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# Efficiency and Productivity Analysis of the Indian Agriculture Sector Based on the Malmquist-DEA Technique

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**Abstract** This article evaluated the agricultural performance of 31 states and union territories (UTs) in India from 2012 to 2017. The best agricultural productivity states and UTs in India were obtained using Malmquist based DEA technique and the efficiency score for each year was found using CCR model. The input parameter is taken as annual rainfall, total population, GDP, Workers, and net cultivated area, and the output parameter is taken as production of rice, wheat, coarse cereals, pulses, oil seeds, and sugarcane. The productivity of the states and UTs are compared, as well as the increase or decrease in productivity is calculated. Total productivity change was calculated using cumulative Malmquist index (CMI). As a results, Punjab, Rajasthan, Sikkim, and Uttar Pradesh are the most efficient states throughout the year, while Kerala and Goa are the least efficient. Maximum states and UTs advanced 61.25 % in 2015-16, whereas maximum states and UTs declined 62.52 % in 2012-13. The overall productivity change in Madhya Pradesh inceases perfectly while Nagaland's is almost decreasing. Other factors that may have an influence on state and UTs agriculture productivity include capital investment and fertiliser use. Additional social and environmental performance criteria, such as contribution to local community development and harmful emission measurement, can be integrated as output criteria for sustainability performance analysis.

**Keywords** Data Envelopment Analysis, Malmquist Index, Cumulative Malmquist Index, Productivity Analysis, Agricultural Efficiency

## 1 Introduction

India is a growing agricultural country, with agriculture functioning as a fundamental basis for economic development, social improvement, and industrial structure adjustment and 60% of the Indian population is directly dependent on the agriculture sector and they contributed 20.19% of India's GDP in 2020-21. As a result, the government has issued a number of policies for agricultural development processes in order to encourage the sustainable and healthy growth of agriculture including the National Agriculture Market (E-MAN), which is a pan-India electronic trade network, which connects the current APMC mandis to form a unified national market for agricultural commodities. In order to increase agricultural production, sustainability, remuneration, and climate resilience, the government of India launched the national mission for sustainable agriculture (NMSA) in 2014-15. Every year, farmers suffer financial losses as a result of damage to crops caused by drought, floods, and rainstorms. As a result, in order to save the crop from this negative impact, the government introduced the Pradhan Mantri Fasal Bima Yojana (PMFBY) in 2016. The government of India has designed the Pradhan Mantri Krishi Sichayee Yojana (PMKSY) with the goal of expanding irrigation coverage and improved water used for agricultural production. The Paramparagat Krishi Vikas Yojana (PKVY) is one of the most important programs of the Indian government. This encourages farmers in India to practise traditional and organic farming. The federal government helped farmers economically by launching the Kisan credit card (KCC) scheme in 1998 and provides agriculture financing at a rate of 4% per annum through this plan. On February 24, 2019, the PM Kisan Samman Nidhi Yojana (PMKSNY) was launched to empower farmers. In this plan, the government of India transfers 6000 rupees per year directly to farmers' bank accounts via direct benefit transfer (DBT). On November 18, 2004, the National Commission on Farmers (NCF), chaired by Prof. M.S. Swaminathan, issued recommendations on land reforms, irrigation, credit and insurance, food security, employment, agricultural production, and farmer competitiveness. These recommendations improve agricultural efficiency, which are dependent on a variety of factors such as availability and quality of agricultural inputs such as land, water, seeds, and fertilisers, access to agricultural credit and crop insurance, assurance of remunerative prices for agricultural produce, and storage and marketing infrastructure. IDEA [1] evaluated factors related to agricultural production and post-harvest activities in India and provided a summary of the country's agricultural status.

The design of the paper is as follows: Section (2) is a brief overview of the literature relevant to this topic. Section (3) discusses the methodology for measuring efficiency, the Malmquist productivity index (MPI), the catch-up effect, the frontier shift, and commutative Malmquist productivity. The data and variables are described in section (4). Section (5) incorporates empirical findings as well as discussions. Section (6) concludes with findings and future directions.

## 2 Literature Review

With the emergence of technology and the complexity and quantity of knowledge, top executives have been forced to use scientific techniques to identify and raise the productivity of the firm under their supervision. Data envelopment analysis (DEA) is a mathematical approach used to estimate the relative efficiency of a group of homogeneous units known as decision-making units (DMUs) that utilize multiple inputs to create multiple outputs. DMUs are said to be homogeneous because they all use the same inputs to generate the same outputs. DEA calculates the relative efficiency of decision-making units by establishing efficiency limits. The main advantages of the DEA approach are, that there is no need to directly give a mathematical form for the production function and capable of dealing with a large number of inputs and outputs. It may be used with any input-output measurement. In each examined unit, the inefficiency scores can be studied and measured. DMUs compare themselves to other DMUs using the dual optimization problem identities. DEA has a number of drawbacks, including the fact that the findings are highly dependent on the inputs and outputs used. The efficiency scores of a DMU can be calculated by combining weights on the input and output parameters in non-unique ways [2]. Productivity is the relationship between output from the company production system and the inputs utilized to get there. The ability to produce more and better products with fewer resources is characterized as productivity. To calculate it, divide the quantity of output by the amount of input. When the productivity of two firms is compared, the more productive firm produces more output for the same input, or the same amount of production for less input. Charnes et al. [3] created a DEA model called CCR model based on Farrell's foundational work [4] and assume that constant returns to scale (CRS). Banker et al. [5] built on the pioneering work of Charnes et al. [3] and introduced the BCC model to evaluate relative efficiency which is assumed that variable returns to scale (VRS). The DEA technique has recently been successfully applied in a wide variety of cases, including industry [6], banking institutions [7], research and development organisations [8] , health care management [9], manufacturing [10], and supply chain management [13].

Dutta [14] suggested some ideas and management strategies to improve agricultural production in terms of yield and money. Hasanov and Nomman [15] used the DEA model to determine technical and allocative efficiency, as well as the efficient and inefficient farms in the Zarafshan valley, based on the frontier. Suresh [16] employed DEA to determine technical efficiency (TE) in agricultural output in 409 Indian districts and divide it into pure technical efficiency (PTE) and scale efficiency (SE). Mathur and Ramnath [17] applied SFA and DEA to assess the efficiency of food grain production in India from 1960-61 to 2013-14 and determine which year was the most efficient. You and Zhang [18] used DEA and the Tobit model to investigate the ecoefficiency of intensive agricultural production in 31 Chinese provinces, and the factors that influence ecoefficiency reveal that farmland area per capita (FA), income per capita (IC), population per household (PH), and population burden coefficient (PB) have statistically significant impacts on total efficiency. Jha et al. [19] utilised the CCR model to evaluate allocative and technical inefficiency in wheat growing on 300 farms of Punjab in India between 1982 and 1983. Nandy and Singh [20] employed FDEA to estimate paddy grower efficiency and rank them, as well as support vector machine (SVM) and random forest (RF) to find the essential driving elements in efficiency prediction. e Souza et al. [21] examined technical efficiency and progress in Brazilian agriculture from 1976 to 2016. Output is the price of goods, whereas inputs are the costs of land, labour, and other inputs. Wysoki´nski et al. [22] used the undesirable W-SBM-DEA model to assess the performance of the EU-27 agriculture sector from 2008 to 2017, using input parameters such as agricultural area, labor, specific costs, overheads, and depreciation, and desirable output parameters such as the gross value of crop and livestock products, and undesirable output parameters such as total GHG emissions. SFA was used to assess China's agricultural production efficiency from 2000 to 2015 [23]. Wan and Zhou [24] used Malmquist-DEA model to measure total factor productivity (TFP), as well as technological change (TC) and technical efficiency change (EC) in 12 cities in China's central province, and the Cobb–Douglas (C-D) method is used to estimate the impacts of TFP and its constituent elements on agricultural management and economic growth. Pan et al. [25] employed a three-stage DEA Malmquist model to examine the agricultural production efficiency of 11 provinces in the YREB from 2010 to 2019 and showed that the adjusted technical efficiency changes, technological development, and total factor productivity increased. Wassif [11] conducted an assessment of the performance (E) of traps in containing suspended soil particles that produce dust, environmental problems, and agricultural problems due to wind erosion in NWCZ, Egypt. Igberi et al. [12] analysed the most important climate smart agricultural (CSA) practises and technology of home farmers in Southeast, Nigeria, using a multi-stage sample approach to identify 326 household farmers.

