Anadolu Üniversitesi Sosyal Bilimler Dergisi | AÜSBD | Anadolu University Journal of Social Sciences

# Dynamic Efficiency Analysis of World Railway Firms: A DEA-Window Analysis with Malmquist Index

## Dünya Demiryolu Firmalarının Dinamik Etkinlik Analizi: Malmquist Endeksli bir VZA-Pencere Analizi

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## Abstract

*This study attempts to obtain Technical Efficiency (TE), Allocative Efficiency (AE) and Average Efficiency of dynamic DEA-Window analysis scores of 31 railway firms operating worldwide. The data set covering the period of 2000 to 2009 is analyzed by CCR and BCC methods. In the analysis conducted by use of the CCR model, while total 17 firms are efficient in the first year, this figure reaches to 18 firms for the last year with one increment. With input oriented and variable return analysis conducted by use of the BCC model, the firms having TE at the beginning of the period were 20 in number. At the end of the period, the figure reaches to 24. Window analysis suggests that all firms in general have stable average efficiency rate and inefficiencies of the firms and standard deviations of their efficiency scores exhibit a similar pattern. Malmquist Index (MI) analysis also suggests that Total Factor Productivity has increased by 0.03% for the entire period.*

**Keywords:** *Panel Data, DEA, TFP, Railway*

## Öz

*Bu çalışmada, 2000-2009 döneminde faaliyette bulunan 31 adet dünya demiryolu şirketinin VZA- Pencere Analizi ile dinamik Teknik Etkinlik ve Tahsis Etkinliği ve Ortalama Etkinlik skorları CCR ve BCC metotlarıyla elde edilmek istenmiştir. CCR modeli ile yapılan analizde ilk yıl için toplam 17 firma etkin iken 2009 yılı için bu sayı 18 firmaya çıkmıştır. BCC modeli ile girdi yönelimli ve değişken getirili analizde dönem başında teknik etkinliğe sahip firma sayısı 20 iken dönem sonunda bu rakam 24'e çıkmaktadır. Pencere Analizi bulguları tüm firmaların dengeli bir ortalama verimlilik oranı ve benzer yapıda standart sapma değerlerine sahip olduklarını göstermektedir. Toplam Faktör Verimliliği için Malmquist Endeksi kullanılarak yıllar boyunca tüm işletmeler için Toplam Faktör Verimliliğinin sadece binde üç düzeyinde arttığı tespit edilmiştir.*

**Anahtar Kelimeler:** *Panel Data, VZA, TFV, Demiryolu*

## Introduction

Occasionally classified as natural monopoly, railway transportation has often been performed by (national) monopolistic firms since it involves enormous fixed costs. Structural changes in the railway firms have sometimes occurred as a result of breakages in the political history of the world. Upon disintegration of the Soviet Union, for instance, the national railway firms appeared in the former Soviets Territory. Similarly countries that emerged after disintegration of Yugoslavia have established their national railway firms. Even autonomous administrations of each ethnical region in Bosnia-Herzegovina have their own regional railway firms like ZBH, (Železnice Bosne I Hercegovine) and ZRS, (Železnice Republike Srpske). As to the example of Spain, although there is no weakness seen in the political integrity of the country, the existence of regional firms is observed (UIC, 2010).

Due to the pressure stemming from the other types of transportation, the efficiency of railways has started to

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be discussed and, as a result, serious structural changes started to be implemented in the recent decades. According to Duman (2006), although the changes made are not same in all countries, they are generally realized in the form of restructuring, incorporating or privatizing. Cowie (1999) states that as a result of the Directive 91/440 issued by the European Union; British, German, Swedish and some other European railway firms have been disintegrated, privatized, converted to partnership or franchised as a result of restructuring.

In this study, total of 31 railway firms engaging with passenger and cargo transportation worldwide are examined as a Decision Making Unit, (DMU). Only three of these firms are private and all firms except eight are integrated firms meaning, infrastructure and transportation services are provided by a single corporate body. Data used in the study has been compiled from the 2011 publications of International Railway Association (UIC) and Republic of Turkey State Railways (TCDD). Data of 199 firms, members of the International Railway Association, has been dealt with individually. The complete and compliant data out of the input and output sets has been examined in the study. Six input and five output variables have been chosen. Comprehensive information about these inputs and outputs and results of the analyses are given in empirical results section.

The information about total cost (EX), total revenue (RE), number of personnel (PN), number of transported passenger (TPN), and length of railway lines (LL) for the years 2000 and 2009 is given in Table 1. In one decade, number of passengers transported by the firms has increased from 15 million to 16 million. A slight decrease has occurred in the length of railway but the personnel increased from 546 thousands to 556 thousands in number. It is observed from the table that passenger capacity has increased, but slightly, in the transportation by railways.

In this study, literature review follows introduction at section two. Then, a brief explanation of methodology, including Data Envelopment Analysis (DEA), window analysis, and MI take place at section three. Empirical results of the analyses are found in section four. Finally, conclusion and suggestions are placed at the end, in section five.

