Sahib (25)	Hoshiarpur 1 (20)	Fatehgarh Sahib (14)	Samrala (8)
	Balachaur (19)	Jagraon (13)	

Notes: same description in Table 5.6's note.

5.5 Efficiency Improvement: Slacks and Targets Setting Analysis

Table 5.8 and Table 5.9 presents the actual values and target values of input-output variables for 77 percent inefficient tehsils in case of wheat, and around 76 percent inefficient tehsils in case of paddy. The most inefficient tehsil in case of wheat is Gurdaspur with OTE score equal to 0.752. This tehsil can achieve efficient target, if all its inputs level proportionally reduced by 24.8 percent. Even after proportional reduction in all inputs, this tehsil would not become Pareto-efficient. Because non-zero inputs and output slacks[6] exist for this tehsil. To reach Pareto-efficient point, some additional slack modifications are required. The estimations of slacks for all inefficient tehsils show that 15 tehsils have non-zero slacks for human labour, 15 tehsils have non-zero slacks for machine, 4 tehsils have non-zero slacks for seed quantity, 1 tehsil has non-zero slacks for fertilizer, and 20 tehsils have non-zero slacks for irrigation hours. Further, no non-zero slacks have been observed for output (production and by-products). Whereas, in case of paddy the most inefficient tehsil is Ajnala which has OTE score equal to 0.516 implying that the tehsil can achieve efficient target if all its inputs level proportionally reduced by 48.4 percent. Among the 22 inefficient tehsils, 17 tehsils have non-zero slacks for human labour, 14 tehsils have non-zero slacks for machine, 12 tehsils have non-zero slacks for seed value, 11 tehsils have non-zero slacks for fertilizer, and 11 tehsils have non-zero slacks for irrigation hours. In other words, it can be concluded that majority of the inefficient tehsils need to reduce their irrigation hours per hectare, use of human hours per hectare, and quantity of fertilizers to attain the same level of output.

To obtain slacks and targets setting analysis across tehsil OTE scores has used with slacks values and actual values are used. The target point $(\hat{x}, \hat{y})$ is defined by the following equations:

$$\hat{x}_{ik} = \theta_k^* x_{ik} + s_i^- \qquad i = 1,2,\ldots\ldots,m$$

$$\hat{y}_{rk} = y_{rk} - s_r^+ \qquad r = 1,2,\ldots\ldots,s$$

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[6] The slacks represent only the leftover portions after reductions in inputs or output. These slacks take place only for inefficient tehsils and give an informative or valuable suggestion to the inefficient tehsils by which an inefficient tehsils can improve and become efficient tehsils. The slacks indicate how these inefficient farms can improve their operations and their efficiency (Jacobs et al., 2006). If a tehsil cannot reach to its efficient target, slacks help to push the tehsil to reach their target (Ozcan, 2008).

where, $\hat{x}_{ik}$ = target input i for k-th tehsil, $\hat{y}_{rk}$ = target output r for k-th tehsil; x_{ik} = actual input i for k-th tehsil; y_{rk} = actual output r for k-th tehsil; θ_k^* = OTE score of k-th tehsil; "s_i^-= optimal input slacks; and s_r^+= optimal output slacks. ($\Delta x_{ik} = x_{ik} - \hat{x}_{ik}$) presents the amount of input i to be reduced, while ($\Delta y_{rk} = y_{rk} - \hat{y}_{rk}$) presents the quantity of output r to be increased to push the inefficient tehsils to efficient frontier. The potential input reduction is for input i and potential output addition for output r is obtained by ($\Delta x_{ik}/x_{ik}$) ×100 and ($\Delta y_{rk}/y_{rk}$) ×100, respectively.

The percentage of potential input reduction and the percentage of output addition implies that most inefficient tehsil in case of wheat, which is Gurdaspur, needs to reduce its human labour hours per-hectare use by 25.5 percent, machine use by 24.8 percent, seed quantity per hectare by 34.1 percent, fertilizer amount by 24.8 percent, and the irrigation hours per hectare by 24.8 percent to achieve frontier level. In case of paddy, the tehsil Ajnala needs to reduce its human labour hours per hectare use by 55.84 percent, machine use by 49.84 percent, seed value per hectare by 62.25 percent, fertilizer amount by 48.41 percent, and the irrigation hours per hectare by 54.46 percent. The similar explanations can be obtained for the other inefficient tehsils. The results are consistent with the findings of Zhang et al., (2015) who studied productivity effect and overuse of pesticides in China. Similarly, the findings of Kumbhakar (1994) reported that in West Bengal, India.

