



# A novel ranking procedure for forecasting approaches using Data Envelopment Analysis



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## ABSTRACT

To compare the accuracy of different forecasting approaches an error measure is required. Many error measures have been proposed in the literature, however in practice there are some situations where different measures yield different decisions on forecasting approach selection and there is no agreement on which approach should be used. Generally forecasting measures represent ratios or percentages providing an overall image of how well fitted the forecasting technique is to the observations. This paper proposes a multiplicative Data Envelopment Analysis (DEA) model in order to rank several forecasting techniques. We demonstrate the proposed model by applying it to the set of yearly time series of the M3 competition. The usefulness of the proposed approach has been tested using the M3-competition where five error measures have been applied in and aggregated to a single DEA score.

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## 1. Introduction

Measuring forecasting performance is a crucial issue. With many different methods in forecasting, understanding their relative performance is critical for more accurate prediction of the quantities of interest. Conclusions about the accuracy of various forecasting methods typically require comparisons using a range of accuracy measures. This is because different measures are designed to assess different aspects of the model. For example, Mean Square Error (MSE) puts heavier penalties on higher errors while Mean Absolute Error (MAE) is designed to lessen the effect of outliers. Various accuracy measures have been used in the literature and their properties have been discussed to some extent (Hyndman and Koehler, 2006). Obviously, it is one thing that no accuracy measure dominates the others and it is another that all reasonable accuracy measures are equally fine. Forecast accuracy evaluation becomes a more challenging task when different forecast methods/forecast scenarios and various forecast accuracy measures are involved. In a given situation, sometimes different accuracy measures will lead to different results as to which forecast method/scenario is best and they give contradictory results. These contradictory results indicate that they are not measuring the same aspect of prediction accuracy (Kitchenham et al., 2001). It has been observed through forecasting competition studies such as the M-competition (Makridakis et al., 1982) and the M3-competition (Makridakis and Hibon, 2000) that the performance of different methods changes

considerably depending on the accuracy measure being used. Syntetos and Boylan (2005) stated that different accuracy measures can lead to different conclusions especially in the context of intermittent demand, where demand appears sporadically, with some time periods showing no demand at all. Chatfield (2013) argued that the best model under one criterion cannot always be the best under some other criteria. No single measure is universally best for all accuracy assessment objectives, and different accuracy measures may lead to conflicting interpretations and conclusions. Considering different forecasting approaches, we may need to produce forecasting in various forecast horizons and/or use various performance accuracy measures to assess the accuracy performance. These issues have been argued in the literature (Athanasopoulos and Hyndman, 2011; Hyndman and Koehler, 2006; Kitchenham et al., 2001; Makridakis and Hibon, 2000; Yokuma and Armstrong, 1995). However, sometimes different accuracy measures will lead to different results in terms of selecting the most accurate forecasting method. Therefore, results may be contradicting each other. Although, this problem has been encountered in the literature of forecast accuracy measurement, however no solution is proposed to facilitate the choice of best forecasting method in the condition of contradictory results. This paper is focused only on proposing a decision support system for determining the best forecasting technique based to the results of given forecasting methods and accuracy measures, rather than improving the forecasting accuracy. We are not concerned with the methods used to provide forecasts. We are interested in how applied forecasting methods can be ranked when various accuracy measures are used to evaluate the accuracy performance. Moreover, the proposed approach can also be applied in other situations such as rank different forecasting scenarios, rank forecasting methods based on the

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forecast accuracy of various horizons and single error measure. In this study Data Envelopment Analysis (DEA) methodology is used to rank the different forecasting approaches based on their values of accuracy measures. The proposed model is a multiplicative DEA model, which is mathematically shown as the right one to handle percentages or ratio data. Each forecasting technique is considered as a Decision Making Unit (DMU). Forecasting measures of each DMU are assumed to be inputs and after being log-linearised, the proposed DEA model is solved for each DMU. The forecasting techniques are ranked based on the scores obtained from DEA model (efficiency). This is an important issue from practitioner's point of view to decide which forecasting method should be selected for forecasting purposes among various approaches, especially when forecasting process is automated and hundred of thousand items need to be predicted. The results of this paper can be implemented by forecasting package software manufacturers which can add more value to their customers. The proposed multiplicative DEA model can objectively provide ranking of forecasting techniques based on efficiency scores. In the presence of ties from the ranking, three meta-frontier techniques are presented, namely cross efficiency, super efficiency and lambda frequency. Section 2 of this paper studies the background of Data Envelopment Analysis and forecast comparison. Section 3 describes the proposed DEA model to select the best forecasting approach. In Section 4 an application of the proposed method on yearly M3-competition time series and forecasting methods is demonstrated and the results are discussed. Conclusions are drawn in Section 5.

## 2. Background and related works

### 2.1. Introduction to Data Envelopment Analysis

Data Envelopment Analysis (DEA), is a method for assessing the comparative performance of units (DMUs) converting a set of inputs to a bundle of outputs, based on certain assumptions. The first models of DEA technique have been proposed by Charnes et al. (1978) and Banker et al. (1984). Thereafter, the area of DEA has been largely expanded with extensions to the aforementioned works. The main characteristic of the DEA technique is its ability to provide a unified efficiency score of an assumed production process where inputs are consumed in order to produce outputs, which in most cases are desirable, though undesirable outputs may occur as well (Seiford and Zhu, 2002). For further details about DEA and its application see Emrouznejad and De Witte (2010) and Cook and Seiford (2009). In cases where the weights of the model provide zero values, then a different multiplicative DEA model must be used.

