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# An Efficiency Analysis of Sugarcane Farming in India: An Interstate Comparison of Performance with Data Envelopment Analysis and Malmquist Index

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## ABSTRACT

**Background:** This paper aims to evaluate the agricultural production of sugarcane in major sugarcane-producing states of India. Even though agriculture's share of India's GDP is decreasing, it still plays a significant role in the labor force by accounting for a sizable number of jobs. Recognizing the importance of sugarcane farming and the variations in resource availability among the states is crucial. The study highlights the importance of enhancing production management and resource allocation to increase sugarcane production and optimize inputs

**Methods:** The present research employs sophisticated statistical techniques, including Data Envelopment Analysis (DEA) and the Malmquist Productivity Index (MPI), to investigate the influence of variables such as land area and labor utilization on the efficacy of sugarcane cultivation at the state level spanning from 2017 to 2022. It uses DEA to analyze the connection between various agricultural inputs and the efficiency of food grain production and provides recommendations for improved resource allocation among Indian states.

**Result:** The results of the investigation indicate that the mean efficiency of sugarcane cultivation across India is approximately 84.2%. Notably, states such as Uttar Pradesh, Tamil Nadu and Karnataka have demonstrated the highest levels of efficiency in terms of input utilization in sugarcane farming. Conversely, Bihar and Uttarakhand have emerged as the least efficient states in this regard. Furthermore, an analysis using the Malmquist productivity index indicates that Uttar Pradesh has exhibited the most significant average productivity growth, with Maharashtra and Gujarat following closely behind. Conversely, states such as Andhra Pradesh, Punjab, Haryana and Tamil Nadu have demonstrated only marginal enhancements in productivity. The study's insights on sustainable sugarcane production and enhanced farmer-level regulatory frameworks have the potential to greatly benefit sugarcane-producing states. By implementing these ideas, we can work towards boosting revenue and reducing poverty in rural areas.


**Key words:** Data envelopment analysis, Malmquist productivity index, Sugarcane farming, Technical efficiency.

## INTRODUCTION

India is an expanding agricultural nation, with agriculture serving as the cornerstone for social advancement, industrial structure modification and economic growth. AI-enabled technology such as Internet of Things (IoT), data analytics and artificial intelligence will soon assist the farming sector in developing post-COVID-19 agricultural practices that are necessary for a new normal (Upendra *et al.*, 2021). Among all the crops, sugarcane has been one of the most important and demanding. In India, sugarcane has been cultivated for centuries as a traditional crop. In the early 20$^{th}$ century, sugarcane was mostly grown in northern subtropical regions. Currently, nevertheless, it is grown in practically every state except the mountainous ones. Across an estimated 4.3 million hectares, sugarcane is cultivated nationwide. Although production levels had previously improved significantly, they have essentially stalled over the past 20 years. The cultivation of sugarcane is under threat from sugarcane yellow leaf disease, which affects practically all kinds grown in India and outside (Hemalatha *et al.*, 2022). One of the defining characteristics of Indian sugarcane agriculture is the wide fluctuations in sugarcane production. Due to rising per-capita sugar consumption by the world's population and the variety of applications for sugarcane, there is a growing demand for the crop. Therefore, it is necessary to increase output on a sustainable basis. Since it's hard to locate additional land for sugarcane, the increase has to come mainly through higher yields.

India's major sugar-producing states comprise Uttar Pradesh, Tamil Nadu, Bihar, Andhra Pradesh, Gujarat,