The current study calculates agricultural productivity and efficiency change in 31 Indian states and UTs using a DEA-based Malmquist productivity index (MPI) technique. Total productivity changes over time are measured using the cumulative Malmquist index (CMI).

# 3 Methodology

Data envelopment analysis (DEA) is a more generalizable frontier-based non-parametric linear programming optimization performance evaluation methodology. This approach is an alternative to parametric regression. If units have many inputs and outputs, the econometric technique cannot accurately assess their efficiency. The primary objective of data envelopment analysis is to calculate the efficiency score of a decision making unit (DMU) with multiple inputs and outputs. For each DMU, DEA finds the most favorable set of weights (i.e., "the set of weights that maximizes the efficiency of DMU rating under the constraint that the efficiencies of all DMUs are less than or equal to 1"). DEA is used to assess the operational efficiency of DMUs and provides benchmarks for inefficient DMUs to improve. Advantages of using DEA include: "The ability to assume a deterministic relationship between inputs and outputs and its ease in estimating the efficiency scale, and the ability to handle multiple inputs and multiple outputs simultaneously without requiring an assumption of a functional form relating inputs to outputs (as regression methods do)". To calculate efficiency, many DEA models have been created. The Constant Return to Scale (CRS) measure in the CCR [3] model has been widely investigated in the agriculture sector and is suggested to evaluate farm productivity.

Suppose that there are $n$ DMUs (decision making units) each having $m$ inputs and $s$ outputs. The input and output vector for $DMU_j,\quad j = 1,2,3,\cdots,n$ can be defined as $x_j = (x_{1j}, x_{2j}, \cdots, x_{mj})^T \in R^m$ and $y_j = (y_{1j}, y_{2j}, \cdots, y_{sj})^T \in R^s$ respectively. The input matrix X as $X = (x_1, x_2, \cdots, x_n) \in R^{m\times n}$ and the output matrix Y as $y = (y_1, y_2, \cdots, y_n) \in R^{s\times n,}$ and assume $X > 0$ *and* $Y > 0$.

The production possibility set $P$ is defined by

$$P = \left\{(x,y):\ x \geq \sum_{j=1}^{n} \lambda_j x_j,\ 0 \leq y \leq \sum_{j=1}^{n} \lambda_j y_j,\ \ \lambda \geq 0\right\}$$

where $\lambda = (\lambda_1, \lambda_2, \cdots, \lambda_n) \in R^n$ is the intensity vector. The input oriented CCR model for $DMU_o,\ (o = 1,2,3,\cdots,n)$ is defined as

$$\begin{aligned} &\min\ \theta_o && (1)\\ &\text{subject to } \theta_o x_{io} \geq \sum_{j=1}^{n} \lambda_j x_{ij},\ \ i = 1,2,\cdots,m\\ &y_{ro} \leq \sum_{j=1}^{n} \lambda_j y_{rj},\ \ r = 1,2,\cdots,s\\ &\text{and } \lambda_j \geq 0,\ \forall j = 1,2,3,\cdots,n. \end{aligned}$$

The optimal solution $\theta_o^*$ is the efficiency score for $DMU_o$ for $o = 1,2,\cdots,n$.

Fare et al. [26] developed a DEA-based Malmquist productivity index (MPI) that evaluates productivity change over time after Malmquist [27] proposed the Malmquist productivity index (MPI). This DEA-based MPI has shown to be an effective method for assessing the productivity change of DMUs. The input and output vector for $DMU_j,\ \ j = 1,2,3,\cdots,n$ in the time period $t$ is defined as $(x_o, y_o)^t = (x_o^t, y_o^t)$.

The production possibility set $P^t$ in the time period t is defined by

$$P^t = \left\{(x,y):\ x \geq \sum_{j=1}^{n} \lambda_j x_j^t,\ 0 \leq y \leq \sum_{j=1}^{n} \lambda_j y_j^t,\ \ \lambda \geq 0\right\}$$

where $\lambda = (\lambda_1, \lambda_2, \cdots, \lambda_n) \in R^n$ is the intensity vector.

The efficiency score of the $DMU_o,\ \ (o = 1,2,\cdots,n)$ in the time period $t$ with respect to the frontier technology by the time period $s$ is denoted by $\rho_o^{t,s}$ and obtained as follows

$$\begin{aligned} &\rho_o^{(t,s)} = \min\ \theta_o && (2)\\ &\text{subject to } \theta_o x_{io}^t \geq \sum_{j=1}^{n} \lambda_j x_{ij}^s,\ \ i = 1,2,\cdots,m\\ &y_{ro}^t \leq \sum_{j=1}^{n} \lambda_j y_{rj}^s,\ \ r = 1,2,\cdots,s\\ &\text{and } \lambda_j \geq 0,\ \ j = 1,2,\cdots,n. \end{aligned}$$

**Definition 1** *The Catch-up (CU) effect of the $DMU_o,\ \ (o = 1,2,\cdots,n)$ from period $t_1$ to $t_2$ is defined as the ratio between efficiency score of the $DMU_o$ in the time period $t_2$ with respect to the frontier technology by the time period $t_2$ and in the time period $t_1$ with respect to the frontier technology by the time period $t_1$. i.e.*

$$\textit{Catch-up effect}(\gamma_o^{(t_1,t_2)}) = \frac{\rho_o^{(t_2,t_2)}}{\rho_o^{(t_1,t_1)}}. \qquad (3)$$

It can be obtained by solving the following LP problems.

$$\rho_o^{(t_1,t_1)} = \min\ \theta_o \tag{4}$$
$$\text{subject to } \theta_o x_{io}^{t_1} \geq \sum_{j=1}^{n} \lambda_j x_{ij}^{t_1},\ \ i = 1,2,\cdots,m$$
$$y_{ro}^{t_1} \leq \sum_{j=1}^{n} \lambda_j y_{rj}^{t_1},\ \ r = 1,2,\cdots,s$$
$$\text{and } \lambda_j \geq 0,\ \ j = 1,2,\cdots,n.$$

and

$$\rho_o^{(t_2,t_2)} = \min\ \theta_o \tag{5}$$
$$\text{subject to } \theta_o x_{io}^{t_2} \geq \sum_{j=1}^{n} \lambda_j x_{ij}^{t_2},\ \ i = 1,2,\cdots,m$$
$$y_{ro}^{t_2} \leq \sum_{j=1}^{n} \lambda_j y_{rj}^{t_2},\ \ r = 1,2,\cdots,s$$
$$\text{and } \lambda_j \geq 0,\ \ j = 1,2,\cdots,n.$$

**Remark 1**

1. $\gamma_o^{(t_1,t_2)} > 1$ *denotes increase in relative efficiency from period* $t_1$ *to* $t_2$.
2. $\gamma_o^{(t_1,t_2)} = 1$ *denotes no change in relative efficiency from period* $t_1$ *to* $t_2$.
3. $\gamma_o^{(t_1,t_2)} < 1$ *denotes decrease in relative efficiency from period* $t_1$ *to* $t_2$.