### 2.2. Comparison of forecasting techniques

Forecasting is designed to help decision making and planning in the present by predicting possible future alternatives. In the taxonomy of forecasting methods (Yokuma and Armstrong, 1995), judgmental and statistical forecasting are the two main categories (Hyndman and Athanasopoulos, 2014). The assessment of forecasting techniques is an interesting subject that has been addressed throughout the years (De Gooijer and Hyndman, 2006). Some studies compared accuracy measured with other criteria such as ease of use, ease of interpretation, cost saving, etc. on forecast evaluation. They concluded that accuracy was the most important criterion for evaluating forecasting techniques (Collopy and Armstrong, 1992; Witt and Witt, 1992). In most of the cases, forecasting techniques are compared against the values of accuracy measures or are examined by situation or data used. The accuracy measures that are often used in order to evaluate the quality of a forecasting technique are Mean Square Error (MSE), Root Mean Square Error (RMSE), Mean Absolute Error (MAE) and Mean Absolute Percentage Error (MAPE). Based on the study of Collopy and Armstrong (1992) that has been conducted with a panel of 49 experts in the field of forecasting, 85% of the respondents consider accuracy measures from

important (56%) to extremely important (29%). Based on the aforementioned study, several works have been published assessing quantitative and qualitative criteria of forecasting techniques (Yokuma and Armstrong, 1995). In that multi-aspect study, an agreement analysis has been performed using a questionnaire survey measuring the opinions of 322 experts divided into 4 categories, namely Decision Maker (DM), Practitioner, Educator and Researcher. Among the questions asked, the largest average agreement score was that of "Accuracy" whereas "Timeliness" in providing forecasts' gathered the second largest score. Comparison of forecasting techniques can also be conducted by testing the techniques, applying to real life data sets representing sales (Abdel-Khalik and El-Sheshai, 1983; Geurts and Patrick Kelly, 1986). It is important to note that due to the advantages and disadvantages of each accuracy measure, no single error measure can capture all aspects of accuracy. Many forecast accuracy measures have been proposed in the literature and the recommendations for selecting the appropriate error measurements are discussed. Authors argued that generally utilization of various accuracy measures should be more efficient, as each accuracy measure may look at a different aspect of accuracy (Kitchenham et al., 2001). A summary of some of the issues is given by (Davydenko and Fildes, 2013; De Gooijer and Hyndman, 2006; Fildes et al., 2011; Hyndman and Koehler, 2006) and (Yokuma and Armstrong, 1995). De Gooijer and Hyndman (2006) reviewed a variety of accuracy measures used in the literature to evaluate the performance of forecasting methods up to 2005. Hyndman and Koehler (2006) provided a critical survey on various accuracy measures. Fildes et al. (2011) argued that no single error measure captures the distributional features of the errors when summarized across data series and discussed four error measures that should capture the essential characteristics of the forecast results. Davydenko and Fildes (2013) discussed many error measures by focusing on the performance measurement of judgemental forecasting.

### 2.3. DEA score as a means for selecting best forecasting techniques

To rank forecasting techniques several approaches have been introduced in the literature using Machine Learning, Data Mining techniques and forecasting with Neural Networks based on their measures. For example, using Machine Learning techniques several indices have been developed such as Adjusted Ratio of Ratios (ARR) which is a multi-criteria evaluation index and resembles to the efficiency measure as it provides the relative efficiency of each technique (Brazdil et al., 2003). However, the performance is relative and concerns only the comparison of two algorithms given a compromise (trade-off) between two criteria. Another shortfall of the proposed approach is that in order to extend the comparisons to more than two algorithms, certain aggregations of the criteria must be made. On the contrary, the efficiency score from DEA technique is objectively extracted. The efficiency of the calculation process using Data Mining techniques is similar to Machine learning. Efficiency is formed as a fraction of the weighted outputs to inputs for of each technique (Nakhaeizadeh and Schnabl, 1997; Nakhaeizadeh and Schnabl, 1998). In a different context, technological forecasting has been examined by Lim et al. (2014). Based on this method, the technological capabilities of different technologies are assessed based on DEA. Technological Forecasting using Data Envelopment Analysis (TFDEA) has also been applied on fighter jet and commercial technology by Inman et al. (2006). However, the proposed DEA method, assesses different versions of DMUs based on inputs and outputs and does not provide a decision support system for determining the best forecasting technique. Later studies prove that classical DEA models are not appropriate to handle percentage or ratio data (Emrouznejad et al., 2010). Duong (1988) mentioned that it is not uncommon in practice to have a set of forecasts which yield different rankings of the underlying techniques for different performance criteria. A hierarchical approach to rank the forecasting techniques has been suggested using the Analytic Hierarchy Process (AHP) as a general framework for obtaining the weights for forecasts combination. Pairwise comparisons of forecast

measures have been determined from a panel of experts provided weights leading to the ranking of each technique. The ranking result is purely based on subjective comparisons of the groups of experts, thus different group of experts could provide different comparisons and consequently, different forecasting methods ranking. Therefore, the ranking result is not robust because of the discussed shortfall of AHP. Standard DEA has also been applied for the evaluation of forecasting of Neural Networks (Pendharkar and Rodger, 2003). Similar to the evaluation of the aforementioned Data Mining and Machine Learning techniques presented above, efficiency is derived as weighted fraction of outputs to inputs. Let's assume that there are  $n$  DMUs.

Model 1: VRS input orientated standard DEA.

$$\begin{aligned} & \min \theta_{j_0} \\ & \text{s.t.} \\ & \sum_{j=1}^n \lambda_j \cdot x_{i,j} \leq \theta_{j_0} \cdot x_{i,j_0}, \quad i = 1, 2, \dots, m \\ & \sum_{j=1}^n \lambda_j \cdot y_{r,j} \geq y_{r,j_0}, \quad r = 1, 2, \dots, s \\ & \sum_{j=1}^n \lambda_j = 1 \\ & \lambda_j \geq 0, \quad j = 1, \dots, n \\ & \theta \text{ free} \end{aligned}$$

Model 2: VRS output orientated standard DEA

$$\begin{aligned} & \max \phi_{j_0} \\ & \text{s.t.} \\ & \sum_{j=1}^n \lambda_j \cdot x_{i,j} \leq x_{i,j_0}, \quad i = 1, 2, \dots, m \\ & \sum_{j=1}^n \lambda_j \cdot y_{r,j} \geq \phi_{j_0} \cdot y_{r,j_0}, \quad r = 1, 2, \dots, s \\ & \sum_{j=1}^n \lambda_j = 1 \\ & \lambda_j \geq 0, \quad j = 1, \dots, n \\ & \phi \text{ free} \end{aligned}$$

( $DMU_j; j = 1, 2, \dots, n$ ), consuming  $m$  inputs ( $x_{i,j}; i = 1, 2, \dots, m$ ), and producing  $s$  outputs ( $y_{r,j}; r = 1, \dots, s$ ). Two main efficiency models in DEA are input-oriented and out-put oriented, as formulated in Model 1 and Model 2.