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Karnataka, Maharashtra, Punjab, Haryana and Uttarakhand. The principal aim of this document is to analyze the efficiency and changes in total factor productivity across these states in the context of sugarcane farming. In our current research, we have utilized an input-oriented data envelopment analysis approach with one output and two inputs to evaluate efficiency. Additionally, we have employed the Malmquist productivity index to quantify total factor productivity. Only a few pieces of literature exist that measure the performance of sugarcane farming and study the variation among different states. Some of the studies are Felix *et al.* (2021), an assessment of the technical inefficiency among Indian farmers in sugarcane cultivation. According to their findings, the overall technical efficiency varies from 0.11 to 0.93, with an average of 0.70. Shinta, (2016) emphasizes the influence of technical inefficiency on farmers' profit earned. The result shows a negative influence of technical inefficiency on profit earned. Singh, (2019) undertook research to assess how climate change affects sugarcane yield in India. The results show that the production and yield of sugarcane are negatively and statistically significantly impacted by varying weather patterns over the seasons. Except for Tamil Nadu, most states exhibit technological inefficiency when it comes to sugarcane cultivation. Gupta and Badal, (2021) assess the total factor productivity of sugarcane in Uttar Pradesh. Their findings indicate a consistent decline in total factor productivity over the examined period, primarily attributed to inefficient practices in sugarcane production. Murali and Puthira Prathap, (2017) evaluated the technical effectiveness of sugarcane plantations in three distinct Tamil Nadu agricultural regions. They used a stochastic frontier production function to measure technical efficiency and applied Garrett's ranking technique for constraint analysis. The results indicate that the mean technical efficiency of sugarcane production was 88%, 78%, 80% and 82% in the Western, North-East Zones, Cauvery Delta and overall pooled data, respectively. Fahriyah *et al.* (2018), suggested that sugar consumption in Indonesia is primarily driven by both household and industrial demands.

Similarly, Coelli *et al.* (2002) highlighted the significance of technical efficiency in driving productivity and fostering agricultural growth. Ahmad *et al.* (2018) carried out a study to examine the expansion and fluctuation of the area, productivity and output of sugarcane farming. The research also evaluated resource utilization efficiency in major sugarcane-producing states in India, as well as the trade performance of sugar. Saravanan and Prof, (2016) investigate the socio-economic attributes of sugarcane cultivators and assess the expenses and benefits linked to sugarcane yield. It explores how resources are utilized among sugarcane growers of different farm sizes and evaluates the technical efficiencies at the farm level in sugarcane production within the Erode District in Tamil Nadu. Haque, (2005), discussed the resource use efficiency in Indian agriculture with various factors and analyzed the changes in factor productivity and profitability over time. Ali and Jan, (2017) analyses the sugarcane grower's varying yield and input levels. Education and experience impact technical inefficiency. Household size did not affect technical efficiency. Bamrungrai *et al.* (2022) stated that there was no discernible difference in the sugar quality components across cultivars and fertilizer application techniques.

## MATERIALS AND METHODS

The research utilizes secondary data spanning five years, from 2017-18 to 2021-22, obtained from ten primary sugarcane-producing states: Andhra Pradesh, Gujarat, Haryana, Bihar, Karnataka, Maharashtra, Punjab, Uttar Pradesh, Tamil Nadu and Uttarakhand. Each state serves as an independent decision-making unit (DMU), employing inputs to generate sugarcane output annually. A total of 5 years of data was gathered from various secondary data sources such as the Directorate of Economics and Statistics Department of Agriculture and Farmers Welfare, Indian Institute of Sugarcane Research Lucknow and the Indiastat website. For calculating efficiency and Malmquist productivity index data of the last 5 years *i.e.* from 2017-18 to 2021-22 is being considered to cover structural and political changes in the agriculture sector of India. This study was conducted during the months of February-April 2024 and all the research work including data collection, data processing and data analysis is being done in the research division of the Aligarh Muslim University, Aligarh, Uttar Pradesh.

This research employs two widely recognized methods, Malmquist Productivity Index (MPI) and Data Envelopment Analysis (DEA) to assess the productivity changes and technical efficiency in ten key states engaged in sugarcane production. To find the variation in productivity of a particular DMU over the years, the Malmquist Productivity Index is being used. The main feature of MPI is that it decomposes productivity change into changes in efficiency, technology, pure technical change and change in scale efficiency. In both, DEA and MPI input-output variables are the same. The MPI scores are computed in the second stage, to assess whether states become less efficient, more efficient, or remain constant over the sample period.