**Definition 2** *The frontier shift (FS) effect for* $DMU_o,\ (o = 1,2,\cdots,n)$ *is defined as*

$$\textit{Frontier Shift } (\phi_o^{(t_1,t_2)}) = \left[ \frac{\rho_o^{(t_1,t_1)}}{\rho_o^{(t_2,t_1)}} \times \frac{\rho_o^{(t_1,t_2)}}{\rho_o^{(t_2,t_2)}} \right]^{1/2} \tag{6}$$

*where* $\rho_o^{(t,s)}, (t = t_1, t_2$ *and* $s = t_1, t_2)$ *is the efficiency score of* $DMU_o$ *in time period* $t$ *measured by the frontier technology of the time period* $s$.

It can be obtained by solving equation (4) and (5), and the following LP problems.

$$\rho_o^{(t_1,t_2)} = \min\ \theta_o \tag{7}$$
$$\text{subject to } \theta_o x_{io}^{t_2} \geq \sum_{j=1}^{n} \lambda_j x_{ij}^{t_1},\ \ i = 1,2,\cdots,m$$
$$y_{ro}^{t_2} \leq \sum_{j=1}^{n} \lambda_j y_{rj}^{t_1},\ \ r = 1,2,\cdots,s$$
$$\text{and } \lambda_j \geq 0,\ \ j = 1,2,\cdots,n.$$

and

$$\rho_o^{(t_2,t_1)} = \min\ \theta_o \tag{8}$$
$$\text{subject to } \theta_o x_{io}^{t_1} \geq \sum_{j=1}^{n} \lambda_j x_{ij}^{t_2},\ \ i = 1,2,\cdots,m$$
$$y_{ro}^{t_1} \leq \sum_{j=1}^{n} \lambda_j y_{rj}^{t_2},\ \ r = 1,2,\cdots,s$$
$$\text{and } \lambda_j \geq 0,\ \ j = 1,2,\cdots,n.$$

**Remark 2**

1. $\phi_o^{(t_1,t_2)} > 1$ *denotes increase in relative efficiency from period* $t_1$ *to* $t_2$.
2. $\phi_o^{(t_1,t_2)} = 1$ *denotes no change in relative efficiency from period* $t_1$ *to* $t_2$.
3. $\phi_o^{(t_1,t_2)} < 1$ *denotes decrease in relative efficiency from period* $t_1$ *to* $t_2$.

**Definition 3** *The Malmquist Index is used to compare the relative efficiency of a* $DMU_o,\ (o = 1,2,\cdots,n)$ *from period* $t_1$ *to period* $t_2$ *and it is defined as the product of the catch-up and frontier-shift indictors.i.e*

$$\textit{Malmquist Index (MI)} = \textit{Catch-up effect (CU)} \times \textit{Frontier-shift effect (FS)}$$

$$\mu_o^{(t_1,t_2)} = \left[ \frac{\rho_o^{(t_1,t_2)}}{\rho_o^{(t_1,t_1)}} \times \frac{\rho_o^{(t_2,t_2)}}{\rho_o^{(t_2,t_1)}} \right]^{1/2} \tag{9}$$

**Remark 3**

1. $\mu_o^{(t_1,t_2)} > 1$ *denotes increase in relative efficiency from period* $t_1$ *to* $t_2$.
2. $\mu_o^{(t_1,t_2)} = 1$ *denotes no change in relative efficiency from period* $t_1$ *to* $t_2$.
3. $\mu_o^{(t_1,t_2)} < 1$ *denotes decrease in relative efficiency from period* $t_1$ *to* $t_2$.

The progress or regress percentage of the $DMU_o,\ o = 1,2,\cdots,n$ from period $t_1$ to $t_2$ is defined as

$$M_o^{(t_1,t_2)} = (\mu_o^{(t_1,t_2)} - 1) \times 100 \tag{10}$$

when $M_o^{(t_1,t_2)} > 0$, the $DMU_o$ is progress, $M_o^{(t_1,t_2)} = 0$, the $DMU_o$ is constant and $M_o^{(t_1,t_2)} < 0$ the $DMU_o$ is regress.

**Definition 4** *The cumulative Malmquist index (CMI) measures the change in productivity of* $DMU_o,\ o = 1,2,\cdots,n$ *from the first period through multiple periods* $(t_1 \to t_p)$, *which is defined as*

$$\Psi_o^{(t_1,t_p)} = \begin{cases} \prod_{k=1}^{p-1} \mu_o^{(t_k,t_{k+1})}, & p > 1 \\ 1, & p = 1 \end{cases} \tag{11}$$

The CMI may be decomposed into a cumulative FS (CFS) and the ratio of efficiency scores between periods $t_1$ and $t_p$, as shown below:

$$\Psi_o^{(t_1,t_p)} = \Phi_o^{(t_1,t_p)} \frac{\rho_o^{(t_p,t_p)}}{\rho_o^{(t_1,t_1)}} \tag{12}$$

where $\Phi_o^{(t_1,t_p)}$ is the CFS to period $t_p$ from the base period $t_1$ for $DMU_o$, $o = 1, 2, \cdots, n$.
The adjusted Malmquist index (AMI) from period $t_1$ to period $t_p$, calculated as the product of the CMI and the efficiency score in the $t_1$ period, is as follows:

$$\Omega^{(t_1,t_p)} = \Psi_o^{(t_1,t_p)} \rho_o^{(t_1,t_1)} \tag{13}$$

This may be expressed as the product of the CFS and the efficiency score in period $t_1$,

$$\Omega^{(t_1,t_p)} = \Phi_o^{(t_1,t_p)} \rho_o^{(t_p,t_p)} \tag{14}$$

AMI can help in evaluating unfortunate DMUs, which are rated very low in terms of efficiency while achieving productivity gains.

# 4 Data Collection

The data used in this study is from the original Indian government website. We take the input parameters as state-wise annual rainfall, Total , GDP, Number of workers, Net sown area, and output parameters are the production of Rice, Wheat, Coarse cereals, Pulse, Oil-seeds, and Sugarcane. The input data likes; rainfall in (mm), the Net cultivated area in (thousand hectares), number of workers in (units), the population in (laces), GDP in (corer). All the output data like rice, wheat, coarse cereals, pulse, oil-seeds, and sugarcane are taken in (thousand tonnes). All the input and output variable is defined in Table (1).

In all the tables, an abbreviation of the states & UTs of India are denoted as "Andhra Pradesh (AP), Arunachal Pradesh (AR), Assam (AS), Bihar (BR), Chhattisgarh (CT), Delhi (DL), Goa (GA), Gujarat (GJ), Haryana (HR), Himachal Pradesh (HP), Jammu & Kashmir (JK), Jharkhand (JH), Karnataka (KA), Kerala (KL), Madhya Pradesh (MP), Maharashtra (MH), Manipur (MN), Meghalaya (ML), Mizoram (MZ), Nagaland (NL), Odisha (OD), Punjab (PB), Puducherry (PY), Rajasthan (RJ), Sikkim (SK), Tamil Nadu (TN), Tripura (TR), Uttarakhand (UT), Uttar Pradesh (UP), West Bengal (WB)".

