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Research Article

A Comparison of Machine Learning Clustering Algorithms Based on the DEA Optimization Approach for Pharmaceutical Companies in Developing Countries

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Abstract

The primary purpose of this paper is to combine optimization and machine learning to extract hidden rules, remove unrelated data, introduce the most productive Decision-Making Units (DMUs) in the optimization part, and to introduce the algorithm with the highest accuracy in Machine learning part. In the optimization part, Data Envelopment Analysis (DEA), which is a scientific modeling method of computing comparative productivities and efficiencies of Decision-Making Units (DMUs) compares productivities with Malmquist Productivity Index (MPI). We apply the DEA evaluation with the abovementioned well-known methods in thirteen pharmaceutical companies for five developing countries over 2014-2019. To find the superior model, we use CCR-DEA (or Charnes, Cooper and Rhodes model), BBC-DEA (or Banker, Charnes and Cooper model), and Free Disposal Hull (FDH) for measuring the performance and efficiency of decision processes. We assess models with financial information from Data-stream, with Research and Development (R&D) investment. R&D expenditures relate to the exploration and progress of a company's properties or facilities. In the machine learning part, we use a specific two-layer data mining filtering pre-processes for clustering algorithms to increase the efficiency and to find the superior algorithm. The results indicate that the FDH model has the most productive results (in MPI) and the highest accurate algorithm (in clustering) during all periods compare with other suggested models. The BCC-DEA and CCR-DEA models have the second and third place, respectively. Meanwhile, HIERARCHICAL CLUSTERER has the highest accuracy among the eight proposed algorithms.

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1. Introduction

Growing novel drugs in the pharmaceutical industry need astrophysical assets and a hard-working group of specialists for stages beyond a decade. Despite these long-period and high-price savings, the danger of effective commercialization of runaway success products is inadequate to less than 10% [1]. DEA in optimization is a non-parametric frontier technique where the effectiveness of a specific entity is calculated by its distance from the highest performance practice frontier created by the most exceptional performance entities inside the group. DEA is a general method for assessing the efficacy of ecological-associated systems [2].

Speculation in R&D has been found as out of sorts donating constituent in TFP growth among the designated companies [3]. A recent study [4] evaluated the amount of DTE created by us-based pharmaceutical companies to find the effect of efficiency on companies' productivity, and as a result, the higher the efficiency, the better the companies' productivity. DEA window analysis and MPI for evaluating the efficacy of the scorching procedure in pharmaceutical manufacturing have been proposed by [5]. Finally, the study outcomes offer a valued response on how to progress efficiency, use properties, and efficiently accomplish manufacturing lines. A similar research paper applied a hybrid fuzzy MCDM technique for calculating the performance of public pharmaceutical companies [6,7]. In an experimental study, the efficiency of Indian pharmaceutical companies through the collapse period applying DEA techniques has been proposed [8]. In an estimation for technical efficiencies, slacks, and input/output targets of 50 large pharmaceutical companies over 2010-2011, inefficiency in the companies was based on unproductive decision-makers performance or low measure operation [9]. In a paper with the same topic, they assess the technical efficiency and productivity of 81 companies related to pharmaceutical manufacturing [10].

The primary purpose of this paper is based on the evaluation of productivity calculation with MPI and clustering algorithms for pharmaceutical companies. Both of the DEA above methods have been applied on three CCR_{IO} (CCR Input Oriented), BCC_{IO} (BCC Input Oriented), and FDH models to find the superior model.

2. Methods

The objective of this study is to compare companies' productivity effectively. Using a comparative DEA with MPI is established to determine the features of pharmaceutical companies in terms of some DMUs with three suggested models. Meanwhile, we consider data mining clustering algorithms at the next step. Finally, the entire progression can be divided into four steps, as follows:

2.1. FDH, CCR, BCC Models

FDH model is a non-parametric method to measure the efficiency of production units or DMUs. FDH model relaxes the convexity assumption of basic DEA models. The computational technique to solve the FDH program considers the mixed integer programming problem compared to the DEA model with a linear programming problem [11].

The BCC model is representative using by VRS. It is characterized by increasing returns-to-scale (IRS), decreasing returns-to-scale (DRS), and constant returns to scale (CRS). The production possibility set of the FDH model is obtained by defining it differently with CCR and BCC models. FDH model allows the free impossibility to construct the production possibility set. Accordingly, the frontier line for the FDH model is developed from the observed inputs and outputs, enabling free failure. The FDH_{IO} is represented as follows:

$$Min\theta$$

$$St. \qquad (1)$$

$$\sum_{j=1}^{n} \lambda_j x_{ij} \leq \theta_p \qquad ,i = 1, \dots\dots, m$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} \geq y_{rp} \qquad ,r = 1, \dots \dots, s$$