***Table 1. Firms Investigated in this Study***

| Firm | $EX_{2000}$ | $RE_{2000}$ | $PN_{2000}$ | $LL_{2000}$ | $TPN_{2000}$ | $EX_{2009}$ | $RE_{2009}$ | $PN_{2009}$ | $LL_{2009}$ | $TPN_{2009}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| BC | 266241 | 346743 | 78034 | 5512 | 167843 | 3352278 | 4411369 | 77073 | 5491 | 83478 |
| $BDZ^{*}_{1}$ | 497 | 429 | 39024 | 4259 | 50029 | 484 | 440 | 15439 | 4150 | 31360 |
| BLS | 361 | 388 | 1568 | 241 | 17944 | 833 | 858 | 2500 | 460 | 47883 |
| SBB CFF FFS | 5665 | 5951 | 28272 | 2975 | 286757 | 7309 | 7824 | 25512 | 3139 | 327530 |
| $CAMRAIL_2$ | 40185 | 42660 | 2710 | 1016 | 1292 | 55644 | 61905 | 2099 | 977 | 1362 |
| CFL | 357 | 353 | 3084 | 261 | 12985 | 530 | 525 | 3038 | 262 | 17039 |
| CIE | 351 | 358 | 5358 | 1919 | 31721 | 415 | 414 | 4679 | 1919 | 38858 |
| $CP_1$ | 390 | 216 | 6294 | 2814 | 148599 | 426 | 318 | 3809 | 2842 | 131278 |
| DB $AG^{*}$ | 21733 | 22065 | 181314 | 36588 | 1712080 | 32927 | 35135 | 239888 | 33721 | 1883321 |
| FGC | 89 | 92 | 1225 | 184 | 60746 | 139 | 73 | 1170 | 270 | 80028 |
| RENFE1 | 2454 | 2516 | 33747 | 14387 | 438872 | 2659 | 2501 | 13903 | 15044 | 466659 |
| FS | 9210 | 8398 | 114373 | 15974 | 478200 | 9389 | 9625 | 87422 | 16686 | 583122 |
| ÖBB | 3481 | 3264 | 50565 | 5568 | 182701 | 5434 | 5748 | 45973 | 5265 | 205754 |
| GySEV/RÖEE2 | 27336 | 27240 | 1987 | 220 | 3054 | 35479 | 35091 | 1733 | 284 | 4676 |
| $JR^{\pm}_{2}$ | 3691457 | 4351063 | 158671 | 20160 | 8654434 | 3684160 | 4262637 | 128761 | 20035 | 8840509 |
| $KORAIL^{\pm}_{1}$ | 1977809 | 1946792 | 31705 | 3123 | 815581 | 4631126 | 5900500 | 30586 | 3378 | 1020319 |
| KTM | 347 | 284 | 5092 | 1636 | 3825 | 420 | 352 | 5370 | 1665 | 38949 |
| $LG^{*}$ | 626 | 634 | 15618 | 1905 | 8852 | 1165 | 1194 | 10506 | 1767 | 4374 |
| ONCFM | 1758 | 2008 | 10667 | 1907 | 13066 | 2963 | 3193 | 8126 | 2190 | 29600 |
| SNCB/NMBS | 2991 | 3119 | 41384 | 3471 | 153300 | 4470 | 3682 | 37130 | 3578 | 220379 |
| $SNCF^{\pm}_{1}$ | 14827 | 15086 | 175163 | 29272 | 849792 | 20002 | 19998 | 156434 | 29903 | 1078048 |
| SZ | 227 | 207 | 9016 | 1201 | 15010 | 374 | 346 | 7892 | 1228 | 16355 |
| TCDD | 558 | 321 | 41285 | 8671 | 85343 | 2382 | 1606 | 29966 | 9080 | 80092 |
| TRA | 28648 | 22107 | 15980 | 1104 | 191478 | 26837 | 19573 | 13473 | 1085 | 179369 |
| $VR_1$ | 691 | 700 | 12722 | 5854 | 54783 | 816 | 843 | 9935 | 5919 | 67555 |
| ZSSK $ZSR^{*}_{\mathbf{1}}$ | 830 | 1024 | 23972 | 3657 | 66806 | 291 | 270 | 4966 | 3623 | 45135 |
| $CD_1$ | 41320 | 37764 | 86079 | 9365 | 182546 | 44332 | 43868 | 38947 | 9477 | 162906 |
| FEVE | 122 | 98 | 1981 | 1194 | 12047 | 175 | 124 | 1924 | 1194 | 9676 |
| HZ | 2685 | 2381 | 18535 | 2726 | 17611 | 3416 | 3422 | 12931 | 2722 | 73545 |
| PKP | 11156 | 9604 | 182784 | 22560 | 291949 | 13407 | 12046 | 113107 | 19764 | 210719 |
| $ZRS^{*}$ | 34 | 36 | 3501 | 424 | 1134 | 89 | 68 | 3433 | 416 | 442 |
| Grand TOTAL | 6154436 | 6853899 | 1381710 | 210148 | 15010380 | 11940368 | 14845548 | 1137725 | 207534 | 15980320 |
| 4 Inefficient | 55317 | 49884 | 292880 | 36269 | 505287 | 61419 | 59528 | 170342 | 33573 | 457288 |
| Ratio of 4 Inefficient | 0.009 | 0.007 | 0.212 | 0.173 | 0.034 | 0.005 | 0.004 | 0.150 | 0.162 | 0.029 |
| 4 Big | 5705826 | 6335006 | 546853 | 89143 | 12031887 | 8368215 | 10218270 | 555669 | 87037 | 12822197 |
| Ratio of 4 Big | 0.927 | 0.924 | 0.396 | 0.424 | 0.802 | 0.701 | 0.688 | 0.488 | 0.419 | 0.802 |

The firms indicated by $^{*}$ are 4 most inefficient ones and the ones indicated by $^{\pm}$ are 4 largest ones in the list. Also all firms except the ones indicated by $_{1}$ are integrated firms, and again all firms except the ones indicated by $_{2}$ are national.

## Literature

A series of studies has been made by using DEA, Frontier Function and other econometric methods on railways, airways, and other means of transportation.