In this model,  $\lambda_j$  provides information for the reference set (peers) in the case where DMU under investigation ( $j_0$ ) is not efficient ( $\theta_{j_0} \neq 1$  or  $\phi_{j_0} \neq 1$ ). Models 1 and 2 are the first DEA models introduced by Charnes et al. (1978). DEA has been used to evaluate forecasting techniques including Autoregressive Integrated Moving Average (ARIMA), Random Walk (RW), Vector Error Correction (VEC), Regression and Error Correction models (Xu and Ouenniche, 2011). Furthermore, basic DEA Models 1 and 2 along with Super-Efficiency models have been applied to the ranking of 14 chosen competing volatility forecasting approaches, applying crude oil price data (Xu and Ouenniche, 2011). However, as we will show applying standard DEA models to forecast accuracy measures may yield incorrect results. Accuracy measures represent ratios thus standard DEA models provide false results due to loss of information while the returns to scale orientation (RTS) is by default Constant Returns to Scale (CRS) (Hollingsworth and Smith, 2003). Emrouznejad et al. (2010) have shown that in the case of ratios in inputs and outputs, multiplicative DEA formulations are more appropriate as the concept of the geometric mean with non-dimensional (unit invariance) properties is used. Furthermore, it is shown in the literature that in the case where data are ratios, classical DEA models provides wrong results as the Production Possibility Set (PPS) is not additive, but multiplicative. Denoting PPS as  $P = \{(x, y) : x \mapsto y\}$ , assuming that inputs  $x$  can produce outputs  $y$  (whereas  $x$  and  $y$  represent vectors of inputs and outputs, respectively), then DEA provides an estimation

of the PPS. Based on the convexity axiom of DEA (Banker et al., 1984), a convex combination of any two points on the:

Model 3: A multiplicative input-oriented DEA model

$$\begin{aligned} & \min \theta_{j_0} \\ & \text{s.t.} \\ & \prod_{j=1}^n x_{i,j}^{\lambda_j} \leq \theta_{j_0} \cdot x_{i,j_0}, \quad i = 1, 2, \dots, m \\ & \sum_{j=1}^n \lambda_j = 1 \\ & \lambda_j \geq 0, \quad j = 1, \dots, n \\ & \theta \text{ free} \end{aligned}$$

PPS also belongs to PPS. In the case a single input, two outputs, representing ratios, the PPS is graphically represented in Fig. 1. If  $P_A, P_B$  are two points of PPS such that  $P_A(x_A, y_A)$  and  $P_B(x_B, y_B)$ , then assuming that point  $P'$  is a convex combination of  $P_A$  and  $P_B$ , then  $P = \lambda \cdot P_A + (1 - \lambda) \cdot P_B$ . Taking values for  $\lambda$ , the new point resulting from the convex combination of  $P_A$  and  $P_B$ , does not belong to the PPS. A relevant example and proof of the aforementioned procedure is demonstrated in Emrouznejad and Amin (2009). Hence, the model that can be applied in this case is a multiplicative DEA model as developed by Emrouznejad et al. (2010).

### 3. Proposed approach

#### 3.1. Multiplicative DEA model

Following the discussion in Section 2.3, the multiplicative DEA model that is used to rank the forecasting techniques applied to yearly time series M3-competition data (Makridakis and Hibon, 2000), is the following (Banker and Mairdiratta, 1986):

As described in the Model 3, the proposed multiplicative DEA model is input oriented (Charnes et al., 1982), considering geometric convexity as any point of the new PPS can be calculated based on the relation  $P^r = (P_A)^\lambda \cdot (P_B)^{1-\lambda}$ . In Model 3,  $x_{i,j}$  denotes  $i$  input of DMU  $j$  whereas  $\lambda_j$  denotes the coefficient to peers of each DMU  $j$ ;  $\theta_{j_0}$  is the efficiency score for each DMU under investigation  $o$ . The above Model 3 is non-linear due to existence of exponential terms ( $\alpha^x$ ). In order to get an optimal solution, an equivalent model is proposed based on log-linearization of Model 3. For log-linearization, the following  $\log_{10}$  function is used:

$$\begin{aligned} & \log_{10} \left( \prod_{j=1}^n (x_{i,j})^{\lambda_j} \right) \leq \log_{10}(x_{i,j_0}) \Leftrightarrow \\ & \left( \sum_{j=1}^n \log_{10}(x_{i,j}) \cdot \lambda_j \right) \leq \log_{10}(x_{i,j_0} + \log_{10}(\theta_{i,j_0})), \quad i = 1, 2, \dots, m, \quad j = 1, \dots, n \end{aligned}$$

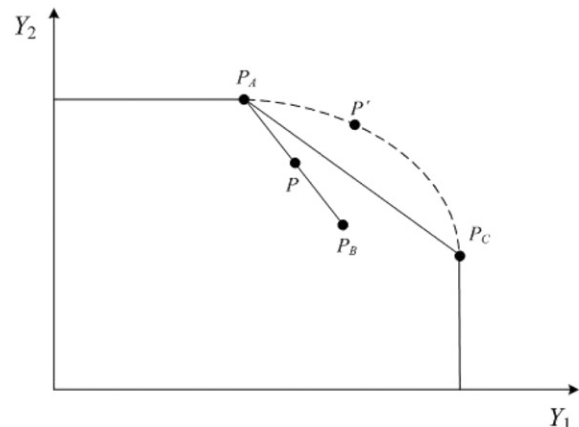


Fig. 1. An output productivity possibility set.

Model 4: Log linearisation of multiplicative input-oriented DEA model

$$\begin{aligned}
 & \min \tilde{\theta}_{j_0} \\
 & \text{s.t.} \\
 & \sum_{j=1}^n \lambda_j \cdot \tilde{x}_{i,j} \leq \tilde{x}_{i,j_0} + \tilde{\theta}_{i,j_0}, i = 1, 2, \dots, m \\
 & \sum_{j=1}^n \lambda_j = 1 \\
 & \lambda_j \geq 0, j = 1, \dots, n \\
 & \tilde{\theta} \text{ free}
 \end{aligned}$$

Taking the logarithm on both sides of the first constraint of Model 4 is derived.

In Linear Programming (LP) Model 4,  $\tilde{x}_{i,j}$  denotes the  $\log_{10}(x_{i,j})$ . Objective function seeks the minimization of log-efficiency of each DMU  $o$  ( $\tilde{\theta}_{j_0}$ ) and efficiency scores are obtained by calculating  $10^{\tilde{\theta}_{j_0}}$  for each DMU, where  $\tilde{\theta}_{j_0}^*$  is the optimal solution from Model 4.

It must be noted that as Model 4 may handle accuracy data per DMU less than one, then logarithm yields a negative value. This is resolved with normalisation procedure, as stated in 2. Given the initial data (input  $i$  for each DMU  $j$ ), if all the data for inputs of all DMUs are above 1, then the new logarithmic input vectors are computed. However, for an input less than 1, then the corresponding column is divided by the minimum number normalizing data to avoiding negative values after logarithm calculation.