Table 5.8: Actual and target values of input and output variables and potential reduction in inputs and potential addition in outputs (Wheat)

Inefficient-tehsils	OTE	Actual values of output and inputs variables						Target values of output and inputs variables						Potential Input reduction (%)					Potential output addition (%)
		Y1	X1	X2	X3	X4	X5	Y1	X1	X2	X3	X4	X5	X1	X2	X3	X4	X5	Y
T1	0.752	32.4	131	12.8	111	191	21.4	32.4	97.5	9.66	73	143	16.1	25.5	24.8	34.1	24.8	24.8	0
T2	0.924	44.6	140	18.8	103	227	55	44.6	95.9	14.1	95.1	210	8.61	31.5	25.2	7.67	7.61	84.3	0
T3	0.935	44.2	99.3	18.8	101	225	40.9	44.2	92.9	14.2	94.2	210	14	6.48	24.4	6.53	6.49	65.8	0
T4	0.929	43.7	109	13.9	101	224	38.0	43.7	101	12.9	94.2	208	16.4	7.19	7.12	7.14	7.14	56.9	0
T5	0.849	38.8	142	18.0	107	164	43.1	38.8	107	13.9	90.9	139	33.2	24.7	22.7	15.1	15.1	22.9	0
T7	0.825	41.8	159	16.5	122	202	48.1	41.8	131	13.6	97.5	166	38.8	17.5	17.6	20.1	17.5	19.4	0
T8	0.885	44.1	367	15.7	107	224	65.4	44.1	96.9	13.7	94.7	198	3.3	73.6	13.2	11.5	11.5	95	0
T9	0.920	46.4	102	15.4	111	262	36.3	46.4	93.7	14.2	102	241	34.3	8.01	7.98	7.93	7.97	5.32	0
T10	0.922	45.7	98.8	15.4	113	286	43.5	45.7	91.1	14.2	104	249	25.7	7.77	7.81	7.8	13	41.0	0
T11	0.971	46.4	103	18.2	100	248	43.6	46.4	94.6	15.2	97.3	240	21.7	8.19	16.6	2.93	2.91	50.1	0
T12	0.991	47.8	93.7	16.9	101	254	45.8	47.8	92.9	16.2	100	252	33.7	0.88	3.74	0.89	0.87	26.6	0
T13	0.945	46.4	145	16.2	102	269	47.6	46.4	92.9	15.3	96.2	254	31.0	35.9	5.49	5.48	5.51	34.8	0
T14	0.979	48.6	133	18.4	104	256	52.4	48.6	99.2	15.8	102	251	22.2	25.3	14.0	2.12	2.07	57.6	0
T15	0.912	42.8	116	14.4	112	204	55.1	42.8	106	13.2	95.3	186	39.2	8.74	8.80	15.1	8.82	28.8	0
T18	0.983	47.3	151	17.5	99	274	47.4	47.3	90.7	16.0	97.3	269	36.2	40.0	8.24	1.68	1.68	23.7	0
T19	0.987	48.9	129	16.8	102	280	47.9	48.9	93.9	16.5	101	276	36.6	27	1.84	1.37	1.29	23.6	0
T21	0.938	47.9	128	17.4	105	294	53.8	47.9	90.9	16.3	98.1	276	38.6	29	6.32	6.28	6.26	28.2	0
T22	0.959	49.0	160	15.2	110	246	69.1	49.0	115	14.5	105	235	19.3	28.3	4.09	4.11	4.11	72.1	0
T23	0.985	48.5	185	16.7	105	226	28.3	48.5	106	15.1	104	223	6.32	43	9.40	1.42	1.55	77.6	0
T25	0.944	47.8	164	18.2	109	229	22.9	47.8	105	14.8	103	216	3.93	36.1	18.4	5.6	5.6	82.8	0
T27	0.930	51.3	114	19.0	122	237	21.4	51.3	106	16.9	113	221	19.9	6.93	11.3	6.99	7.0	6.97	0
T29	0.890	44.3	114	16.1	107	220	9.05	44.3	97.0	13.8	95.6	196	4.39	14.8	14.3	11.0	11.1	51.5	0
T30	0.823	42.5	202	23.9	120	225	5.73	42.5	104	13.3	92.9	185	4.72	48.7	44.4	22.6	17.6	17.7	0

Notes: Y= production and by products, x1=human labour, x2= machine, x3 = seed quantity, x4=fertilizer, x5=irrigation.