Cantos et al. (1999) studied the transformation of the railway firms' productivity in Europe for the period of 1970-95 by using non-parametric method to determine whether it depends on the change in the efficiency or technologic development. The study determined that many firms experienced reform process mostly in the period of 1985-95 and that the productivity increase mostly as a result of the technological improvement.

Coelli and Perelman (1999) studied TE of the railway firms in Europe using multi-output distance functions and compared the results obtained by parametric frontier analysis, DEA and corrected ordinary least squares (COLS) method by using linear programming. Input oriented, output oriented, and constant returns to scale distance functions were estimated and comparisons were made. The existence of a powerful correlation found out for each of three methods.

According to Cowie (1999), with effect of the market powers on the railway system, the railway firms throughout Europe were changed considerably. By issuing the Directive 91/440 in 1991, the European Union has actively supported this radical change. This directive has financially separated the railway infrastructure from operation and in this way the monopolistic aspect of the national firms has been reduced to a certain extent.

Wang and Liao (2006) studied cost structure of Taiwan Railways and growth in its efficiency by using monthly data for the period 1991-2000. A cost function was estimated where pension and benefits were assumed to be fixed and variables of cargo and passenger transportation were correlated. They stated that the Total Factor Productivity (TFP), increased towards the end of the period due to the effect of technological developments and economies of scale.

Sabri et al. (2008) analyzed differences in the technical and financial performance of five railway firms in North Africa for the period of 1990-2004 by using Malmquist DEA TFP Index. When the technological and administrative advancement have been separated, social service liability and firm's performance have contravened.

Yu (2008) made efficiency and effectiveness measurements by traditional DEA and network DEA methods using data on 40 global railway firms for the year 2002. When the results of two different methods have been compared, it has been seen that magnitude of performance values look different, but the performance ranking of the firms are similar.

The first and most important study in DEA with Window analysis is the study by Charnes et al. (1995) on the efficiency of airplane maintenance departments of 14 air force units. Performance of these DMU is evaluated via output and input variables listed in conducting maintenance services keeping the confidentiality in mind.

Çekerol and Nalçakan (2011) analyzed the demand for the railway transportation in Turkey. In the analysis, taking the significant activities in the logistics into consideration, the variables were identified and Ridge Regression method has been preferred due to the multi-linear regression problem. Mixed results were found with respect to the domestic cargo transportation.

## Methodology

Debreu (1951), Koopmans (1951), and Farrell (1957) introduced the efficiency analysis to the economics literature and since then there have been so many studies devoted to the measurement of efficiency. The usage of the parametric and non-parametric methods in the studies where the performance assessment is measured in terms of Economic Efficiency, TE, and AE is seen.

In non-parametric analysis as in Charnes A, Cooper WW, Rhodes E (1979), the specification of any particular functional form is not necessary to define the efficient frontier or envelopment surface.

### Structure of DEA and Efficiency

Efficiency may be defined as achievement to obtain the highest output possible by preferring the method which uses the input composition in the most productive way. Assuming a DMU generates the outputs $y_i$, $(i=1,2,\dots,t)$ from the inputs $x_k$, $(k=1,2,\dots,m)$, the equation can be expressed in the following way by the help of the appropriate weights ($v_i=1,2,\dots,t$; $w_k=1,2,\dots,m$) on the variables:

$$\sum_{i=1}^{t} v_i \; y_i \,/ \sum_{k=1}^{m} w_k \; x_k \qquad (1)$$

Fractional program utilizes the TFP rate. In a sense, DEA should be considered as a conceptual model and the linear model as a practical method in the efficiency calculations. In DEA, weights are determined pertaining to DMUs for each input and output. DEA takes the inputs ($x_k$) and outputs ($y_i$) in the equation given above as data and selects the weights that maximize the performance of the DMU "*p*" related to the performances of other units:

$$Max\ v_i w_k \left(\sum_{i=1}^{t} v_i, y_{ip} / \sum_{k=1}^{m} w_k, x_{kp}\right) \qquad (2)$$

Here, the efficiency value of "z" number DMUs under the ≤ 1 constraint is as follows:

$$0 \leq \sum_{i=1}^{t} v_i y_{ic} / \sum_{k=1}^{m} w_k x_{kc} \leq 1 \qquad (c = 1,2,\ldots,p,\ldots,z;\ v_i = 1,2,\ldots,t;\ w_k = 1,2,\ldots,m) \qquad (3)$$

In the model, "v" and "w" constitute the weight on the inputs and outputs variables in the equation. Solution of the model gives an efficiency value of "p" DMU and a set of necessary weights to reach this value.

Solution of non-parametric efficiency measurement model in the form of fractional programming form was converted to the linear programming model easier to solve (Charnes et al., 1978, 1979; Banker et al., 1984).

**Window Analysis**

When there exists limited amount of DMU to be investigated by DEA compared to the number of input and output variables, some problems may arise. In order to overcome these type of problems, one may consider collecting a panel data to use with DEA window analysis (Cooper et al. 2007). Average Efficiency of a DMU may fluctuate over time and capturing these variations over time is possible with window analysis within the DEA as proposed by Charnes et al. (1985). This way, performance comparisons of both a DMU in a specific time slot to the same DMU in other time periods as well as to another DMU in the same period can be possible. This analysis evaluates the performance of a DMU over time by assuming the DMU as a different unit in each time period.

The methodology used evaluating panel dataset with DEA comes from Tulkens and Eeckaut (1995). A k sized window k ∈{1, 2 . . . . . n; n < m} at time t can be illustrated as a subset of adjacent time points $T^{kt}$ = {γ| γ = t, t + 1 . . . . , t + k; t < m − k. Observed values of this window can be used to build a production set with an intertemporal reference, representing the period of time [t, t + k]. Generating sequential windows, defined for t = 1, 2 , . . . , m-k, creates a series of reference non-nested sets of production. The purpose of treating time series in window analysis is mainly averaging over the time periods defined by the window.