Model 5: Super efficiency DEA model

$$\begin{aligned}
 & \min \tilde{\theta}_{j_0} \\
 & \text{s.t.} \\
 & \sum_{\substack{j=1 \\ j \neq j_0}}^n \lambda_j \tilde{x}_{i,j} \leq \tilde{x}_{i,j_0} + \tilde{\theta}_{i,j_0}, i = 1, 2, \dots, m \\
 & \sum_{\substack{j=1 \\ j \neq j_0}}^n \lambda_j = 1 \\
 & \lambda_j \geq 0, j = 1, \dots, n \\
 & \tilde{\theta} \text{ free}
 \end{aligned}$$

### 3.2. Finding the best forecasting technique in case of ties

When using DEA to rank forecasting techniques, it is quite common to get ties of ranking due to the fact that two or more forecasting techniques become efficient. In order to deal with those cases where there is a tie in the ranking of forecasting techniques, cross efficiency, super efficiency and lambda frequency can be used.

#### 3.2.1. Cross efficiency

The idea of cross efficiency (Cook and Zhu, 2013) is to support the weak discrimination of basic DEA models. In order to compute the cross efficiency the following steps are followed. Firstly, optimal solutions for weights variable (in the dual of Model 4) are derived. Then, the cross efficiency of each DMU under investigation is calculated based on the weights of other DMUs. For full description of cross efficiency see (Cook and Zhu, 2013).

#### 3.2.2. Super efficiency

Super efficiency (Chen, 2005; Cook et al., 2009) has been widely used in order to assess the efficiency of DMUs and to provide more discrimination power to basic DEA models. The concept of super efficiency is based on assessing the efficiency of all the DMUs while excluding the DMU under investigation from the left hand side of Model 4, this is

presented in Model 5. The proposed model with the concept of super efficiency is presented in Model 8.

#### 3.2.3. Lambda frequency

When solving a DEA problem, besides the results that concern efficiency, lambda values (peers) are also calculated. These values are interpreted as the resemblance of the DMU under investigation with the units that belong to its reference set. Non-efficient units have as peers (positive lambda values) only efficient DMsUs. Thus, in order to discriminate the ranking in case of a tie between two or more DMUs then counting only the instances where an efficient DMU is a peer in the reference set of a non-efficient DMU, can be used as a discriminating measure.

### 3.3. An illustrative example

In order to provide better understanding of the proposed approach and to make it reproducible, an illustrative example is presented with 5 forecasting techniques. For each forecasting technique, 3 error measures have been calculated to evaluate its accuracy. From this figure, we cannot clearly answer this question, “which forecasting technique is the best?”. The optimal point would be the one that would minimize all accuracy measures simultaneously. Let us look at FOR02 and FOR05 in Fig. 3; it can be seen that FOR02 performs better in measure 1 comparing to measures 2 and 3. On the contrary, FOR05 performs better in measures 2, 3 and worst in measure 3. The data for each forecasting technique are presented in Table 1.

As indicated in Table 1, the values of measure  $M_1$  for each forecasting technique are greater than 1 and the  $\log_{10}$  can be calculated straightforward. The same stands for measure  $M_2$  but as can be seen in the last measure ( $M_3$ ), the value of forecasting technique 1 (FOR01) is less than 1. Thus, calculating the  $\log_{10}$  value would provide negative results, thus based on log-normalisation procedure (Fig. 2), all the elements of the column  $M_3$  are divided by a small positive infinitesimal number ( $\epsilon = 10^{-5}$ ). After that normalisation, the  $\log_{10}$  value of the last column is calculated as well. The results are presented in Table 2.

Based on Model 4, the following LP models are solved for each DMU (FOR01, ..., FOR05).

By solving the LP models as presented in Table 3, the optimal values regarding  $\tilde{\theta}^*$ ,  $\theta^* = 10^{\tilde{\theta}^*}$  and  $\lambda^*$  variables are derived.

- FOR01:  $\tilde{\theta}^* = 0$ ,  $\theta^* = 1$  (100%), ( $\lambda_1^* = 1$ )
- FOR02:  $\tilde{\theta}^* = -0.434$ ,  $\theta^* = 0.368$  (36.8%) ( $\lambda_1^* = 1$ )
- FOR03:  $\tilde{\theta}^* = -0.309$ ,  $\theta^* = 0.491$  (49.1%), ( $\lambda_1^* = 0.613, \lambda_5^* = 0.387$ )
- FOR04:  $\tilde{\theta}^* = -0.425$ ,  $\theta^* = 0.375$  (37.5%) ( $\lambda_1^* = 0.478, \lambda_5^* = 0.522$ )
- FOR05:  $\tilde{\theta}^* = 0$ ,  $\theta^* = 1$  (100%), ( $\lambda_5^* = 1$ )

Forecasting techniques are ranked based on the efficiency score. FOR01 and FOR05 are ranked first, FOR03 is ranked second, FOR04 is ranked third and FOR02 is ranked fourth. As it can be seen, there is a tie in the ranking between FOR01 and FOR05. Based on lambda frequency, presented in Section 3.2, the count of positive  $\lambda^*$  values that are referred to FOR01 are 3 while the corresponding number for FOR05 are 2. Accordingly, we can conclude that the rankings are as follows: FOR01 > FOR05 > FOR03 > FOR04 > FOR02.

**Table 1**  
Data for illustrative example.

Forecasting technique	$M_1$	$M_2$	$M_3$
FOR01	62.24	37.618	0.0377
FOR02	168.937	127.708	42.479
FOR03	250.522	74.292	22.614
FOR04	415.936	96.076	7.063
FOR05	362.426	34.747	4.741

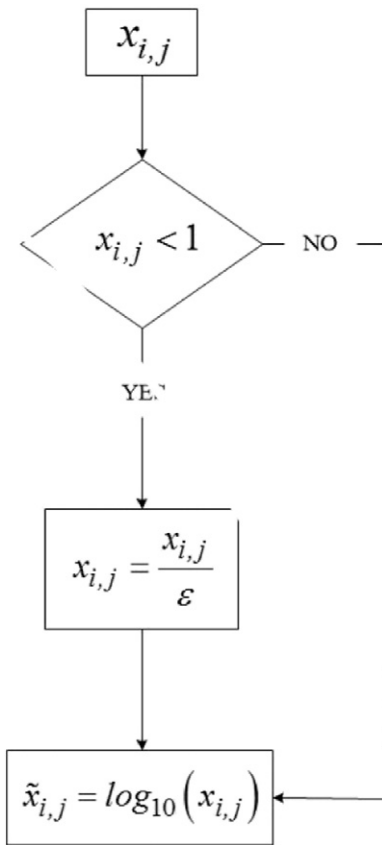


Fig. 2. Normalisation process for process for input data.