Table 5.9: Actual and target values of input and output variables and potential reduction in inputs and potential addition in outputs (Paddy)

Inefficient-tehsils	OTE	Actual values of output and inputs variables						Target values of output and inputs variables						Potential Input reduction (%)					Potential output addition (%)
		Y1	X1	X2	X3	X4	X5	Y1	X1	X2	X3	X4	X5	X1	X2	X3	X4	X5	Y
T1	0.642	36.59	496.5	10.76	1564	142.7	122.2	36.59	152.1	6.356	922.3	91.53	78.42	69.37	40.95	41.04	35.84	35.84	0
T2	0.683	57.78	540.1	13.18	1864	197.2	291.4	57.78	240.1	9.009	1142	130.2	170.4	55.54	31.66	38.71	33.97	41.52	0
T3	0.516	39.65	399.0	12.50	2494	166.2	258.9	39.65	176.2	6.269	941.5	85.75	117.9	55.84	49.84	62.25	48.41	54.46	0
T4	0.681	46.42	380.0	10.63	2273	165.7	266.9	46.42	192.9	7.237	917.6	104.6	136.9	49.24	31.89	59.63	36.86	48.72	0
T5	0.691	58.77	390.0	13.44	1670	194.8	305.7	58.77	243.8	9.282	1153	132.3	174.1	37.49	30.94	30.93	32.10	43.04	0
T6	0.701	58.92	540.5	14.58	1553	221.0	288.9	58.92	241.3	10.23	1089	131.4	180.8	55.36	29.85	29.85	40.57	37.43	0
T7	0.715	60.57	356.9	16.25	1465	197.3	262.5	60.57	243.8	11.62	1048	136.1	187.7	31.70	28.50	28.50	31.03	28.50	0
T8	0.675	62.56	446.6	14.44	1890	231.1	278.3	62.56	260.0	9.754	1237	141.0	184.5	41.78	32.47	34.55	38.98	33.71	0
T9	0.951	72.15	336.5	14.49	1470	165.3	244.0	72.15	301.5	13.35	1398	157.1	227.2	10.43	7.868	4.948	4.948	6.909	0
T10	0.909	75.51	336.2	16.48	1408	200.3	258.6	75.51	302.4	14.88	1279	169.8	235.0	10.06	9.685	9.122	15.23	9.122	0
T11	0.84	58.44	345.9	13.14	1591	155.6	196.6	58.44	251.8	9.784	1336	130.7	165.1	27.22	25.56	16.03	16.03	16.03	0
T14	0.985	73.82	351.1	19.12	1501	163.1	286.1	73.82	311.3	13.36	1478	160.6	230.5	11.35	30.12	1.539	1.539	19.43	0
T15	0.674	56.19	340.8	14.33	1681	190.1	277.8	56.19	229.8	9.665	1053	128.2	165.7	32.57	32.57	37.36	32.57	40.35	0
T16	0.966	73.78	327.0	15.40	1571	166.1	269.6	73.78	313.6	13.11	1517	160.3	228.8	4.106	14.87	3.44	3.44	15.13	0
T17	0.973	76.00	326.1	17.15	1583	185.6	206.0	76.00	310.9	13.67	1540	180.5	200.4	4.682	20.33	2.749	2.749	2.749	0
T18	0.947	76.88	329.9	14.51	1793	214.6	191.2	76.88	312.3	13.01	1638	191.6	181.1	5.311	10.32	8.631	10.71	5.311	0
T22	0.767	63.33	334.0	14.59	2517	231.5	213.1	63.33	256.2	11.05	1208	155.4	163.4	23.30	24.29	52.01	32.86	23.30	0
T24	0.968	74.03	371.3	14.71	2049	169.9	215.8	74.03	323.9	11.86	1774	164.4	208.8	12.76	19.37	13.41	3.248	3.248	0
T25	0.881	67.11	326.7	17.11	1769	171.1	213.7	67.11	287.7	11.24	1543	150.7	188.2	11.93	34.3	12.77	11.93	11.93	0
T26	0.683	60.43	374.4	13.79	2917	214.5	282.2	60.43	251.1	9.422	1195	136.2	178.2	32.93	31.66	59.05	36.5	36.85	0
T27	0.655	58.55	361.7	19.22	1883	229.4	229.4	58.55	236.9	10.18	1120	144.0	150.2	34.51	47.07	40.53	37.23	34.51	0
T28	0.755	59.23	358.4	14.55	1502	187.8	210.0	59.23	240.8	10.62	1135	141.9	158.7	32.82	27.00	24.45	24.45	24.45	0

Notes: Y= production and by products, x1=human labour, x2= machine, x3 = seed value, x4=fertilizer, x5=irrigation.