Charnes *et al.* (1978), initially proposed the CCR model which is based on a constant return to scale (CRS) assumption. Later, the BCC model was suggested by Banker *et al.* (1984) to differentiate between technical efficiency and scale efficiency. It relaxed the assumption of CRS and made it possible to assess the performance of DMUs using variable return to scale (VRS). By taking the ratio of the weighted sum of the outputs to the weighted sum of the inputs, the DEA calculates each DMU's efficiency. The DEA model uses the data to determine these weights to maximize the efficiency of each DMU.

$$\text{Efficiency ratio} = \frac{\text{Weighted sum of output}}{\text{Weighted sum of inputs}}$$

The input-oriented model's envelope form for a model with m input variables, s output variables and n DMUs are as follows:

$$\min \theta$$
$$\theta \lambda$$
Subject to:
$$\theta x_0 - X\lambda \geq 0$$
$$Y\lambda \geq y_0 \quad \text{...(1)}$$
$$\lambda \geq 0,$$

Where:

$y_0$ and $x_0$ = Output vector and input vector respectively for $DMU_0$.

Y and X = Matrices of output and input vectors respectively for all DMUs.

θ= The objective function θ is a radial contraction factor that can be applied to the inputs of $DMU_0$.

λ = Column vector of intensity-related variables that represent a linear combination of DMUs.

Since DEA evaluates efficiency empirically about the data sample, having a small number of DMUs will typically lead to a high percentage of them being determined to be efficient. Banker *et al.* (1984) gives a broad guideline for the bare minimum of DMUs relative to the number of variables needed to provide a meaningful outcome with a separate set of units that are efficient and inefficient:

$$n \geq \max\{m \times s, 3(m+s)\} \quad \text{.....(2)}$$

Where,

s, m and n = Numbers of outputs, inputs and DMUs respectively.

The model presented in Eq. 1 aims to determine the greatest percentage (*i.e.*, 1-θ) that may be used to lower all inputs while maintaining a similar level of outputs as the original DMU. The efficiency score of the DMU in question can be determined by evaluating the ideal value of θ, represented by θ*. This value falls between zero and one, inclusive.

The Malmquist index described by the (Coelli and Rao, 2005) for the total factor productivity for the period t is given by the relation:

$$M_t = \frac{D^t(X^{t+1}, Y^{t+1})}{D^t(X^t, Y^t)} \quad \text{....(3)}$$

For the period t+1, the MPI was given by the relation:

$$M_{t+1} = \frac{D^{t+1}(X^{t+1}, Y^{t+1})}{D^{t+1}(X^t, Y^t)} \quad \text{....(4)}$$

Thus, the change in total factor productivity was given by the geometric mean of the above two indexes, respectively:

$$M_{t,t+1} = \sqrt{\frac{D^t(X^{t+1}, Y^{t+1})}{D^t(X^t, Y^t)} \times \frac{D^{t+1}(X^{t+1}, Y^{t+1})}{D^{t+1}(X^t, Y^t)}} \quad \text{....(5)}$$

Considering the constant return to scale technology, this index can be decomposed into the dimension of change in technical efficiency (effch) and technological progress (techch). In variable return to scale technology, it can also reflect pure technical efficiency change(pech) and scale efficiency change (sech). An MPI value greater than 1 indicates the total factor productivity has increased over the two successive periods. A value equal to 1 indicates no change in factor productivity and a value below 1 indicates a fall in total factor productivity from period t to t+1.

Specification of input and output variables is crucial in DEA and MPI. The output and input variables are chosen based on the brief survey of literature and the availability of published data. This study uses one output and two inputs for measuring productivity and efficiency change. The output variable is the aggregate production of sugarcane and its bi-products produced by a particular state in a single year. The input parameters are the total land area available for sugarcane production and labor employed in each state. The aggregate production is taken in terms of millions of tonnes of sugarcane and its bi-products produced through sugarcane farming, variable land is taken as the total land area (in lakh hectares) available in each state for sugarcane farming and variable labor is taken as the total man-hours used in the sugarcane farming. Table 1 gives the descriptive statistics of outputs and inputs for each of the selected years.

## Results and Discussion

Data Envelopment Analysis and the Malmquist Productivity index have been applied to assess the efficiency and productivity of 10 major sugarcane-producing states *i.e.* Andhra Pradesh, Bihar, Haryana, Karnataka, Gujarat, Maharashtra, Punjab, Tamil Nadu, Uttar Pradesh and Uttarakhand, over 5 years from 2017-18 to 2021-22 separately. The result has been analyzed in two stages: In the first stage, measures of technical efficiency and return to scale of the sample states over the different years have been obtained using the input-oriented CCR model and in the second stage, the result of Malmquist productivity index has been analyzed. The input-oriented technical efficiency scores of 10 sugarcane-producing states in different years are given in Table 2.