Having a narrower window size may lead to a fewer number of DMU's and this combined with large numbers of variables diminish the discriminatory power of the analysis. Having larger window size, however, may provide misleading outcomes since any important change may be covered by more windows Cooper et al. (2011).

**Malmquist Index**

Malmquist productivity Index is one of the indices that investigate change in the production (Malmquist, 1953). Used in the DEA (Caves et al. 1982), this index consists of difference functions representing multi-output and multi-input technologies based on the input and output quantities.

The index can be calculated by parametrical and linear programming methods. Two functions are obtained by use of DEA. One of these functions expresses the technical change and the other one expresses the is change in the TE (Liu and Wang, 2008).

MI can be calculated as input oriented or output oriented. A production oriented Malmquist TFP change index $M_h^{t+1}$ can be expressed in the following way:

$$M_h^{t+1}(X_h^{t+1}, Y_h^{t+1}, X_h^{t}, Y_h^{t}) = \left[\frac{D_h^t(X^{t+1}, Y^{t+1})}{D_h^t(X^t, Y^t)} \frac{D_h^{t+1}(X^{t+1}, Y^{t+1})}{D_h^{t+1}(X^t, Y^t)}\right]^{1/2} \qquad (4)$$

The equation above shows the production element of $D_h$ in the period t and t+1. Taking the technology in the period of t as reference, the period t+1 is used. Reference category can be selected arbitrarily. Here, the inputs being (h=1,2,…..31) in the application related to the railways, the input vector is $x_h^t = (X_{1h}, X_{2h} ....)'$ and the output vector is $y_h^t = (Y_{1h}, Y_{2h} ....)'$.

## Empirical Findings

The productivity structure of the railway firms in a period of ten years, from 2000 to 2009 is investigated. As seen in Table 2, an analysis with 6 inputs $(X_1, X_2, X_3, X_4, X_5, X_6)$ and 5 outputs $(Y_1, Y_2, Y_3, Y_4, Y_5)$ variables has been made on these DMUs. It is seen that no such amount of input has been used in many studies. In this respect, both temporal format and use of many inputs and outputs distinguish this study among the others.

***Table 2. Model Variables***

| | | |
|---|---|---|
| **Inputs (X of each Firm)** | | |
| $X_1$ : EXt* | Total Annual Costs of Operation | $10^6$ NCU |
| $X_2$ : PNt | Average Annual Number of Employees | Each FTE |
| $X_3$ : LLt | Total Length of Main Line | KM |
| $X_4$ : LNt | Total Number of Traction Vehicles | Each |
| $X_5$ : PWNt | Total Number of Passenger Cars | Each |
| $X_6$ : CWNt | Total Number of Cargo Cars | Each |
| **Outputs (Y by each Firm)** | | |
| $Y_1$ : REt | Annual Total Revenues Earned | $10^6$ NCU |
| $Y_2$ : TPNt | Total Number Of Passengers Transported | $10^3$ Each |
| $Y_3$ : TPPKMt | Total Number Of Passengers Per Kilometers | $10^6$ Each /KM |
| $Y_4$ : CTOt | Total Cargo Ton Transported | $10^3$ Ton |
| $Y_5$ : CTPKMt | Total Cargo Ton Per Kilometers Transported | $10^6$ Ton/KM |
| **Dependent Variables** | | |
| $TE_{CCRt}$ | CCR Technical Efficiency | |
| $AE_{CCRt}$ | CCR Allocative Efficiency | |
| $TE_{BCCt}$ | BCC Technical Efficiency | |
| $AE_{BCCt}$ | BCC Allocative Efficiency | |

*(t=0,1,…,9)

TE and AE of the railway firms have also been obtained in this study. When finding the efficiency values with the DEA, the excess of inputs or scarcity of outputs is determined differently by using input oriented or output oriented models. Thus, first the TE and AE have been calculated by using the CCR with input oriented constant returns to scale model (Charnes et al., 1978, 1979) and the BCC with input oriented variable returns to scale model (Banker et al., 1984) in a single dimension and the results have been assessed. The economic efficiency score has not been included here again since it is a product of these two data.

Table 3 gives TE and AE scores of the CCR model for railway firms. The number of the firms with TE is 17 at the beginning and at the end of the period. Throughout the period, it is seen that ten railway firms, namely; BC of Belarus, SNCF of France, JR of Japan, FGC of Spain, BLS of Switzerland, KORAIL of South Korea, TRA of Taiwan, RENFE of Spain, GySEV/RÖEE of Hungary, and CFL of Luxembourg always had TE. On the other hand, ten firms; FEVE of Spain, ZRS of Bosnia-Herzegovina, PKP of Poland, HZ of Croatia, CD of Czech Republic, ÖBB of Austria, SZ of Slovenia, SNCB/NMBS of Belgium, DB AG of Germany, and LG of Lithuania never had TE in entire period. The first five of these inefficient firms have TE averages of below 0.74 (74%). Out of 31 firms, only 2 firms had AE in 2000 and one of them lost the AE in 2009. BC of Belarus had 8, SNCF of France had 4, JR of Japan had 4, BLS of Switzerland had 3, CFL of Luxembourg had 3, FGC of Spain had 2 and remaining 25 firms never had AE score of 1 in the period. While the average TE scores vary between 0.67 and 1, this value is in the range of 0.04 to 0.976 for AE.