Table 2  
Log values of data of illustrative example.

Forecasting technique	$\log_{10}(M_1)$	$\log_{10}(M_2)$	$\log_{10}(\frac{M_3}{\epsilon})$
FOR01	1.794	1.575	3.576
FOR02	2.228	2.106	6.628
FOR03	2.399	1.871	6.354
FOR04	2.619	1.983	5.849
FOR05	2.559	1.541	5.676

4. A real application to M3-competition data

We demonstrate use of the proposed approach by applying it in the yearly M3-competition data (Makridakis and Hibon, 2000). We consider 22 forecasting methods discussed in the M3-competition. Our aim is to observe the data at each forecast period and calculate the forecast accuracy assuming that we have different forecast approaches and various forecast performance measures. Please refer to Makridakis and Hibon (2000) for details of forecasting methods used in this study. In Table 4 the forecasting techniques used in this instance are demonstrated and are presented as DMUs of the proposed DEA model.

4.1. Forecasting performance evaluation

The measures used for comparing the forecasting accuracy are the Root Mean Square Error (RMSE), Mean Absolute Error (MAE), Mean Absolute Percentage Error (MAPE), Symmetric Mean Absolute Percentage Error (sMAPE) and Mean Absolute Scaled Error (MASE) which are defined as follows (Hyndman and Koehler, 2006):

1. Root Mean Square Error (RMSE) =  $\sqrt{\frac{1}{n} \sum_{t=1}^n e_t^2}$
2. Mean Absolute Error (MAE) =  $\frac{1}{n} \sum_{t=1}^n |e_t|$

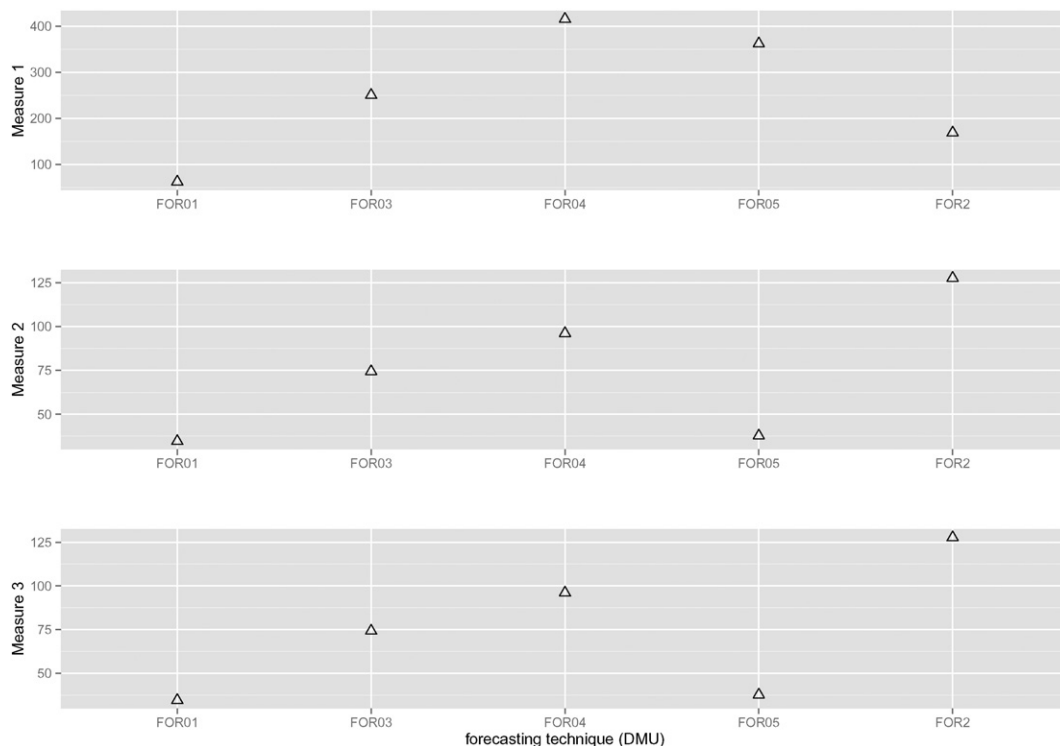


Fig. 3. Comparison of 5 forecasting techniques based on their accuracy measures.