$$\sum_{j=1}^{n} \lambda_j = 1$$

$$\lambda_j \in \{0, 1\} \qquad ,j = 1, \dots, n$$

The efficiency of an assumed DMU is calculated based on the CCR_{IO} model as follows:

$$Min\theta$$

$$St. \qquad (2)$$

$$\sum_{j=1}^{n} \lambda_j x_{ij} \leq \theta_p \qquad ,i = 1, \dots \dots, m$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} \geq y_{rp} \qquad ,r = 1, \dots \dots, s$$

$$\lambda_j \geq 0 \qquad ,j = 1, \dots, n$$

The BCC_{IO} is represented as follows:

$$Min\theta$$

$$St. \qquad (3)$$

$$\sum_{j=1}^{n} \lambda_j x_{ij} \leq \theta_p \qquad ,i = 1, \dots \dots, m$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} \geq y_{rp} \qquad ,r = 1, \dots \dots, s$$

$$\sum_{j=1}^{n} \lambda_j = 1$$

$$\lambda_j \geq 0 \qquad ,j = 1, \dots, n$$

2.2. Evaluation in Clustering

Clustering is a foremost duty of explorative data mining, and a public procedure for numerical data analysis utilized in several areas, containing machine learning, pattern recognition, and bioinformatics. The numeric attributes used in the clustering algorithms include energy consumption [12-16] [18-26], cement production, pollution control investment, and waste material removed. The MPI efficiency score is the class of clustering algorithms. DMUs with the MPI status greater than one is characterized with "yes," and DMUs with the MPI status of less than one is designated with" no." The validity of the proposed method must be evaluated in each study. To confirm the validity of the proposed model and to test the authority of this research, data were divided into two groups, test data, and educational data in clustering algorithms. With this method, the final outputs are reviewed, and the validity of the research is verified. In this study, 70 percent of the data were designated as training data sets, and 30 percent of the data were selected as experimental data sets. The suggested clustering method aims to identify performance configurations within regular outlines of diverse constructing systems from raw data sets. To randomly select the

experimental data, the Excel software has been used. Finally, to compare and to find the superior algorithms, eight designated clustering algorithms in WEKA software such as CANOPY, COBWEB CLUSTERING, Make density based cluster, Expectation maximization, Farthest first, Filtered cluster, Hierarchical cluster, K-means are considered [17].

3. Discussion in the MPI Model

3.1 Discussion in MPI -CCR Model

The average MPI-CCR for all pharmaceutical companies over 2015-2019 is given in Table 1.

Table 1. Productivity measurement results based on MPI-CCR for 30 companies over 2015-2019

Companies	MPI	Rank	Companies	MPI	Rank
1	0.94	21	16	0.48	30
2	1.15	16	17	1.94	1
3	0.88	23	18	0.90	22
4	1.34	12	19	1.70	7
5	0.80	25	20	1.92	2
6	1.63	8	21	1.04	18
7	1.28	13	22	0.65	28
8	0.95	20	23	1.09	17
9	1.87	4	24	1.16	15
10	0.78	26	25	1.42	11
11	1.24	14	26	0.84	24
12	1.56	9	27	1.81	5
13	1.48	10	28	1.77	6
14	1.03	19	29	1.91	3
15	0.68	27	30	0.57	29

3.2 Discussion in MPI-BCC Model

The average MPI-BCC for all pharmaceutical companies over 2015-2019 is given in Table 2.

Table 2. Productivity measurement results based on MPI-BCC for 30 companies over 2015-2019

Companies	MPI	Rank	Companies	MPI	Rank
1	0.95	21	16	0.49	30
2	1.16	16	17	1.95	1
3	0.89	23	18	0.91	22
4	1.35	12	19	1.73	7
5	0.81	25	20	1.93	2
6	1.64	8	21	1.05	18
7	1.30	13	22	0.67	28
8	0.96	20	23	1.10	17
9	1.89	4	24	1.17	15
10	0.79	26	25	1.45	11
11	1.25	14	26	0.85	24
12	1.58	9	27	1.82	5
13	1.49	10	28	1.78	6
14	1.04	19	29	1.92	3
15	0.69	27	30	0.59	29

3.3 Discussion in MPI-FDH Model

The average MPI-FDH for all pharmaceutical companies over 2015-2019 is given in Table 3.