In the analysis by the BCC model, shown in Table 4, the number of firms having TE in the beginning of the period is 20 which is an optimistic figure. At the end of the period, this figure rises to 24. HZ of Croatia, SNCB/NMBS of Belgium, and CD of Czech Republic have no TE or AE in the period. In addition to them, there are firms which have TE only for one or two years but inefficient in the rest of the years. For example, SZ of Slovenia and ÖDB of Austria have TE only in one period while TCDD of Turkey, BDZ of Bulgaria, and CIE of Ireland have TE only in two periods. On the other hand, SNCF of France, FGC of Spain, JR of Japan, DB AG of Germany, and CFL of Luxemburg, have both technical and AE throughout the period. BC of Belarus and BLS of Switzerland has no missing TE but former one has 1 missing AE and the latter one has 2 missing AE. KORAIL of South Korea has also TE for the entire period but this firm has AE for only 3 years. Table 3 shows that the same firms are also the most efficient ones in the model with CCR model. The average TE scores is 0.934 and average AE scores is 0.642 for 31 firms in BCC model.

Efficient and inefficient firms in both models almost match up with the results. Only as a difference, it is seen that the efficiency score between the beginning and the end of the period does not change much for the CCR model. While about 55% of the firms have had TE at the beginning of the period, this rate remains the same at the end of the period. Such thing may not be said for the BCC model. While the firms have a TE of about 65% at the beginning of the period, this value increases to 77.5% at the end. The basic difference between two models is that while there is a static condition in the model of constant return to scale, a change is noticeable in the model with variable return to scale.

By looking from a difference perspective, whether the efficiency scores of the firms have any influence on the size of the DMU's is also investigated. As shown in Table 1, the firms DB AG of Germany, JR of Japan, KORAIL of South Korea and SNCF of France have one million or above passengers in 2009. JR of Japan has the highest passenger capacity serving 8.8 million out of about 16 million passengers of all firms in 2009. The number of passengers transported by four firms is 12.8 million which equals to about 80% of all passengers. The efficiency analyses conducted both by CCR and BCC models show that these four firms are highly efficient. In CCR model, DB AG of Germany and in BCC model, KORAIL of South Korea have some low AE.

On the other hand, in the efficiency analysis conducted with CCR and BCC models, there are four firms with the lowest AE and these firms are BDZ of Bulgaria, LG of Latvia, ZSSK ZSR of Slovakia and ZRS of Bosnia-Herzegovina. While the number of passengers transported by these four firms in 2000 was around 127 thousands, this number dropped to 81 thousands in 2009. These firms are losing passenger over time which implies that other means of transportation have been preferred in these countries. Railway operation of larger firms seems more effective than that of the smaller ones.

**Window Productivity Analysis**

The type of window size selection in this study is suitable with the Tulkens, and Vanden Eeckaut (1995) methodology. The first window includes the years 2000, 2001, and 2002.When a new window is constructed, the earliest period is dropped and a new period next to the last one is added. In window two, year 2000 is dropped and year 2003 is added. Therefore the analyses are performed until window 8 includes years 2007, 2008, and 2009. As DEA window analysis treats a DMU as different entity in each year, a tree-year window with 31 DMUs is equivalent to 93 DMUs. Subsequently, 8 three-year window would considerably increase the number of observations of the sample to 744, providing a greater degree of freedom. DEA window analysis was performed with the CCR with input oriented constant returns to scale model.

Window averages of the firms are provided in Table 5. Last column of the table, which is in the form of eight windows, presents the average of the windows. In the table, BLS of Switzerland has complete efficiency score along all windows. It is followed by RENFE of Spain. Interestingly, while two Spanish firms, FGC and RENFE, take place among the most efficient firms, another Spanish firm, FEVE, is the least efficient firm. While efficiency score of this firm was 0.686 in the 2000-02 period, it went down to 0.586 in the 2007-09 period. ZRS of Bosnia-Herzegovina is the second least efficient firm with the efficiency score of 0.763 in the 2000-02 period and 0.624 in the 2007-09 period.