**Table 1.** Variable used in the study

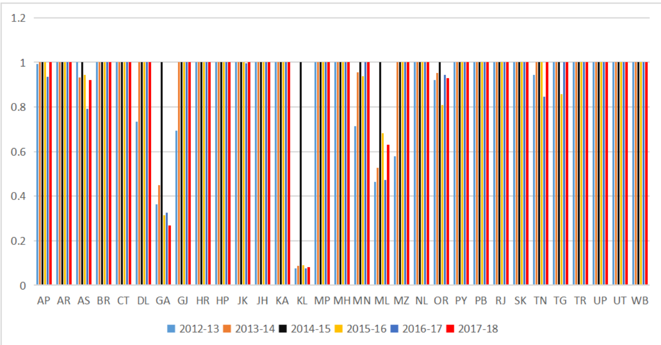
| Variable | Role | Details |
|---|---|---|
| State-wise annual rainfall | Input | Indian Meteorological Department [28] |
| Net shown area | Input | Ministry of Agriculture and Farmers Welfare [29]. |
| Total population | Input | Economic Survey, Govt. of India [30]. |
| GDP | Input | The Ministry of Statistics and Program Implementation [29]. |
| Number of workers | Input | Annual Survey of Industries (ASI) [29]. |
| Production of Rice | Output | Ministry of Agriculture and Farmers Welfare [29]. |
| Production of Wheat | Output | Ministry of Agriculture and Farmers Welfare [29]. |
| Production of Coarse cereals | Output | Ministry of Agriculture and Farmers Welfare [29]. |
| Production of Pulse | Output | Ministry of Agriculture and Farmers Welfare [29]. |
| Production of Oil seeds | Output | Ministry of Agriculture and Farmers Welfare [29]. |
| Production of Sugarcane | Output | Ministry of Agriculture and Farmers Welfare [29]. |

# 5 Results and Discussion

The DEA approach measures the efficiency of DMUs in the range [0, 1]. If efficiency score of a DMU is 1, it is efficient; otherwise, it is inefficient. The CCR model is used to calculate efficient and inefficient DMUs. According to Table (2), there were 61.23%, 67.74%, 74.19%, 67.74%, 70.96%, and 70.96% efficient states & UTs and 38.77%, 32.26%, 25.81%, 32.26%, 29.04%, and 29.04% inefficient states and UTs in 2012, 2013, 2014, 2015, 2016, and 2017 respectively. In 2014, all states and UTs had the outstanding performances. This year, 74.19% of states and UTs were efficient. In 2012, all states and UTs had poor performance. This year, 61.23% of states and territories were inefficient. Punjab, Rajasthan, Sikkim, and Uttar Pradesh were efficient, with an efficiency score of 1, while Kerala and Goa were inefficient from 2012 to 2017 and the compassion results are shown in Figure (1).

The Malmquist index (MI) evaluates whether states and UTs are advancing or regressing from year to year. If the MI is more than one, the performance is assumed to be in progress in the following year; otherwise, it regresses to the following year. From Table (3), it was found that 35.48%, 58.06%, 38.71%, 61.25%, and 54.84% states and UTs were in progress while 62.52%, 41.94%, 61.29%, 38.77%, and 45.16% states and UTs were in regress in periodic time 2012-13, 2013-14, 2014-15, 2015-16, and 2016-17 respectively. In Figure (2), (3), (4), (5) and (6), the orange reflects productivity growth, while green represents decreased productivity in states and UTs. Maximum states and UTs are progressing in 2015-16, whereas maximum states and UTs are regressing in 2012-13 shown in Figure (5) and (2) respectively. According to Table (4), Mizoram was one of the most progress states, with a progressing percentage of 33.5%, while Telangana was one of the most regressive states, with a regressing percentage of -33.4% in 2012-13. In 2013-14, Mizoram had incremental progress with a progressive ratio of 31.3%, while Arunachal Pradesh experienced extreme regress with a regressing percentage of -71.4%. Similarly, in 2014-15, 2015-16, and 2016-17, Jammu and Kashmir, Jharkhand, and Madhya Pradesh made significant progress, with percentages of 13.5%, 14.2% and 30.6% respectively while Ma-

**Figure 1.** Efficiency score of states and UTs




nipur, Meghalaya, and Mizoram made the most of the percentage regression is -33.3%, -15.5%, -21.7% respectively.

CMI and CFS are useful in observing trends in the growth rate by comparison. In Table (5), the cumulative Malmquist index is calculated to determine trends of the total productivity change for states and UTs increased or decreased from 2012 to 2017. The productivity change of states and UTs are shown in Figure (7) and Madhya Pradesh is ideally constantly expanding from 2012-17; Delhi, Rajasthan, Uttarakhand, and Uttar Pradesh are roughly increasing from 2012-17; Nagaland is roughly decreasing from 2012-17; and Assam, Chhatisgarh, Jammu & Kasmir, and Sikim are approximately decreasing from 2012-17. In Table (6), the cumulative Frontier Shift is calculated to determine which states and UTs have increased or decreased in productivity from 2012 to 2017. The states and UTs are compaired in Figure (8) and Madhya Pradesh is ideally continuously rising from 2012-17; Delhi, Goa, Rajasthan, Uttarakhand, and Uttar Pradesh are approximately increasing from 2012-17; Nagaland is approximately decreasing from 2012-17; and Assam, Bihar, Chhatishghar, Jammu & Kashmir, and Sikkim are approximately decreasing from 2012-17.

The adjusted Malmquist index(AMI) is useful for observing trends in the average relative efficiency of a comparison. In Table (7), the adjusted Malmquist index(AMI) is calculated to determine the trends in relative productivity changes for states and UTs from 2012 to 2017. The relative productivity changes for states and UTs are compaired in Figure (9) and, Madhya Pradesh and change in Andhra Pradesh are continuously increasing from 2012-17; Goa and Nagaland are approximately decreasing from 2012-17. Since productivity increase reflects both total productivity and relative efficiency change. It is clearly the main way to evaluate productivity improvement by looking at the profiles where most states and UTs are located.

**Table 2.** Efficiency Score of the states and UTs

| State/ UT | 2012-13 | 2013-14 | 2014-15 | 2015-16 | 2016-17 | 2017-18 |
|---|---|---|---|---|---|---|
| AP | 0.993 | 0.999 | 1 | 1 | 0.935 | 1 |
| AR | 1 | 0.999 | 1 | 1 | 1 | 1 |
| AS | 1 | 0.931 | 1 | 0.945 | 0.790 | 0.921 |
| BR | 1 | 1 | 1 | 0.999 | 1 | 1 |
| CT | 1 | 0.999 | 0.999 | 1 | 1 | 0.999 |
| DL | 0.733 | 1 | 1 | 1 | 1 | 1 |
| GA | 0.363 | 0.448 | 0.999 | 0.313 | 0.326 | 0.269 |
| GJ | 0.693 | 1 | 1 | 0.999 | 1 | 1 |
| HR | 1 | 1 | 1 | 1 | 0.999 | 1 |
| HP | 1 | 1 | 1 | 1 | 1 | 1 |
| JK | 1 | 1 | 0.999 | 1 | 0.995 | 1 |
| JH | 0.999 | 1 | 0.999 | 1 | 1 | 0.999 |
| KA | 1 | 1 | 1 | 1 | 1 | 0.999 |
| KL | 0.077 | 0.087 | 0.999 | 0.090 | 0.0748 | 0.084 |
| MP | 1 | 1 | 1 | 0.999 | 1 | 1 |
| MH | 1 | 1 | 1 | 1 | 1 | 1 |
| MN | 0.713 | 0.954 | 1 | 0.938 | 1 | 1 |
| ML | 0.463 | 0.526 | 1 | 0.683 | 0.472 | 0.631 |
| MZ | 0.580 | 1 | 1 | 1 | 1 | 1 |
| NL | 1 | 1 | 0.999 | 1 | 1 | 1 |
| OR | 0.920 | 0.952 | 1 | 0.809 | 0.943 | 0.928 |
| PY | 1 | 1 | 1 | 1 | 1 | 1 |
| PB | 1 | 1 | 1 | 1 | 1 | 1 |
| RJ | 1 | 1 | 1 | 1 | 1 | 1 |
| SK | 1 | 1 | 1 | 1 | 1 | 1 |
| TN | 0.943 | 1 | 0.999 | 1 | 0.846 | 1 |
| TG | 1 | 1 | 1 | 0.857 | 1 | 1 |
| TR | 1 | 0.999 | 1 | 1 | 1 | 1 |
| UP | 1 | 1 | 1 | 1 | 1 | 1 |
| UT | 1 | 1 | 0.999 | 1 | 1 | 0.999 |
| WB | 0.999 | 1 | 1 | 1 | 1 | 1 |