5.6 Allocative and Cost Efficiency Analyses

Table 5.10 presents the estimation of Equations (5.4) and Equation (5.5). The results show that only 3.33 percent in case of wheat and 3.44 percent in case of paddy tehsils are found to be allocative efficient. These efficient tehsils are operating with the optimal combination of inputs at given input prices. It indicates that majority of the tehsils are using inappropriate combinations of input-mix at given input prices. Further, only 3 percent of the tehsils are cost efficient in both crops. Further, 23 percent inefficient tehsils, in case of wheat; and 15 percent in case of paddy are operating under higher cost of production. The inefficient tehsils can minimize their production cost by 27.3 percent in case of wheat; and 31 percent in case of paddy to achieve the same level of output. They can reduce their costs by carefully selecting the appropriate combinations of inputs at given input prices. In the results, in case of wheat-Jalandhar; and in case of paddy- Malerkotla both are fully allocative efficient tehsils showing that they have efficient farmers in crop cultivation. Therefore, other farmers need to learn from these farmers to improve their efficiency level. These results are consistent with existing studies that showed that the majority of rice farms are unable to apply correct mixer of inputs that is necessary for achieving cost minimization due to which they are both allocatively and economically inefficient (Watkins et al., 2014).

As mentioned, only Jalandhar tehsil (in case of wheat) and Malerkotla tehsil (in case of paddy) are fully profit-efficient[7]. The tehsils that have technical efficiency scores greater than allocative efficiency (TE>AE) scores, show the inability of the farmers to use optimum mix of resources to minimize cost at given inputs. If TE<AE, it implies that farmers are cultivating with exploitative use of input resources. The results presented in Table 5.10 show that the two tehsils in case of wheat and 14 tehsils in case of paddy have technical efficiency scores less than allocative efficiency scores. In case of paddy, most of the tehsils have

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[7] A farm is said to be fully profit efficient if and only if that farm is technically, allocatively and scale efficient (Forsund et al., 1980).

TE<AE, which specifies that farmers of these tehsils are using input resources in an inefficient manner.

Table 5.10: Estimated results from Equations 5.4 and Equation 5.5 for wheat and rice

Tehsils	Wheat			Paddy		
	TE	(AE =CE/TE)	(CE=TE*AE)	TE	(AE =CE/TE)	(CE=TE*AE)
T1	0.752	0.794	0.597	0.530	0.595	0.315
T2	0.924	0.778	0.718	0.691	0.669	0.462
T3	0.935	0.856	0.800	0.536	0.822	0.441
T4	0.929	0.859	0.798	0.681	0.736	0.501
T5	0.849	0.821	0.697	0.694	0.896	0.622
T6	1.000	0.472	0.472	0.976	0.536	0.523
T7	0.825	0.798	0.658	0.684	0.881	0.602
T8	0.885	0.381	0.337	0.675	0.834	0.536
T9	0.920	0.830	0.764	0.867	0.862	0.748
T10	0.922	0.765	0.706	0.900	0.813	0.731
T11	0.971	0.812	0.788	0.700	0.943	0.660
T12	0.991	0.820	0.813	1.000	0.983	0.983
T13	0.945	0.723	0.683	0.979	0.890	0.871
T14	0.979	0.771	0.755	0.839	0.801	0.672
T15	0.912	0.860	0.785	0.668	0.884	0.591
T16	1.000	0.837	0.837	0.907	0.778	0.706
T17	1.000	0.773	0.773	0.935	0.878	0.821
T18	0.983	0.686	0.675	0.941	0.905	0.852
T19	0.987	0.738	0.728	1.000	0.847	0.847
T20	1.000	1.000	1.000	0.986	0.885	0.872
T21	0.938	0.727	0.681	1.000	1.000	1.000
T22	0.959	0.740	0.710	0.768	0.904	0.694
T23	0.985	0.689	0.678	1.000	0.956	0.956
T24	1.000	0.743	0.743	0.913	0.836	0.764
T25	0.944	0.759	0.717	0.834	0.966	0.805
T26	1.000	0.889	0.889	0.778	0.798	0.620
T27	0.930	0.922	0.857	0.656	0.918	0.602
T28	1.000	0.804	0.804	0.678	0.991	0.671
T29	0.890	0.893	0.794	0.595	0.929	0.553
T30	0.823	0.666	0.548	-	-	-

Note: TE= Technical efficiency; AE= Allocative efficiency; CE=Cost efficiency.