**Table 3**  
LP formulations for each forecasting technique of the illustrative example.

DMU	LP formulation
FOR01	$\min \bar{\theta}$ $s.t.$ $1.794\lambda_1 + 2.228\lambda_2 + 2.399\lambda_3 + 2.619\lambda_4 + 2.559\lambda_5 - \bar{\theta} \leq 1.794$ $1.575\lambda_1 + 2.106\lambda_2 + 1.871\lambda_3 + 1.983\lambda_4 + 1.541\lambda_5 - \bar{\theta} \leq 1.575$ $3.576\lambda_1 + 6.628\lambda_2 + 6.354\lambda_3 + 5.849\lambda_4 + 5.676\lambda_5 - \bar{\theta} \leq 3.576$ $\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 = 1$ $\lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5 \geq 0, \bar{\theta} \text{ free}$
	$\min \bar{\theta}$ $s.t.$ $1.794\lambda_1 + 2.228\lambda_2 + 2.399\lambda_3 + 2.619\lambda_4 + 2.559\lambda_5 - \bar{\theta} \leq 2.228$ $1.575\lambda_1 + 2.106\lambda_2 + 1.871\lambda_3 + 1.983\lambda_4 + 1.541\lambda_5 - \bar{\theta} \leq 2.106$ $3.576\lambda_1 + 6.628\lambda_2 + 6.354\lambda_3 + 5.849\lambda_4 + 5.676\lambda_5 - \bar{\theta} \leq 6.628$ $\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 = 1$ $\lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5 \geq 0, \bar{\theta} \text{ free}$
	$\min \bar{\theta}$ $s.t.$ $1.794\lambda_1 + 2.228\lambda_2 + 2.399\lambda_3 + 2.619\lambda_4 + 2.559\lambda_5 - \bar{\theta} \leq 2.399$ $1.575\lambda_1 + 2.106\lambda_2 + 1.871\lambda_3 + 1.983\lambda_4 + 1.541\lambda_5 - \bar{\theta} \leq 1.871$ $3.576\lambda_1 + 6.628\lambda_2 + 6.354\lambda_3 + 5.849\lambda_4 + 5.676\lambda_5 - \bar{\theta} \leq 6.354$ $\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 = 1$ $\lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5 \geq 0, \bar{\theta} \text{ free}$
	$\min \bar{\theta}$ $s.t.$ $1.794\lambda_1 + 2.228\lambda_2 + 2.399\lambda_3 + 2.619\lambda_4 + 2.559\lambda_5 - \bar{\theta} \leq 2.619$ $1.575\lambda_1 + 2.106\lambda_2 + 1.871\lambda_3 + 1.983\lambda_4 + 1.541\lambda_5 - \bar{\theta} \leq 1.983$ $3.576\lambda_1 + 6.628\lambda_2 + 6.354\lambda_3 + 5.849\lambda_4 + 5.676\lambda_5 - \bar{\theta} \leq 5.849$ $\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 = 1$ $\lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5 \geq 0, \bar{\theta} \text{ free}$
	$\min \bar{\theta}$ $s.t.$ $1.794\lambda_1 + 2.228\lambda_2 + 2.399\lambda_3 + 2.619\lambda_4 + 2.559\lambda_5 - \bar{\theta} \leq 2.559$ $1.575\lambda_1 + 2.106\lambda_2 + 1.871\lambda_3 + 1.983\lambda_4 + 1.541\lambda_5 - \bar{\theta} \leq 1.541$ $3.576\lambda_1 + 6.628\lambda_2 + 6.354\lambda_3 + 5.849\lambda_4 + 5.676\lambda_5 - \bar{\theta} \leq 5.676$ $\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 = 1$ $\lambda_1, \lambda_2, \lambda_3, \lambda_4, \lambda_5 \geq 0, \bar{\theta} \text{ free}$

- Mean Absolute Percentage Error (MAPE) =  $\frac{1}{n} \sum_{i=1}^n |100 \cdot \frac{e_t}{Y_t}|$
- Symmetric Mean Absolute Percentage Error (sMAPE) =  $\frac{1}{n} \sum_{i=1}^n \frac{100 \cdot |e_t|}{Y_t + F}$
- Mean Absolute Scaled Error (MASE) =  $\frac{1}{n} \sum_{i=1}^n \left( \frac{e_t}{\frac{1}{n-1} \cdot \sum_{i=2}^n |Y_i - Y_{i-1}|} \right)$

4.2. Case study

The case study that is selected to demonstrate the applicability of the presented approach, uses times series data retrieved from M3-competition, where the evaluation of efficiency has been performed based on five measures, namely RMSE, MAE, MAPE, sMAPE and MASE, derived from 22 forecasting techniques. In this section, the application of the proposed DEA approach to yearly M3-competition data set is demonstrated. As shown in Fig. 4, 22 forecasting techniques are applied providing values for five measures (RMSE, MAE, MAPE, sMAPE and MASE). As it can be seen, more or less all forecasting techniques provide a uniform image with slight modifications per measure. The following DEA model is applied to extract the efficiency and rank DMUs based on the given measures. In Model 6 ( $\tilde{\cdot}$ ) express the  $\log_{10}(\cdot)$  and a VRS technology is assumed as well.

Fig. 4 shows the original error measures of forecasting techniques while Fig. 5 presents these measures after a logarithmic transformation. Due to the fact that logarithmic function is monotonically increasing function, the trend is the same between actual data and this representation. The last graph of Fig. 5 yields the efficiency of each forecasting technique in the range of [0, 1] after applying the transformation  $10^{\tilde{\cdot}}$ . The results are also presented in Table 5. Solving the dual of Model 4, the weights reported are not zero.

Model 6: Linearization of multiplicative input-oriented DEA model

$$\min \bar{\theta}_{j_0}$$

$$s.t.$$

$$\sum_{j=1}^{22} \lambda_j \cdot \overline{RMSE}_{i,j} \leq \overline{RMSE}_{i,j_0} + \bar{\theta}_{j_0}$$

$$\sum_{j=1}^{22} \lambda_j \cdot \overline{MAE}_{i,j} \leq \overline{MAE}_{i,j_0} + \bar{\theta}_{j_0}$$

$$\sum_{j=1}^{22} \lambda_j \cdot \overline{MAPE}_{i,j} \leq \overline{MAPE}_{i,j_0} + \bar{\theta}_{j_0}$$

$$\sum_{j=1}^{22} \lambda_j \cdot \overline{sMAPE}_{i,j} \leq \overline{sMAPE}_{i,j_0} + \bar{\theta}_{j_0}$$

$$\sum_{j=1}^{22} \lambda_j \cdot \overline{MASE}_{i,j} \leq \overline{MASE}_{i,j_0} + \bar{\theta}_{j_0}$$

$$\sum_{j=1}^{22} \lambda_j = 1$$

$$\lambda_j \geq 0, j = 1, \dots, 22$$

$$\bar{\theta} \text{ free}$$

In Table 5 the efficiency score is presented for each forecasting technique. Based on the data from yearly M3-competition, forecasting techniques FOR01, FOR02, FOR03 and FOR04 have the largest efficiency and are ranked as 1. The extracted efficiency is used as a unified measure based on which forecasting techniques are ranked. The importance of the proposed approach is that the efficiency is extracted after comparing the values of measures of each DMU against each other and the score is calculated objectively. This technique is served as a multi-criteria decision making technique, as each forecasting technique is not performing the same in all measures. Moreover, as each proposed measure is equally important to evaluation of each forecasting technique, the score provided can be used for assessing forecasting techniques based on one or more measures. One of the disadvantages of DEA is that by construction, the technique is designed to measure efficiency/productivity and not providing a single winner; in this case ranking of forecasting techniques is performed upon multiplying the values of different criteria.

4.3. Handling ties

Another way to determine the true ranking of forecasting techniques in case of a tie it to measure the lambda frequency. More specifically, by measuring how many times the non-efficient DMUs refer to them in their reference set, then the higher the frequency, the better for that forecasting technique (FOR). Taking as an example the results for lambda values from Table 6, then the frequency of positive lambda values are shown in the last row which it can be seen that the DMU with the highest lambda frequency is FOR03, whereas the forecasting technique with the lowest lambda frequency is FOR04. The ranking obtained based on Table 6 is FOR03 > FOR01 > FOR02 > FOR04.