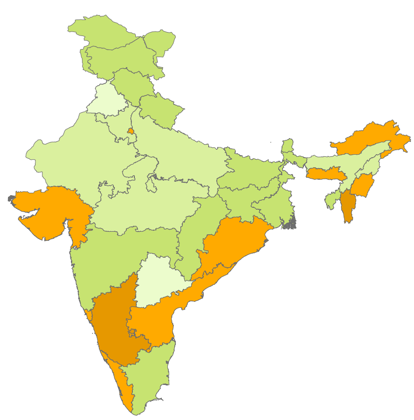


**Figure 2.** MI of 2012-13

**Table 3.** Malmquist index of states and UTs

| State/ UT | 2012-13 | 2013-14 | 2014-15 | 2015-16 | 2016-17 |
|---|---|---|---|---|---|
| AP | 1.013 | 1.03 | 0.987 | 0.984 | 1.074 |
| AR | 1.108 | 0.286 | 1.050 | 1.031 | 0.977 |
| AS | 0.913 | 0.977 | 0.912 | 0.910 | 1.023 |
| BR | 0.936 | 0.919 | 1.098 | 0.999 | 0.993 |
| CT | 0.972 | 0.976 | 0.977 | 1.107 | 0.812 |
| DL | 1.121 | 1.002 | 1.057 | 1.017 | 0.982 |
| GA | 1.017 | 0.957 | 0.907 | 1.064 | 0.952 |
| GJ | 1.009 | 1.031 | 0.930 | 1.052 | 0.971 |
| HR | 0.854 | 1.124 | 0.877 | 1.054 | 1.030 |
| HP | 0.938 | 0.968 | 1.076 | 1.078 | 0.896 |
| JK | 0.986 | 0.865 | 1.135 | 0.991 | 0.985 |
| JH | 0.956 | 1.012 | 0.952 | 1.142 | 0.990 |
| KA | 1.191 | 1.007 | 0.913 | 1.022 | 1.010 |
| KL | 1.027 | 1.042 | 0.999 | 0.898 | 1.083 |
| MP | 0.841 | 1.218 | 1.086 | 1.050 | 1.306 |
| MH | 0.985 | 1.042 | 0.945 | 1.012 | 1.117 |
| MN | 1.045 | 1.287 | 0.667 | 1.073 | 1.074 |
| ML | 1.032 | 1.019 | 1.114 | 0.845 | 1.150 |
| MZ | 1.335 | 1.313 | 1.048 | 0.950 | 0.783 |
| NL | 0.921 | 0.840 | 0.975 | 0.964 | 0.951 |
| OR | 1.004 | 1.012 | 0.888 | 1.131 | 0.896 |
| PY | 0.976 | 0.971 | 0.876 | 1.053 | 1.167 |
| PB | 0.772 | 1.226 | 0.889 | 1.033 | 1.015 |
| RJ | 0.920 | 1.105 | 0.932 | 1.098 | 1.064 |
| SK | 0.933 | 0.972 | 1.031 | 0.945 | 0.949 |
| TN | 0.951 | 0.977 | 0.981 | 0.951 | 1.095 |
| TG | 0.666 | 0.536 | 0.8831 | 1.056 | 1.018 |
| TR | 0.961 | 0.981 | 1.028 | 1.018 | 0.980 |
| UP | 0.873 | 1.217 | 1.002 | 0.931 | 1.187 |
| UT | 0.942 | 1.023 | 0.991 | 1.048 | 1.013 |
| WB | 0.982 | 1.022 | 1.017 | 0.961 | 1.012 |