5.7 Impact of Crop Diversification on Economic Efficiency

Table 5.11 presents the estimation of Equation (5.6). From the estimation, it is observed that the crop diversification has a positive and statistical significant impact on the technical efficiency as well as on cost efficiency in case of both crops-wheat and paddy. It implies that as a farmer becomes more diversified, their economic efficiency significantly increases.

These results are consistent with the findings Coelli and Fleming (2004) that crop diversification has significantly improves technical efficiency of farms in Guinea, but this results does not support the outcomes by Llewelyn and Williams (1996) who found that crop diversification significantly led to greater technical inefficiencies in East-Java, Indonesia.

Table 5.11: Estimation of Equation (5.6)

Variables	Wheat		Paddy	
	Technical efficiency	Cost efficiency	Technical efficiency	Cost efficiency
Age	-0.0002 (0.0006)	-0.0008 (0.0015)	0.0009 (0.0020)	0.0016 (0.0021)
Female	0.00096 (0.0305)	0.0272 (0.0705)	-0.0937 (0.0936)	-0.0578 (0.0997)
Education				
Up to primary	-0.0284 (0.02781)	0.0348 (0.0643)	-0.0357 (0.0866)	-0.1324 (0.0922)
Up to secondary	-0.0090 (0.03030)	0.0309 (0.0701)	-0.0869 (0.0953)	-0.1853 (0.1015)
Secondary	-0.0168 (0.0337)	0.0639 (0.0781)	-0.0124 (0.1241)	-0.2057 (0.1321)
Post-Secondary	-0.0839 (0.0598)	0.0763 (0.1385)	0.0501 (0.1957)	0.0205 (0.2083)
Major occupation				
Crop production	-0.0400 (.03452)	0.0551 (0.0798)	-0.1811 (0.1025)	-0.1875 (0.1091)
Non-crop agriculture	-0.0095 (0.0473)	-0.0188 (0.0740)	-0.0441 (0.1012)	-0.0699 (0.1078)
Other work	-0.0313 (0.0473)	-0.0417 (0.1094)	-0.0532 (0.1389)	-0.0129 (0.1479)
HHI	.6570*** (0.1972)	1.2412*** (0.4563)	1.8883*** (0.9205)	2.0466*** (0.9800)
R-squared	54	37	50	39
Observation	30	30	29	29

Note: *** p<0.01, ** p<0.05, * p<0.1 represent the significance level at 1%, 5%, and 10% respectively, and Standard errors are in the parentheses.

5.8 Conclusions

The injudicious use of inputs affect sustainability of agriculture, specifically in developing countries where agricultural resources are scarce and adopting better technologies is not feasible due to financially weak farmers. In this context, three key issues are address in this chapter; (i) to estimate the economic efficiency of crop production in Punjab; (ii) to determine the effect of crop diversification on economic efficiency.

It is found that overall around 23 percent tehsils are operating at flatter portion of long-run average cost curve, and remaining 77 percent tehsils are performing above or below the optimum scale of production. Further, it found a greater portion of inefficiency is mainly attributed by scale inefficiency rather than pure technical inefficiency. Additionally, it is observed that tehsils are allocating their inputs resources with exploitative manner due to which, they fail to choose a suitable combination of inputs which is necessary to achieve cost minimization. Moreover, it is also found that 23 percent tehsils in case of wheat; and 15 percent inefficient tehsils are working under higher cost of production.

Thus, the study suggests that there is substantial scope for upgrading in the performance of inefficient tehsils by carefully choosing combination of inputs at given input prices and scale size. The inefficient tehsils need better guidance and information in selecting the appropriate combination of inputs at given input prices. Moreover, it is also pointed out that here the efficiency is measured at the farm level in Punjab, this farm-level information may show the ways to formulate appropriate efficiency generating policies.