Results of the CCR model suggest that states such as Tamil Nadu, Uttar Pradesh and Karnataka are efficient in all five years. The average efficiency of all the states varies between 82.9% to 85.5%. It is clear from the (Table 2) that from the year 2017-18 to 2021-22, average efficiency has declined

The year 2019-20 is the worst performing year in which the average efficiency of all these states is only 82.9%, whereas the year 2018-19 is the best performing year for sugarcane production as it shows the average efficiency of all the sugarcane-producing states is 85.5%. The overall average efficiency score of these states in all five years is 84.2%, which indicates that all these states can reduce their input resources up to 15.8% while producing the same amount of output.

In terms of state-specific analysis, it is observed that Bihar is the worst-performing entity among the sample states. The technical efficiency of Bihar sees a declining trend throughout the five years with the average technical efficiency over the five years being 66.5%, which indicates that it is using 33.5% more input resources as compared to the best-performing states. The states of Gujarat and Uttarakhand have improved significantly over the years in terms of technical efficiency scores. In 2017-18, the technical efficiency of Gujarat and Uttarakhand were 66.5% and 69.8% respectively, which have been improved to 80.8% for Gujarat and 73.2% for Uttarakhand in 2021-22. Similarly, technical efficiency scores of states like Andhra Pradesh, Haryana and Punjab have declined from 79.01%, 87.61% and 83.7% in 2017-18 to 71.08%, 75.24% and 75.01% in 2021-22respectively. States like Karnataka, Tamil Nadu and Uttar Pradesh remain the most efficient states throughout the five years. However, Bergendahl, (1998) suggests that only based on the DEA scores, it is hard to find out the most efficient states and benchmark them. According to Mostafa, (2009), units with fewer appearances in the peer set are not as likely to have the characteristics needed to establish a benchmark for that peer set. Here it is suggested that these states have the potential to improve

**Table 1:** Descriptive statistics of variables used.

| Variable | Obs. | Mean | Std. dev. | Min | Max |
|---|---|---|---|---|---|
| **2017-18** | | | | | |
| Output (in million tonnes) | 10 | 36.592 | 54.46053 | 6.27 | 177.03 |
| Land (in lakh Ha) | 10 | 4.493 | 6.733112 | 0.9 | 22.34 |
| Labor (Man-Hrs) | 10 | 1256.413 | 491.2601 | 680.67 | 1908.14 |
| **2018-19** | | | | | |
| Output (in million tonnes) | 10 | 39.118 | 55.69365 | 6.33 | 179.71 |
| Land (in lakh Ha) | 10 | 4.802 | 6.95774 | 0.91 | 22.24 |
| Labor (Man-Hrs) | 10 | 1251.532 | 522.0493 | 570.06 | 2380.85 |
| **2019-20** | | | | | |
| Output (in million tonnes) | 10 | 35.499 | 54.38385 | 6.72 | 179.54 |
| Land (in lakh Ha) | 10 | 4.34 | 6.648345 | 0.86 | 22.08 |
| Labor (Man-Hrs) | 10 | 1144.853 | 436.3271 | 559.47 | 2010.4 |
| **2020-21** | | | | | |
| Output (in million tonnes) | 10 | 38.782 | 57.10066 | 4.12 | 177.67 |
| Land (in lakh Ha) | 10 | 4.652 | 6.854521 | 0.55 | 21.8 |
| Labor (Man-Hrs) | 10 | 1241.829 | 358.8064 | 733.33 | 1833.59 |
| **2021-22** | | | | | |
| Output (in million tonnes) | 10 | 42.518 | 59.7247 | 3.52 | 179.17 |
| Land (in lakh Ha) | 10 | 4.944 | 7.018199 | 0.44 | 21.77 |
| Labor (Man-Hrs) | 10 | 52.1485 | 13.77202 | 28.83 | 76.08 |

Source: Ministry of Agriculture and Farmers Welfare, Govt. of India.