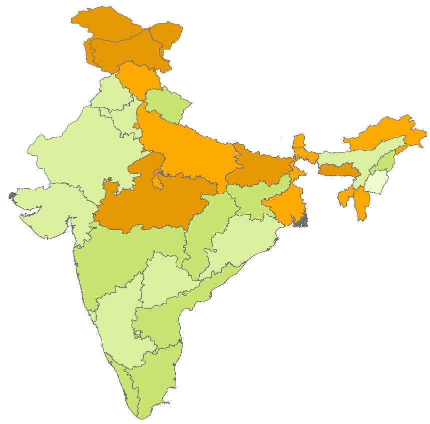


**Figure 4.** MI of 2014-15

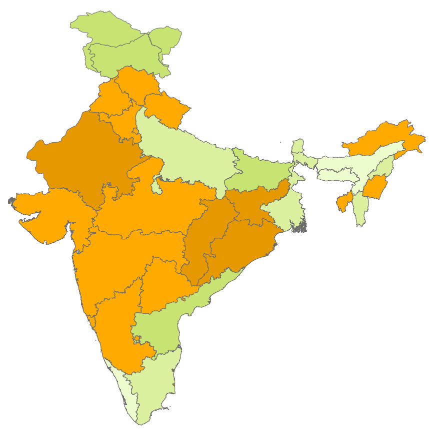


**Figure 5.** MI of 2015-16

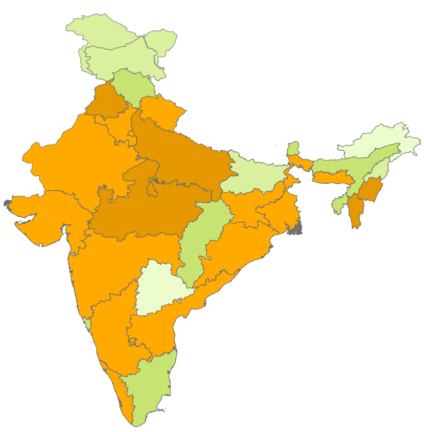


**Figure 3.** MI of 2013-14

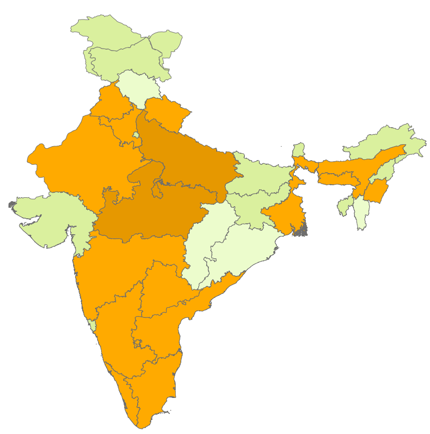


**Figure 6.** MI of 2016-17

**Figure 7.** Cumulative Malmquist index of states and UTs

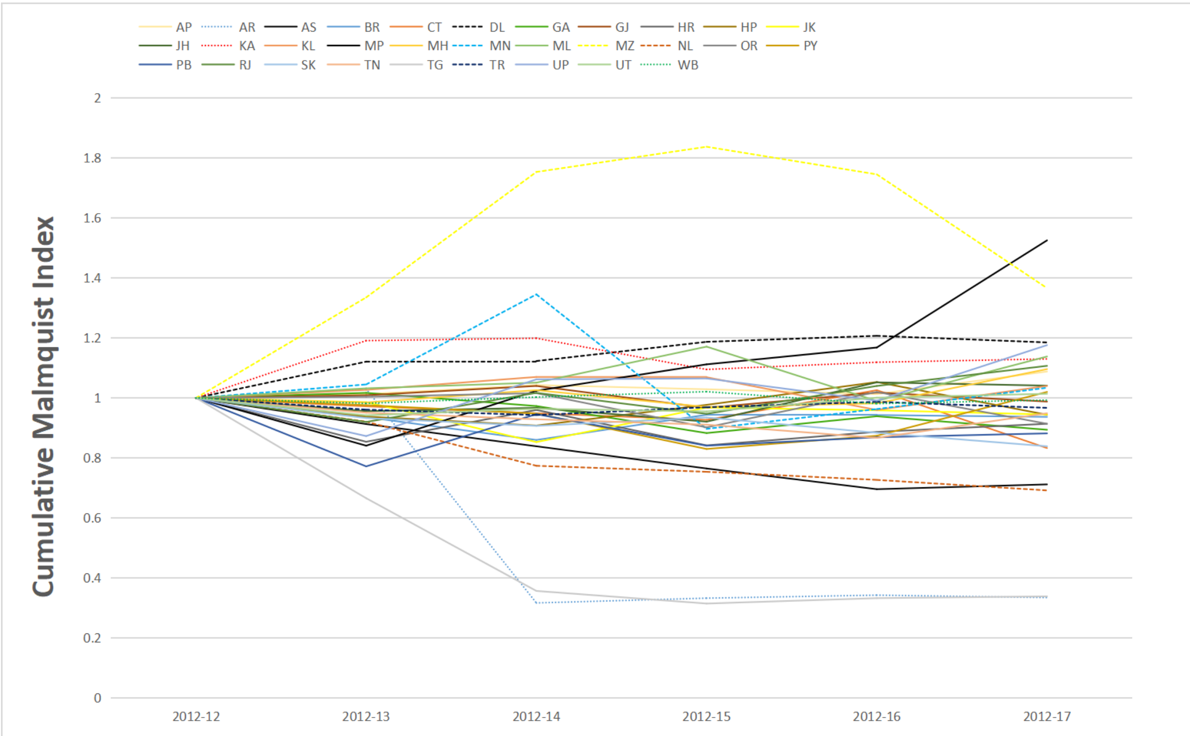



**Figure 8.** Cumulative frontier shift of states and UTs

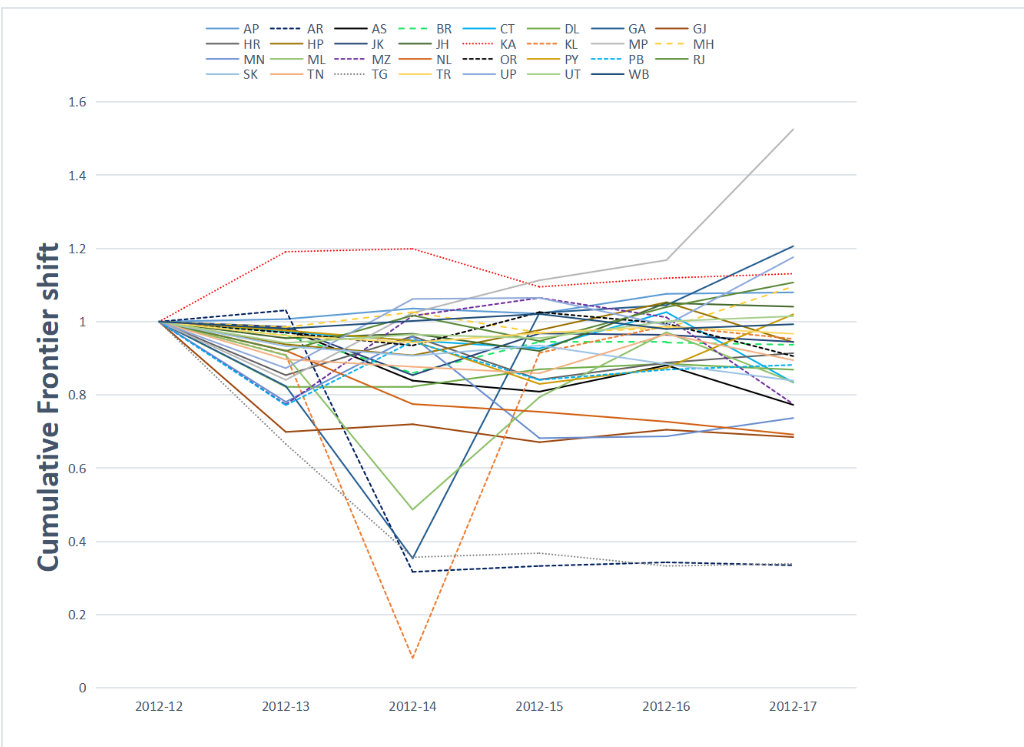


**Figure 9.** Adjusted Malmquist Index of states and UTs

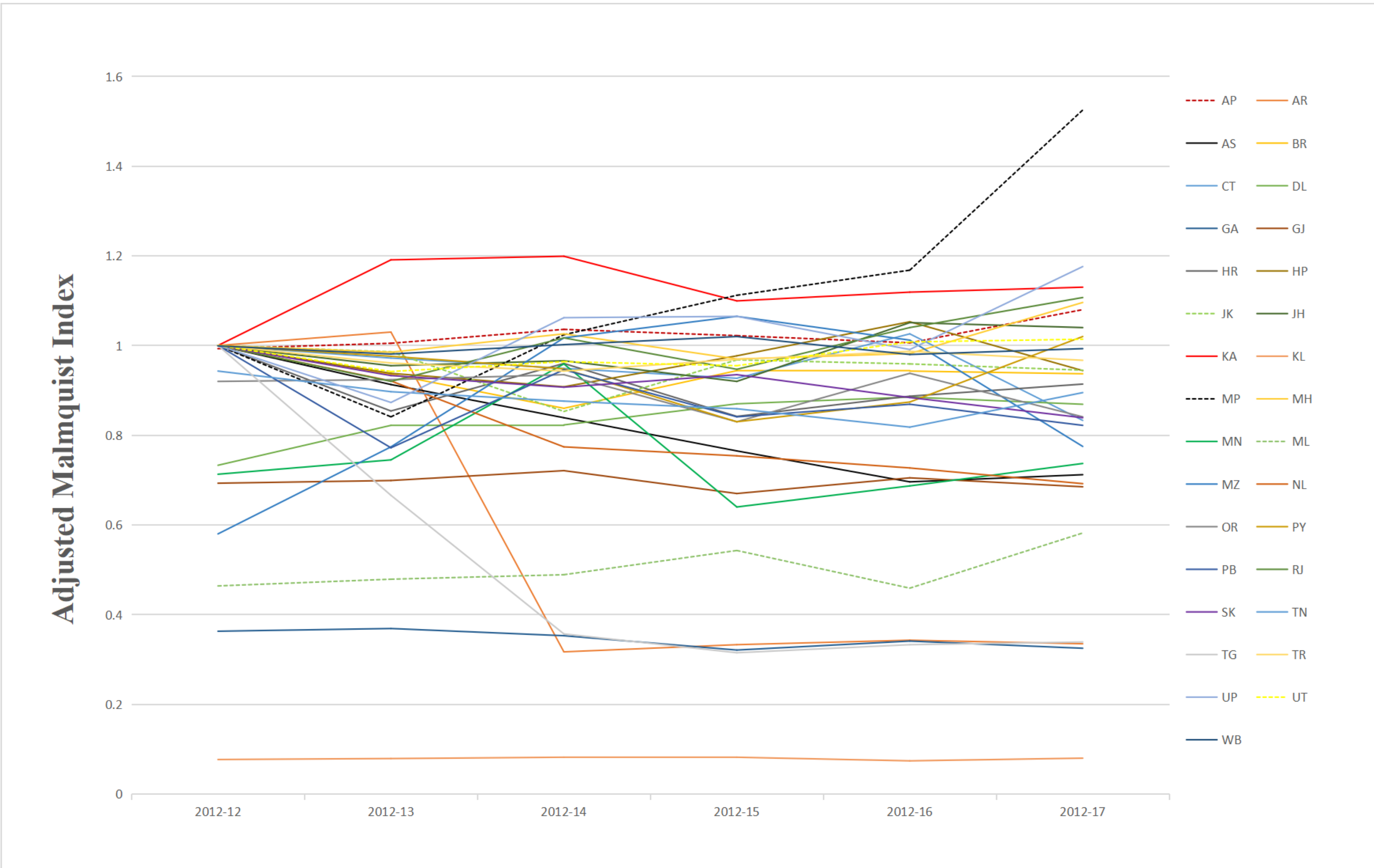


**Table 4.** Progress and regress percentage(%) of states and UTs

| State/ UT | 2012-13 | 2013-14 | 2014-15 | 2015-16 | 2016-17 |
|---|---|---|---|---|---|
| AP | 1.3 | 3 | -1.3 | -1.6 | 7.4 |
| AR | 10.8 | -71.4 | 5 | 3.1 | -2.3 |
| AS | -8.7 | -2.3 | -8.8 | -9 | 2.3 |
| BR | -6.4 | -8.1 | 9.8 | -0.1 | -0.7 |
| CT | -2.8 | -2.4 | -2.3 | 10.7 | -18.8 |
| DL | 12.1 | 0.2 | 5.7 | 1.7 | -1.8 |
| GA | 1.7 | -4.3 | -9.3 | 6.4 | -4.8 |
| GJ | 0.9 | 3.1 | -7 | 5.2 | -2.9 |
| HR | -14.6 | 12.4 | -12.3 | 5.4 | 3 |
| HP | -6.2 | -3.2 | 7.6 | 7.8 | -10.4 |
| JK | -1.4 | -13.5 | 13.5 | -0.9 | -1.5 |
| JH | -4.4 | 1.2 | -4.8 | 14.2 | -1 |
| KA | 19.1 | 0.7 | -8.7 | 2.2 | 1 |
| KL | 2.7 | 4.2 | -0.1 | -10.2 | 8.3 |
| MP | -15.9 | 21.8 | 8.6 | 5 | 30.6 |
| MH | -1.5 | 4.2 | -5.5 | 1.2 | 11.7 |
| MN | 4.5 | 28.7 | -33.3 | 7.3 | 7.4 |
| ML | 3.2 | 1.9 | 11.4 | -15.5 | 15 |
| MZ | 33.5 | 31.3 | 4.8 | -5 | -21.7 |
| NL | -7.9 | -16 | -2.5 | -3.6 | -4.9 |
| OR | 0.4 | 1.2 | -11.2 | 13.1 | -10.4 |
| PY | -2.4 | -2.9 | -12.4 | 5.3 | 16.7 |
| PB | -22.8 | 22.6 | -11.1 | 3.3 | 1.5 |
| RJ | -8 | 10.5 | -6.8 | 9.8 | 6.4 |
| SK | -6.7 | -2.8 | 3.1 | -5.5 | -5.1 |
| TN | -4.9 | -2.3 | -1.9 | -4.9 | 9.5 |
| TG | -33.4 | -46.4 | -11.6 | 5.7 | 1.8 |
| TR | -3.9 | -1.9 | 2.8 | 1.8 | -2 |