***Table 3. Technical and Allocative Efficiency Values of 31 Firms According to the CCR Model***

| Firm | 2000 | | 2001 | | 2002 | | 2003 | | 2004 | | 2005 | | 2006 | | 2007 | | 2008 | | 2009 | | AVERAGE | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $TE_{00}$ | $AE_{00}$ | $TE_{01}$ | $AE_{01}$ | $TE_{02}$ | $AE_{02}$ | $TE_{03}$ | $AE_{03}$ | $TE_{04}$ | $AE_{04}$ | $TE_{05}$ | $AE_{05}$ | $TE_{06}$ | $AE_{06}$ | $TE_{07}$ | $AE_{07}$ | $TE_{08}$ | $AE_{08}$ | $TE_{09}$ | $AE_{09}$ | TE | AE |
| BC | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.997 | 1 | 1 | 1 | 1 | 1 | 0.763 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.976 |
| BDZ | 0.93 | 0.099 | 0.876 | 0.135 | 0.921 | 0.121 | 0.986 | 0.145 | 1 | 0.149 | 0.82 | 0.21 | 0.821 | 0.197 | 0.9 | 0.191 | 0.919 | 0.179 | 0.85 | 0.179 | 0.902 | 0.161 |
| BLS | 1 | 0.665 | 1 | 0.717 | 1 | 0.75 | 1 | 0.929 | 1 | 0.905 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.775 | 1 | 0.799 | 1 | 0.854 |
| SBB | 1 | 0.71 | 1 | 0.603 | 1 | 0.672 | 0.98 | 0.692 | 1 | 0.66 | 1 | 0.733 | 1 | 0.702 | 1 | 0.799 | 1 | 0.747 | 1 | 0.823 | 0.998 | 0.714 |
| CAMRAIL | 1 | 0.821 | 1 | 0.903 | 0.931 | 0.996 | 1 | 0.899 | 0.976 | 0.883 | 0.901 | 0.991 | 0.991 | 0.691 | 0.948 | 0.815 | 0.887 | 0.955 | 0.87 | 0.972 | 0.950 | 0.893 |
| CD | 0.704 | 0.382 | 0.813 | 0.403 | 0.752 | 0.428 | 0.817 | 0.455 | 0.776 | 0.48 | 0.755 | 0.514 | 0.613 | 0.555 | 0.698 | 0.585 | 0.711 | 0.573 | 0.758 | 0.583 | 0.740 | 0.496 |
| CFL | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.761 | 1 | 0.724 | 1 | 0.497 | 1 | 0.324 | 1 | 0.292 | 1 | 0.838 | 1 | 0.777 | 1 | 0.721 |
| CIE | 0.891 | 0.559 | 0.91 | 0.581 | 0.889 | 0.642 | 0.884 | 0.669 | 0.948 | 0.559 | 0.884 | 0.627 | 0.882 | 0.659 | 1 | 0.552 | 1 | 0.504 | 1 | 0.511 | 0.929 | 0.586 |
| CP | 1 | 0.351 | 1 | 0.366 | 1 | 0.383 | 1 | 0.377 | 1 | 0.401 | 0.943 | 0.452 | 1 | 0.46 | 1 | 0.492 | 1 | 0.497 | 1 | 0.497 | 0.994 | 0.428 |
| DB AG | 0.917 | 0.581 | 0.95 | 0.605 | 0.938 | 0.599 | 0.898 | 0.683 | 0.903 | 0.688 | 0.891 | 0.765 | 0.882 | 0.821 | 0.893 | 0.824 | 0.925 | 0.701 | 0.957 | 0.704 | 0.915 | 0.697 |
| FEVE | 0.663 | 0.243 | 0.8 | 0.215 | 0.776 | 0.217 | 0.706 | 0.241 | 0.681 | 0.249 | 0.608 | 0.313 | 0.593 | 0.286 | 0.622 | 0.295 | 0.634 | 0.279 | 0.615 | 0.26 | 0.670 | 0.260 |
| FGC | 1 | 0.965 | 1 | 0.903 | 1 | 1 | 1 | 0.986 | 1 | 1 | 1 | 0.934 | 1 | 0.911 | 1 | 0.906 | 1 | 0.922 | 1 | 0.914 | 1 | 0.944 |
| RENFE | 1 | 0.709 | 1 | 0.748 | 1 | 0.772 | 1 | 0.76 | 1 | 0.753 | 1 | 0.669 | 1 | 0.73 | 1 | 0.736 | 1 | 0.887 | 1 | 0.83 | 1 | 0.759 |
| FS | 1 | 0.633 | 1 | 0.655 | 1 | 0.796 | 1 | 0.81 | 1 | 0.803 | 1 | 0.839 | 1 | 0.82 | 1 | 0.785 | 0.996 | 0.764 | 1 | 0.715 | 1 | 0.762 |