**Table 2:** The efficiency scores of Indian States' sugarcane productivity over 5 years.

| | Input-oriented technical efficiency | | | | | |
|---|---|---|---|---|---|---|
| States | 2017-18 | 2018-19 | 2019-20 | 2020-21 | 2021-22 | Average efficiency scores over the years |
| Andhra Pradesh | 0.79018 | 0.76815 | 0.72495 | 0.73153 | 0.71080 | 0.74512 |
| Bihar | 0.63528 | 0.95278 | 0.65363 | 0.51063 | 0.57633 | 0.66573 |
| Gujarat | 0.66512 | 0.70794 | 0.66672 | 0.75367 | 0.80835 | 0.72036 |
| Haryana | 0.87615 | 0.79390 | 0.82809 | 0.87143 | 0.75242 | 0.82440 |
| Karnataka | 0.92840 | 1.00000 | 1.00000 | 1.00000 | 1.00000 | 0.98568 |
| Maharashtra | 1.00000 | 0.86821 | 0.95314 | 0.99272 | 1.00000 | 0.96281 |
| Punjab | 0.83785 | 0.79213 | 0.76490 | 0.82185 | 0.75010 | 0.79337 |
| Tamil Nadu | 1.00000 | 1.00000 | 1.00000 | 1.00000 | 1.00000 | 1.00000 |
| Uttar Pradesh | 1.00000 | 1.00000 | 1.00000 | 1.00000 | 1.00000 | 1.00000 |
| Uttarakhand | 0.69870 | 0.67369 | 0.69986 | 0.80915 | 0.73222 | 0.72272 |
| Average efficiency scores | 0.84317 | 0.85568 | 0.82913 | 0.84910 | 0.83302 | 0.84202 |

Note: Author's own calculations.

**Table 3:** Malmquist productivity index summary of Indian States from 2017 to 2022.

| DMUs | Technical efficiency change | Technical change | Pure technical change | Scale efficiency change | Total factor productivity change/ mpi |
|---|---|---|---|---|---|
| Andhra Pradesh | 0.974 | 1.046 | 1.010 | 0.965 | 1.019 |
| Bihar | 0.976 | 1.207 | 0.963 | 1.014 | 1.178 |
| Gujarat | 1.050 | 1.272 | 1.088 | 0.965 | 1.335 |
| Haryana | 0.963 | 1.078 | 0.990 | 0.973 | 1.037 |
| Karnataka | 1.019 | 1.304 | 1.000 | 1.019 | 1.329 |
| Maharashtra | 1.000 | 1.482 | 1.000 | 1.000 | 1.482 |
| Punjab | 0.973 | 1.049 | 0.979 | 0.993 | 1.021 |
| Tamil Nadu | 1.000 | 1.067 | 1.000 | 1.000 | 1.067 |
| Uttar Pradesh | 1.000 | 1.603 | 1.000 | 1.000 | 1.603 |
| Uttarakhand | 1.012 | 1.044 | 1.000 | 1.012 | 1.056 |
| Mean | 0.996 | 1.201 | 1.003 | 0.994 | 1.197 |

Note: All Malmquist index averages are geometric means. Author's own calculations.

**Table 4:** Malmquist index summary of annual means for states during 2017-18 to 2021-22.

| Year | Technical efficiency change | Technical change | Pure technical change | Scale efficiency change | Total factor productivity change/MPI |
|---|---|---|---|---|---|
| 2018-19 | 1.018 | 1.027 | 1.002 | 1.016 | 1.046 |
| 2019-20 | 0.965 | 1.011 | 0.970 | 0.995 | 0.976 |
| 2020-21 | 1.020 | 0.981 | 1.040 | 0.980 | 1.000 |
| 2021-22 | 0.983 | 2.045 | 0.999 | 0.984 | 2.011 |
| Mean | 0.996 | 1.201 | 1.003 | 0.994 | 1.197 |

Note: 2017-18 is reference year. Author's own calculations.

technical efficiency by reducing the amount of inputs usage without compromising the level of output in sugarcane farming.