| UP | -12.7 | 21.7 | 0.2 | -6.9 | 18.7 |
| UT | -5.8 | 2.3 | -0.9 | 4.8 | 1.3 |
| WB | -1.8 | 2.2 | 1.7 | -3.9 | 1.2 |

**Table 5.** Cumulative Malmquist index of states and UTs

| State/ UT | 2012-12 | 2012-13 | 2012-14 | 2012-15 | 2012-16 | 2012-17 |
|---|---|---|---|---|---|---|
| AP | 1 | 1.013 | 1.043 | 1.029 | 1.013 | 1.088 |
| AR | 1 | 1.03 | 0.317 | 0.333 | 0.343 | 0.335 |
| AS | 1 | 0.913 | 0.839 | 0.765 | 0.696 | 0.712 |
| BR | 1 | 0.936 | 0.860 | 0.944 | 0.943 | 0.937 |
| CT | 1 | 0.972 | 0.949 | 0.927 | 1.026 | 0.833 |
| DL | 1 | 1.121 | 1.123 | 1.187 | 1.207 | 1.185 |
| GA | 1 | 1.017 | 0.973 | 0.883 | 0.939 | 0.894 |
| GJ | 1 | 1.009 | 1.040 | 0.967 | 1.018 | 0.988 |
| HR | 1 | 0.854 | 0.960 | 0.842 | 0.887 | 0.914 |
| HP | 1 | 0.938 | 0.908 | 0.977 | 1.053 | 0.944 |
| JK | 1 | 0.986 | 0.853 | 0.968 | 0.959 | 0.945 |
| JH | 1 | 0.956 | 0.967 | 0.921 | 1.052 | 1.041 |
| KA | 1 | 1.191 | 1.199 | 1.095 | 1.119 | 1.130 |
| KL | 1 | 1.027 | 1.070 | 1.069 | 0.960 | 1.040 |
| MP | 1 | 0.841 | 1.024 | 1.112 | 1.168 | 1.525 |
| MH | 1 | 0.985 | 1.026 | 0.970 | 0.982 | 1.096 |
| MN | 1 | 1.045 | 1.345 | 0.897 | 0.963 | 1.034 |
| ML | 1 | 1.032 | 1.051 | 1.171 | 0.990 | 1.138 |
| MZ | 1 | 1.335 | 1.753 | 1.837 | 1.745 | 1.366 |
| NL | 1 | 0.921 | 0.774 | 0.754 | 0.727 | 0.692 |
| OR | 1 | 1.004 | 1.016 | 0.902 | 1.020 | 0.914 |
| PY | 1 | 0.976 | 0.948 | 0.830 | 0.874 | 1.020 |
| PB | 1 | 0.772 | 0.946 | 0.841 | 0.869 | 0.882 |
| RJ | 1 | 0.920 | 1.017 | 0.947 | 1.040 | 1.107 |
| SK | 1 | 0.933 | 0.907 | 0.935 | 0.884 | 0.839 |
| TN | 1 | 0.951 | 0.929 | 0.911 | 0.867 | 0.949 |
| TG | 1 | 0.666 | 0.357 | 0.315 | 0.333 | 0.339 |
| TR | 1 | 0.961 | 0.943 | 0.969 | 0.987 | 0.967 |
| UP | 1 | 0.873 | 1.062 | 1.065 | 0.991 | 1.176 |
| UT | 1 | 0.942 | 0.964 | 0.955 | 1.0008 | 1.014 |
| WB | 1 | 0.982 | 1.003 | 1.021 | 0.981 | 0.993 |