| ÖBB | 0.798 | 0.431 | 0.834 | 0.444 | 0.925 | 0.438 | 0.9 | 0.497 | 0.863 | 0.533 | 0.804 | 0.579 | 0.81 | 0.527 | 0.849 | 0.525 | 0.86 | 0.373 | 0.928 | 0.38 | 0.857 | 0.473 |
| GySEV/RÖEE | 1 | 0.78 | 1 | 0.83 | 1 | 0.798 | 1 | 0.829 | 1 | 0.758 | 1 | 0.76 | 1 | 0.604 | 1 | 0.689 | 1 | 0.789 | 1 | 0.752 | 1 | 0.759 |
| HZ | 0.688 | 0.171 | 0.693 | 0.238 | 0.594 | 0.284 | 0.625 | 0.308 | 0.789 | 0.287 | 0.757 | 0.342 | 0.652 | 0.413 | 0.753 | 0.502 | 0.822 | 0.475 | 0.811 | 0.536 | 0.718 | 0.356 |
| JR | 1 | 0.927 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.96 | 1 | 0.973 | 1 | 1 | 1 | 0.873 | 1 | 0.979 | 1 | 0.902 | 1 | 0.961 |
| KORAIL | 1 | 0.76 | 1 | 0.811 | 1 | 0.788 | 1 | 0.753 | 1 | 0.702 | 1 | 0.688 | 1 | 0.603 | 1 | 0.731 | 1 | 0.938 | 1 | 0.969 | 1 | 0.774 |
| KTM | 1 | 0.259 | 1 | 0.296 | 0.98 | 0.271 | 0.96 | 0.229 | 0.864 | 0.682 | 1 | 0.628 | 0.936 | 0.667 | 1 | 0.616 | 1 | 0.662 | 0.887 | 0.519 | 0.963 | 0.483 |
| LG | 0.842 | 0.158 | 0.913 | 0.154 | 0.909 | 0.208 | 0.892 | 0.214 | 0.93 | 0.175 | 0.918 | 0.15 | 0.906 | 0.106 | 0.974 | 0.092 | 0.962 | 0.158 | 0.928 | 0.148 | 0.917 | 0.156 |
| ONCFM | 0.936 | 0.248 | 1 | 0.245 | 1 | 0.235 | 1 | 0.232 | 1 | 0.236 | 1 | 0.284 | 1 | 0.315 | 1 | 0.362 | 1 | 0.418 | 1 | 0.505 | 0.994 | 0.308 |
| PKP | 0.717 | 0.273 | 0.672 | 0.29 | 0.717 | 0.273 | 0.788 | 0.332 | 0.748 | 0.349 | 0.666 | 0.338 | 0.684 | 0.3 | 0.723 | 0.307 | 0.721 | 0.314 | 0.743 | 0.302 | 0.718 | 0.308 |
| SNCB/NMBS | 0.874 | 0.405 | 0.929 | 0.404 | 0.886 | 0.447 | 0.891 | 0.476 | 0.814 | 0.5 | 0.893 | 0.554 | 0.887 | 0.616 | 0.91 | 0.621 | 0.892 | 0.659 | 0.851 | 0.646 | 0.883 | 0.533 |
| SNCF | 1 | 0.851 | 1 | 0.909 | 1 | 0.995 | 1 | 0.986 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.943 | 1 | 0.977 | 1 | 0.966 |
| SZ | 0.786 | 0.123 | 0.834 | 0.134 | 0.846 | 0.158 | 0.932 | 0.197 | 0.934 | 0.2 | 0.817 | 0.257 | 0.873 | 0.182 | 0.902 | 0.19 | 0.879 | 0.235 | 0.839 | 0.244 | 0.864 | 0.192 |
| TCDD | 1 | 0.2 | 1 | 0.223 | 0.754 | 0.327 | 0.899 | 0.358 | 0.804 | 0.372 | 0.82 | 0.411 | 0.798 | 0.455 | 0.833 | 0.478 | 0.712 | 0.503 | 0.805 | 0.452 | 0.843 | 0.378 |
| TRA | 1 | 0.875 | 1 | 0.813 | 1 | 0.807 | 1 | 0.77 | 1 | 0.806 | 1 | 0.799 | 1 | 0.678 | 1 | 0.689 | 1 | 0.677 | 1 | 0.698 | 1 | 0.761 |
| VR | 0.949 | 0.233 | 0.99 | 0.236 | 0.993 | 0.257 | 1 | 0.287 | 1 | 0.274 | 0.97 | 0.361 | 1 | 0.309 | 1 | 0.368 | 1 | 0.366 | 1 | 0.378 | 0.990 | 0.307 |
| ZRS | 0.832 | 0.022 | 0.837 | 0.028 | 0.76 | 0.023 | 0.678 | 0.022 | 0.612 | 0.024 | 0.805 | 0.04 | 0.583 | 0.046 | 0.658 | 0.059 | 0.702 | 0.064 | 0.633 | 0.067 | 0.710 | 0.040 |
| ZSSK | 1 | 0.116 | 1 | 0.137 | 0.932 | 0.154 | 0.842 | 0.184 | 0.861 | 0.176 | 1 | 0.144 | 1 | 0.112 | 1 | 0.129 | 1 | 0.133 | 1 | 0.125 | 0.964 | 0.141 |