**Table 4**  
Forecasting techniques used in M3-competition time series data and in DEA analysis.

Forecasting technique	DMU	Forecasting Technique	DMU
ROBUST	FOR01	PP Autocast	FOR12
AutoBox2	FOR02	ForecastPro	FOR13
ForcX	FOR03	Flors.Pearsc1	FOR14
RBF	FOR04	SMARTF	FOR15
SINGLE	FOR05	B.J.aut	FOR16
THETAsm	FOR06	AutoBox3	FOR17
NAIVE2	FOR07	DAMPEN	FOR18
THETA	FOR08	ARARMA	FOR19
Auto.ANN	FOR09	WINTER	FOR20
Flors.Pearc2	FOR10	HOLT	FOR21
COMB.S.H.D	FOR11	AutoBox1	FOR22

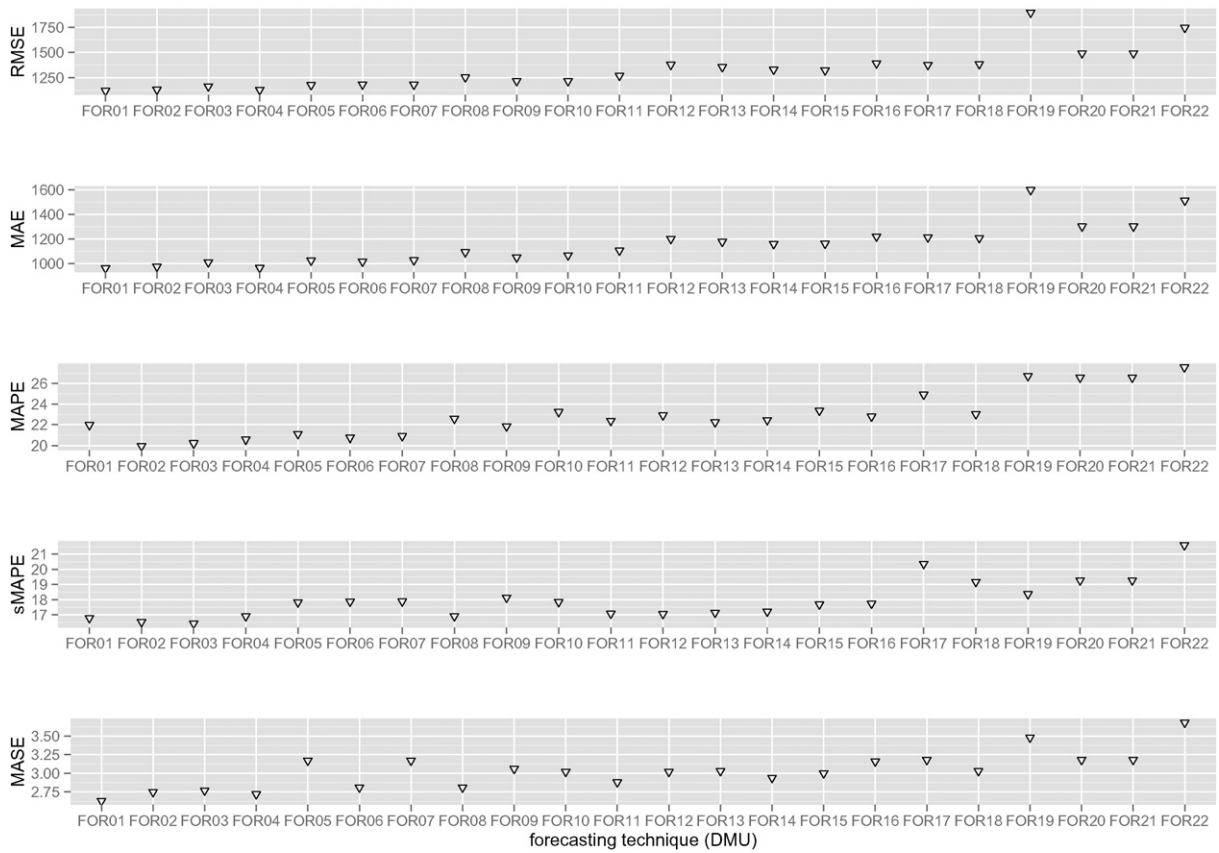


Fig. 4. Comparison of the 22 forecasting techniques applied to time series data (M3-competition).