**Table 6.** Cumulative Frontier shift of states and UTs

| State/ UT | 2012-12 | 2012-13 | 2012-14 | 2012-15 | 2012-16 | 2012-17 |
|---|---|---|---|---|---|---|
| AP | 1 | 1.007 | 1.036 | 1.022 | 1.076 | 1.080 |
| AR | 1 | 1.031 | 0.317 | 0.333 | 0.343 | 0.335 |
| AS | 1 | 0.981 | 0.839 | 0.809 | 0.881 | 0.773 |
| BR | 1 | 0.963 | 0.860 | 0.945 | 0.943 | 0.937 |
| CT | 1 | 0.972 | 0.949 | 0.927 | 1.026 | 0.834 |
| DL | 1 | 0.822 | 0.823 | 0.870 | 0.885 | 0.869 |
| GA | 1 | 0.824 | 0.354 | 1.024 | 1.045 | 1.206 |
| GJ | 1 | 0.699 | 0.720 | 0.671 | 0.705 | 0.685 |
| HR | 1 | 0.854 | 0.960 | 0.842 | 0.888 | 0.914 |
| HP | 1 | 0.938 | 0.908 | 0.977 | 1.053 | 0.944 |
| JK | 1 | 0.986 | 0.854 | 0.968 | 0.964 | 0.945 |
| JH | 1 | 0.955 | 0.967 | 0.920 | 1.051 | 1.041 |
| KA | 1 | 1.191 | 1.199 | 1.095 | 1.119 | 1.131 |
| KL | 1 | 0.909 | 0.082 | 0.915 | 0.988 | 0.953 |
| MP | 1 | 0.841 | 1.024 | 1.113 | 1.168 | 1.525 |
| MH | 1 | 0.985 | 1.026 | 0.970 | 0.982 | 1.096 |
| MN | 1 | 0.781 | 0.959 | 0.682 | 0.687 | 0.737 |
| ML | 1 | 0.908 | 0.487 | 0.794 | 0.971 | 0.835 |
| MZ | 1 | 0.774 | 1.016 | 1.065 | 1.012 | 0.775 |
| NL | 1 | 0.921 | 0.775 | 0.754 | 0.727 | 0.692 |
| OR | 1 | 0.970 | 0.935 | 1.026 | 0.995 | 0.906 |
| PY | 1 | 0.976 | 0.948 | 0.830 | 0.874 | 1.020 |
| PB | 1 | 0.772 | 0.946 | 0.841 | 0.869 | 0.882 |
| RJ | 1 | 0.920 | 1.017 | 0.947 | 1.040 | 1.107 |
| SK | 1 | 0.933 | 0.907 | 0.935 | 0.884 | 0.839 |
| TN | 1 | 0.897 | 0.877 | 0.859 | 0.966 | 0.895 |
| TG | 1 | 0.666 | 0.357 | 0.368 | 0.333 | 0.339 |
| TR | 1 | 0.962 | 0.943 | 0.969 | 0.987 | 0.967 |
| UP | 1 | 0.873 | 1.062 | 1.065 | 0.991 | 1.176 |
| UT | 1 | 0.942 | 0.965 | 0.955 | 1.0008 | 1.015 |
| WB | 1 | 0.981 | 1.002 | 1.021 | 0.980 | 0.993 |

**Table 7.** Adjusted Malmquist Index of states and UTs

| State/ UT | 2012-12 | 2012-13 | 2012-14 | 2012-15 | 2012-16 | 2012-17 |
|---|---|---|---|---|---|---|
| AP | 0.993 | 1.005 | 1.036 | 1.022 | 1.006 | 1.08 |
| AR | 1 | 1.03 | 0.317 | 0.333 | 0.343 | 0.335 |
| AS | 1 | 0.913 | 0.839 | 0.765 | 0.696 | 0.712 |
| BR | 1 | 0.936 | 0.860 | 0.944 | 0.943 | 0.937 |
| CT | 1 | 0.972 | 0.949 | 0.927 | 1.026 | 0.833 |
| DL | 0.733 | 0.822 | 0.823 | 0.870 | 0.885 | 0.869 |
| GA | 0.363 | 0.369 | 0.353 | 0.321 | 0.341 | 0.325 |
| GJ | 0.693 | 0.699 | 0.721 | 0.670 | 0.705 | 0.685 |
| HR | 1 | 0.854 | 0.960 | 0.842 | 0.887 | 0.914 |
| HP | 1 | 0.938 | 0.908 | 0.977 | 1.053 | 0.944 |
| JK | 1 | 0.986 | 0.853 | 0.968 | 0.959 | 0.945 |
| JH | 0.999 | 0.955 | 0.966 | 0.920 | 1.051 | 1.040 |
| KA | 1 | 1.191 | 1.199 | 1.099 | 1.119 | 1.13 |
| KL | 0.077 | 0.0791 | 0.082 | 0.082 | 0.074 | 0.080 |
| MP | 1 | 0.841 | 1.024 | 1.112 | 1.168 | 1.525 |
| MH | 1 | 0.985 | 1.026 | 0.970 | 0.982 | 1.096 |
| MN | 0.713 | 0.745 | 0.959 | 0.640 | 0.687 | 0.737 |
| ML | 0.464 | 0.479 | 0.489 | 0.543 | 0.459 | 0.582 |
| MZ | 0.580 | 0.774 | 1.017 | 1.065 | 1.012 | 0.775 |
| NL | 1 | 0.921 | 0.774 | 0.754 | 0.727 | 0.692 |
| OR | 0.920 | 0.924 | 0.935 | 0.830 | 0.938 | 0.841 |
| PY | 1 | 0.976 | 0.948 | 0.830 | 0.874 | 1.02 |
| PB | 1 | 0.772 | 0.946 | 0.841 | 0.869 | 0.822 |
| RJ | 1 | 0.920 | 1.017 | 0.947 | 1.040 | 1.107 |
| SK | 1 | 0.933 | 0.907 | 0.935 | 0.884 | 0.839 |
| TN | 0.943 | 0.897 | 0.876 | 0.859 | 0.818 | 0.895 |
| TG | 1 | 0.666 | 0.357 | 0.315 | 0.333 | 0.339 |
| TR | 1 | 0.961 | 0.943 | 0.969 | 0.987 | 0.967 |
| UP | 1 | 0.873 | 1.062 | 1.065 | 0.991 | 1.176 |
| UT | 1 | 0.942 | 0.964 | 0.955 | 1.008 | 1.014 |
| WB | 0.999 | 0.981 | 1.002 | 1.020 | 0.980 | 0.993 |

## 6 Conclusion

The overall objective of this article is to improve agriculture efficiency and productivity in states of India's and UTs. It also demonstrates how the efficiency of states and UTs is progressing and falls in subsequent years, as well as how it is continuously progressing or regressing depending on productivity improvements from 2012 to 2017. This study looked at which states and UTs are doing well and which ones need improvement. The DEA-Malmquist productivity index proved to be an effective tool for evaluating DMU efficiency changes over time. For efficiency measurement, classical DEA-based MI uses optimistic DEA models. The results only show changes in efficiency from the excellent DEA's point of view. The MI measures productivity change between two consecutive periods, while CMI and AMI measure the change in productivity from the starts. As a result, it must be emphasized that the choice of the starting period has an impact on the entire set of outcomes. This article used DEA models to estimate efficiency in the agriculture sector in India starting with 2012–13 to 2017–18. Table (2) indicates which states and UTs are efficient and inefficient in the Indian agriculture sector, and Graph (4) compares the performance of India's states and UTs. In Table (4), this article has calculated the MI value of states and UTs in the Indian agriculture industry. We use the MI value to determine whether states and UTs are improving or regressing in the future year. In Table (5), this study determines the CMI value of the India's states and UTs. From 2012 to 2017, the CMI value tells us which states and UTs have made consistent progress or regressed. We look at Graph (7) and compare whether states and UTs continually progress or regress from 2012 to 2017. The CFS value of India's states and UTs is calculated in Table (6), which shows that the productivity of states and UTs has been continually improving or regressing from 2012 to 2017, and the change in productivity for states and UTs is compared in Graph (8). The findings are expected to be useful in analyzing potential changes in agriculture policy affecting these states and UTs.

Based on the research, the following limitation can be addressed:

1. The extent of the study findings is limited by the length of data collecting. Changing the research community may impact the findings, so increasing or decreasing the number of units in the agriculture sector is also change the productivity and efficiency.

2. Additional variables, such as capital investment and fertiliser used, that may have an impact on state and UT agriculture productivity. From an output perspective, additional criteria on social and environmental performance, such as contributing community development and measuring harmful emission, can be combined to analyse sustainability performance.

3. This method is only a quantitative method based on linear programming, which is unable to investigate the qualitative properties of decision units.

4. The disadvantage of this study is the lack of more effective indicators for evaluating efficiency and agricultural productivity.

## Funding

There was no external funding for this study.

## Data Availability Statement

The data used in this study were a re-analysis of existing data, which is freely available at the sites listed in the reference section.

## Declarations

The authors have no conflicts of interest to declare that are relevant to the content of this article.

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