To gauge the change in efficiency over time, the Malmquist productivity index is being used. It is calculated as the product of innovation (frontier shift) and recovery (catch-up). The result of the Malmquist Productivity Index (MPI) is given in Table 3. It is observed from the table that all the 10 states have shown an improvement in terms of MPI index or Total factor productivity change. Amongst them, Uttar Pradesh has seen the highest average productivity growth which is 60.3%. This is purely due to the increase in technical change to the extent of 60.3%. This implies that over the years the state of Uttar Pradesh has shifted its frontier upward which is an indication of positive technical change in sugarcane farming. The second and the third highest improvements in terms of total factor productivity change are shown by the states of Maharashtra and Gujarat respectively. Whereas, for Maharashtra, the average total factor productivity change is 48.2% and for Gujarat, the average total factor productivity change is 33.5%. The increase in productivity in Karnataka is due to the increase in technical efficiency and scale efficiency to the extent of 1.9% but pure efficiency change remains stagnant for Karnataka. The state of Andhra Pradesh has shown the least improvement in terms of average total factor productivity change to the extent of 1.9% over the years. This is due to the decline in technical efficiency to the extent of 2.6% and the decline in scale efficiency to the extent of 3.5%. States such as Haryana, Punjab, Tamil Nadu and Uttarakhand have achieved a single-digit growth rate in terms of average total factor productivity change which is 3.7%, 2.1%, 6.7% and 5.6% respectively. Overall, we can say that in sugarcane farming in India, all these states have shown a significant increase in total factor productivity. But the result also reflects that some sugar farming states such as Andhra Pradesh, Haryana, Punjab, Tamil Nadu and Uttarakhand need to close the efficiency gap and improve productivity with the help of government persistent interventions.

Table 4 shows the annual average total factor productivity change of all 10 states for the year 2017-18 to 2021-22. It is observed from the table that productivity was higher in the year 2021-22 (2.011), which is purely attributed to the technical change, whereas technical efficiency change (0.983), pure efficiency change (0.999) and scale efficiency change (0.984) have declined in 2021-22. The year 2019-20 remains the worst-performing year in which the average total factor productivity has declined to 2.4%. This can be linked to external factors such as the all-India lockdown due to the spread of the COVID-19 virus which impacted all the sectors of the country.

## CONCLUSION

India's total production of sugarcane is changing, although at highly varied rates depending on the location. This study looks into the efficiency and change in productivity of sugarcane farming in 10 large sugarcane farming states over a time period of 2017 to 2022. For measuring the efficiency and change in productivity we used the input-oriented Data Envelopment Analysis methodology and Malmquist Productivity Index. Results of the study show that the overall average efficiency of sugarcane farming in India is around 84.2%. States like Uttar Pradesh, Tamil Nadu and Karnataka are the most efficient states in terms of input utilization in sugarcane farming. In contrast, states like Bihar and Uttarakhand are the worst-performing states in terms of input-oriented technical efficiency. The result suggests that there is a lot of room for enhancement in terms of operational procedures to increase input utilization efficiency in sugarcane farming for all the states in India. Inputs like labor, the area cultivated, fertilizers manure, etc. have played an important part in improving sugarcane farming. Recent government regulations also emphasize that input reduction strategies will significantly increase farmers' incomes and agricultural output. The distribution of land size for agricultural purposes may also provide insight into the high level of inequality within the highly productive states.

The results of the Malmquist productivity index show that Uttar Pradesh has seen the highest average productivity growth followed by the state of Maharashtra and Gujarat. Most of the change in productivity in these states over the sample years is attributed to the change in technology (*i.e.* shift in production frontier). The states that have shown the least improvement in terms of productivity are Andhra Pradesh, Punjab, Haryana and Tamil Nadu. The reason for the lower productivity of these states can be attributed to changes in technical efficiency and scale efficiency. It is also observed that all the states have shown improvement in terms of technical change over the sample period. The years 2021-22 have shown a major improvement in the productivity of all these states. This is due to favourable government policies for sugarcane farming and improvement in credit facilities for farmers. Thus, farmers in sugarcane farming become more financially stable and would be able to use high-yield varieties of seed, more irrigation facilities and improved technologies in farming.

### Conflict of interest

Every author certifies that there are no possible conflicts of interest associated with the release of their work. This covers any financial or interpersonal ties that might have seemed to have an impact on the publication's content.

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