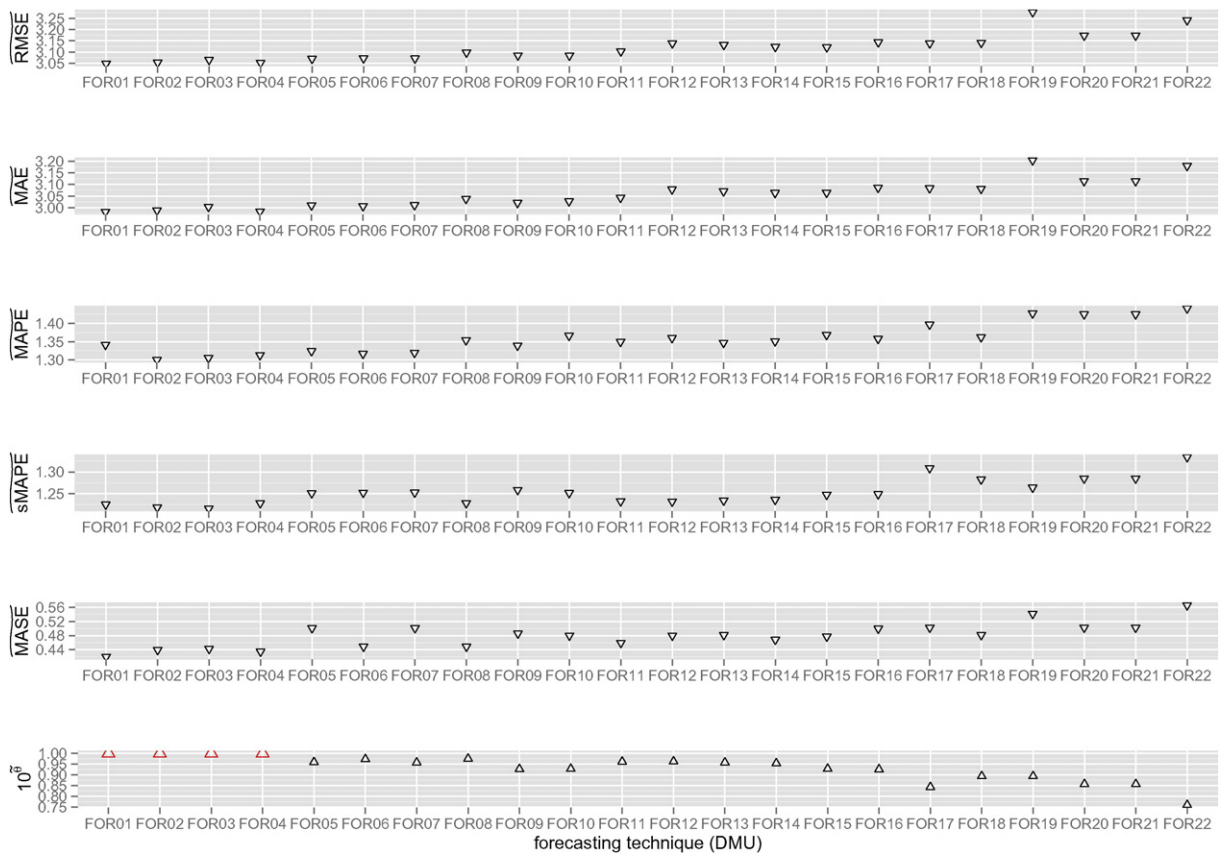


Fig. 5. Logarithmic transformation of accuracy measures and efficiency (sales from M3-competition).

**Table 5**  
Efficiency and ranking of forecasting techniques based on the proposed DEA model (M3 competition data).

DMU	DEA score	Rank	DMU	DEA score	Rank
FOR01	1	1	FOR14	0.954096	12
FOR02	1	1	FOR15	0.928733	13
FOR03	1	1	FOR10	0.928525	14
FOR04	1	1	FOR09	0.927467	15
FOR08	0.975753823	5	FOR16	0.926114	16
FOR06	0.973362993	6	FOR18	0.894389	17
FOR12	0.963049853	7	FOR19	0.894336	18
FOR11	0.9619215	8	FOR20	0.857651	19
FOR05	0.95990411	9	FOR21	0.857651	20
FOR13	0.957992999	10	FOR17	0.843845	21
FOR07	0.957929481	11	FOR22	0.760537	22

## 5. Overview of the proposed approach

In this paper a DEA procedure for ranking forecasting techniques has been proposed. Based on this procedure, each forecasting technique is treated as a DMU and forecasting errors of each technique as inputs. As forecasting measures are ratio data, the proposed DEA model is multiplicative. In order to handle the data, a log-normalisation of the data is performed in advance (Fig. 2). The use of a multiplicative DEA model in this paper, against classical DEA models, is mathematically justified in Section 3. Introducing the log-normalised data to Model 4, forecasting techniques are ranked based on their efficiency. In the presence of more than one “winner”, cross efficiency, super efficiency or Lambda frequency approaches can be used as meta-frontier analysis techniques. The strength of the proposed model is its capability to provide an objective ranking of forecasting techniques, independently of the number of measures involved. The measures are all taken into consideration and a multiplicative DEA model is used as a benchmarking technique. Ranking derived from the proposed technique is robust as it is based on the results of efficiency score. Robustness of the ranking proposed based on multiplicative DEA model is also justified due to the absence of a Decision Maker; unlike AHP, Analytic Network Process (ANP) or MCDM techniques where DMs provide pairwise comparisons (or weights to criteria) for forecast measures, multiplicative DEA leaves no room for DM interventions. However, if necessary, extra constraints can be introduced to model preference (weights) to each forecasting measure compared to others. Another strength of the proposed approach is its simplicity. The user only provides the data (forecasting measures),

**Table 6**  
Peers and Lambda frequency of each forecasting technique.

DMU	$\lambda_1$	$\lambda_2$	$\lambda_3$	$\lambda_4$
FOR01	1			
FOR02		1		
FOR03			1	
FOR04				1
FOR05	0.15311	0.846889		
FOR06	0.12135	0.878642		
FOR07	0.026352	0.973648		
FOR08	0.19682		0.803818	
FOR09	0.153105	0.846895		
FOR10	0.173738	0.826262		
FOR11			1	
FOR12			1	
FOR13			1	
FOR14			1	
FOR15			1	
FOR16			1	
FOR17	0.54925	0.45075		
FOR18	0.328412	0.671588		
FOR19			1	
FOR20	0.299323		0.700677	
FOR21	0.299323		0.700677	
FOR22			1	
Number of positive $\lambda$	11	8	12	1

while the ranking is derived by solving iteratively the multiplicative DEA model for each DMU. Despite its strengths, the proposed approach has also few weaknesses. As DEA is a benchmarking technique, it is quite common for two or more DMUs to be efficient, leading to ties in the corresponding ranking. This shortfall is handled by applying cross efficiency, super efficiency or lambda frequency techniques to DMUs that are efficient and have ties in the ranking.

## 6. Conclusions

The discipline of forecasting is very important as it has grown over the last years given the number of articles that have been published. The importance of forecasting is the development of techniques that predict future values for demand, consumption of energy, energy, oil prices etc. However, the acceptance or rejection of a technique is based on how well the model is fitted to the data set, for in-sample adjustments and afterwards for out-of-sample forecasting. For that reason, forecasting or accuracy measures have been proposed to check the performance of a forecasting technique when applied to a time series data set. Nevertheless, as there is a plethora of accuracy measures, the forecasting technique may perform better in one measure but not in another measure comparing to another forecasting technique. In order to overcome this obstacle, a model that provides an overall score that takes all the different accuracy measures into account and forecasting techniques will be ranked upon, is proposed. The proposed multiplicative DEA model is used as the data (accuracy measures) express percentages and in this case, additive models that have been used to provide a unified score of forecasting techniques provide wrong results and do not satisfy fundamental principles of DEA. The data are log-normalised and the multiplicative DEA model is solved for each DMU. In the presence of ties in the ranking of DMUs, three meta-frontier analyses are proposed; namely cross efficiency, super efficiency and lambda frequency. The applicability of the model is demonstrated on yearly M3-competition time series data set. The proposed model can be implemented in forecasting software packages to help forecasters make a decision in regards to the best forecasting methods with conflicting results. One possible direction for future works is to develop an approach based on DEA to measure forecast accuracy and consequently select the best forecasting method across a cross-sectional and/or temporal hierarchy.

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