Table 3. Productivity measurement results based on MPI-FDH for 30 companies over 2015-2019

Companies	MPI	Rank	Companies	MPI	Rank
1	0.96	21	16	0.50	30
2	1.17	16	17	1.96	1
3	0.90	23	18	0.92	22
4	1.36	12	19	1.76	7
5	0.82	25	20	1.94	2
6	1.65	8	21	1.06	18
7	1.32	13	22	0.69	28
8	0.97	20	23	1.11	17
9	1.91	4	24	1.18	15
10	0.80	26	25	1.48	10
11	1.26	14	26	0.86	24
12	1.60	9	27	1.83	5
13	1.50	10	28	1.79	6
14	1.05	19	29	1.93	3
15	0.70	27	30	0.61	29

3.4 Results

Although the difference between productivity scores among the three suggested models is negligible, the FDH model has the highest rank. BCC, and CCR models are in the 2nd, 3rd places, respectively. Finally, the following relation is applicable for all DMUs in all MPIs and all years:

$$FDH > BCC > CCR \tag{13}$$

3.5 Discussion in the clustering

After applying clustering steps (step A and step B), the accuracy and average accuracy in each stage are presented in Tables 4, 5, and 6 for CCR, BCC, and FDH models, respectively.

Table 4. Accuracy comparison contained by clustering algorithms for CCR model (All Numbers Are in Percent)

Algorithms	Step A	Step B
CANOPY	54.6364	55.5455
COBWEB	4.8182	18.1818
EXPECTATION MAXIMIZATION	64.0999	74.7273
FARTHEST FIRST	71	73.7273
FILTERED CLUSTERER	52.9091	55.5455
HIERARCHICAL CLUSTERER	72.8182	82.8182
MAKE DENSITY BASED CLUSTER	52.8182	55.5455
K-MEANS	51.9091	55.5455
Avg. of eight algorithms accuracy	**53.126**	**58.9545**

Table 5. Accuracy comparison contained by clustering algorithms for BCC model (All Numbers Are in Percent)

Algorithms	Step A	Step B
CANOPY	56.6364	57.5455
COBWEB	6.8182	20.1818
EXPECTATION MAXIMIZATION	66.0999	76.7273
FARTHEST FIRST	73	75.7273
FILTERED CLUSTERER	55.9091	58.5455
HIERARCHICAL CLUSTERER	75.8182	86.8182
MAKE DENSITY BASED CLUSTER	56.8182	59.5455
K-MEANS	52.9091	56.5455
Avg. of eight algorithms accuracy	**55.5011**	**61.4545**

Table 6. Accuracy comparison contained by clustering algorithms for FDH model (All Numbers Are in Percent)

Algorithms	Step A	Step B
CANOPY	60.6364	61.5455
COBWEB	8.8182	21.1818
EXPECTATION MAXIMIZATION	67.0999	77.7273
FARTHEST FIRST	74	76.7273
FILTERED CLUSTERER	56.9091	59.5455
HIERARCHICAL CLUSTERER	76.8182	**87.8182**
MAKE DENSITY BASED CLUSTER	58.8182	64.5455
K-MEANS	53.9091	57.5455
Avg. of eight algorithms accuracy	**57.1261**	**63.3295**

It can be concluded from Table 4, 5, and 6 as the layers of filtering increases:

- The maximum of accuracy within two assessment approaches is improved.
- The average accuracy within eight algorithms, links to each filtering step is augmented.
- The accuracy of all algorithms is increased as well.

HIERARCHICAL CLUSTERER at step A and B has the highest accuracy. In fact, according to our unique data, attributed, and instances using the HIERARCHICAL CLUSTERER algorithm in proposed combining DEA and data mining methodology has the highest accuracy. Finally, the FDH model has the highest rank. BCC, and CCR models are in the 2nd, 3rd places, respectively. Finally, the following relation is applicable for all DMUs in all MPIs and all years:

$$FDH > BCC > CCR \tag{14}$$

4. Conclusion

In this study, we describe how companies operate in the presence of similar companies. Therefore, companies that have a higher score can improve their productivity. The more taking available information, the higher accurate and accessible data will be available. Each company needs a productivity measurement to know its current status. So, productive companies are the best reference for increasing the efficiency of inefficient companies. The FDH model has a more positive impact on efficiency score compare with other suggested models such as CCR and BCC. The proposed approach, geometric average, results, and predictions derived from the period and productivity score can help the practitioner to compare the productivity of uncertain cases and instruct accordingly. In the future, applying window analysis and comparing final productivities result with MPI will be valuable. Meanwhile, using fuzzy and random data for window analysis will be interesting as a final comparison. Since the proposed MPI method is based on a moving average, it is useful for finding per efficiency trends over time. So, the results and predictions can be helpful for managers of these companies and other managers who benefit from this approach to achieve a higher relative efficiency score. Besides, managers can compare the efficiency of the current year with other similar companies over the past years. Finally, for the novelty of this paper, data mining clustering algorithms with unique preprocessed filtering methods introduce the best performing algorithm. As the future approach, we will improve the method by combining with some other available optimization and machine learning techniques such as but not limited to [27-45].

Conflict of Interest:

The authors declare that they have no conflict of interest

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