**Table 4. Technical and Allocative Efficiency Values of 31 Firms According to the BCC Model**

| Firm | 2000 | | 2001 | | 2002 | | 2003 | | 2004 | | 2005 | | 2006 | | 2007 | | 2008 | | 2009 | | AVERAGE | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $TE_{00}$ | $AE_{00}$ | $TE_{01}$ | $AE_{01}$ | $TE_{02}$ | $AE_{02}$ | $TE_{03}$ | $AE_{03}$ | $TE_{04}$ | $AE_{04}$ | $TE_{05}$ | $AE_{05}$ | $TE_{06}$ | $AE_{06}$ | $TE_{07}$ | $AE_{07}$ | $TE_{08}$ | $AE_{08}$ | $TE_{09}$ | $AE_{09}$ | TE | AE |
| BC | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.766 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.977 |
| BDZ | 0.934 | 0.108 | 0.896 | 0.145 | 0.952 | 0.127 | 1 | 0.152 | 1 | 0.161 | 0.834 | 0.21 | 0.857 | 0.2 | 0.925 | 0.211 | 0.195 | 0.178 | 0.885 | 0.186 | 0.848 | 0.168 |
| BLS | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.826 | 1 | 0.832 | 1 | 0.966 |
| SBB | 1 | 0.789 | 1 | 0.653 | 1 | 0.695 | 1 | 0.698 | 1 | 0.689 | 1 | 0.767 | 1 | 0.726 | 1 | 0.875 | 0.875 | 0.749 | 1 | 0.837 | 0.988 | 0.748 |
| CAMRAIL | 1 | 0.823 | 1 | 0.905 | 1 | 0.932 | 1 | 0.902 | 1 | 0.864 | 1 | 0.896 | 1 | 0.687 | 1 | 0.774 | 0.774 | 0.849 | 1 | 0.847 | 0.977 | 0.848 |
| CD | 0.707 | 0.403 | 0.814 | 0.416 | 0.753 | 0.443 | 0.824 | 0.46 | 0.781 | 0.484 | 0.778 | 0.552 | 0.62 | 0.603 | 0.706 | 0.699 | 0.494 | 0.678 | 0.762 | 0.653 | 0.724 | 0.539 |
| CFL | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| CIE | 0.893 | 0.683 | 0.972 | 0.658 | 0.971 | 0.665 | 0.943 | 0.722 | 0.988 | 0.635 | 0.929 | 0.73 | 0.888 | 0.754 | 1 | 0.615 | 0.615 | 0.645 | 1 | 0.603 | 0.920 | 0.671 |
| CP | 1 | 0.383 | 1 | 0.405 | 1 | 0.427 | 1 | 0.421 | 1 | 0.46 | 0.944 | 0.522 | 1 | 0.537 | 1 | 0.567 | 0.567 | 0.587 | 1 | 0.59 | 0.951 | 0.490 |
| DB AG | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| FEVE | 0.887 | 0.665 | 1 | 0.61 | 1 | 0.563 | 0.98 | 0.592 | 0.967 | 0.632 | 0.912 | 0.651 | 0.998 | 0.578 | 1 | 0.608 | 0.608 | 0.642 | 1 | 0.636 | 0.935 | 0.618 |
| FGC | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| RENFE | 1 | 0.718 | 1 | 0.755 | 1 | 0.778 | 1 | 0.765 | 1 | 0.76 | 1 | 0.671 | 1 | 0.735 | 1 | 0.758 | 0.758 | 0.887 | 1 | 0.833 | 0.976 | 0.766 |
| FS | 1 | 0.732 | 1 | 0.725 | 1 | 0.807 | 1 | 0.812 | 1 | 0.804 | 1 | 0.84 | 1 | 0.822 | 1 | 0.787 | 0.787 | 0.781 | 1 | 0.724 | 0.979 | 0.783 |
| ÖBB | 0.84 | 0.411 | 0.846 | 0.441 | 0.938 | 0.433 | 0.956 | 0.485 | 0.909 | 0.52 | 0.928 | 0.76 | 0.902 | 0.711 | 0.947 | 0.814 | 0.772 | 0.927 | 1 | 0.922 | 0.904 | 0.642 |
| GySEV/RÖEE | 1 | 0.784 | 1 | 0.833 | 1 | 0.802 | 1 | 0.833 | 1 | 0.762 | 1 | 0.763 | 1 | 0.607 | 1 | 0.692 | 0.692 | 0.792 | 1 | 0.756 | 0.969 | 0.762 |
| HZ | 0.689 | 0.174 | 0.696 | 0.243 | 0.594 | 0.287 | 0.626 | 0.311 | 0.791 | 0.289 | 0.763 | 0.34 | 0.659 | 0.41 | 0.757 | 0.504 | 0.381 | 0.474 | 0.812 | 0.553 | 0.677 | 0.359 |
| JR | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| KORAIL | 1 | 0.829 | 1 | 0.817 | 1 | 0.789 | 1 | 0.753 | 1 | 0.727 | 1 | 0.735 | 1 | 0.603 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.825 |
| KTM | 1 | 0.269 | 1 | 0.298 | 1 | 0.273 | 1 | 0.231 | 1 | 0.635 | 1 | 0.729 | 1 | 0.734 | 1 | 0.734 | 0.734 | 0.799 | 1 | 0.578 | 0.973 | 0.528 |
| LG | 0.846 | 0.158 | 0.919 | 0.155 | 0.912 | 0.211 | 0.893 | 0.293 | 0.932 | 0.259 | 1 | 0.56 | 0.998 | 0.455 | 1 | 1 | 1 | 1 | 1 | 0.92 | 0.950 | 0.501 |
| ONCFM | 0.953 | 0.267 | 1 | 0.294 | 1 | 0.323 | 1 | 0.374 | 1 | 0.382 | 1 | 0.473 | 1 | 0.452 | 1 | 0.508 | 0.508 | 0.439 | 1 | 0.507 | 0.946 | 0.402 |
| PKP | 1 | 0.711 | 1 | 0.657 | 1 | 0.634 | 1 | 0.808 | 1 | 0.76 | 1 | 0.742 | 1 | 0.633 | 1 | 0.651 | 0.651 | 0.69 | 0.903 | 0.692 | 0.955 | 0.698 |
| SNCB/NMBS | 0.93 | 0.385 | 0.941 | 0.403 | 0.902 | 0.444 | 0.926 | 0.459 | 0.897 | 0.459 | 0.921 | 0.537 | 0.911 | 0.616 | 0.93 | 0.63 | 0.586 | 0.654 | 0.899 | 0.621 | 0.884 | 0.521 |
| SNCF | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| SZ | 0.807 | 0.151 | 0.859 | 0.153 | 0.882 | 0.162 | 0.984 | 0.189 | 1 | 0.19 | 0.872 | 0.273 | 0.972 | 0.207 | 0.984 | 0.246 | 0.242 | 0.222 | 0.916 | 0.236 | 0.852 | 0.203 |
| TCDD | 1 | 0.212 | 1 | 0.235 | 0.773 | 0.33 | 0.901 | 0.364 | 0.817 | 0.374 | 0.821 | 0.414 | 0.798 | 0.458 | 0.851 | 0.479 | 0.408 | 0.505 | 0.854 | 0.465 | 0.822 | 0.384 |
| TRA | 1 | 0.879 | 1 | 0.82 | 1 | 0.812 | 1 | 0.776 | 1 | 0.814 | 1 | 0.806 | 1 | 0.684 | 1 | 0.699 | 0.699 | 0.683 | 1 | 0.703 | 0.970 | 0.768 |
| VR | 0.951 | 0.242 | 0.994 | 0.243 | 0.999 | 0.261 | 1 | 0.29 | 1 | 0.279 | 0.972 | 0.36 | 1 | 0.374 | 1 | 0.598 | 0.598 | 0.61 | 1 | 0.457 | 0.951 | 0.371 |
| ZRS | 1 | 0.34 | 1 | 0.354 | 1 | 0.23 | 1 | 0.199 | 1 | 0.123 | 1 | 0.075 | 1 | 0.086 | 1 | 0.105 | 0.105 | 0.114 | 1 | 0.126 | 0.911 | 0.175 |
| ZSSK | 1 | 0.119 | 1 | 0.139 | 0.935 | 0.156 | 0.845 | 0.185 | 0.862 | 0.176 | 1 | 0.163 | 1 | 0.168 | 1 | 0.296 | 0.296 | 0.229 | 1 | 0.157 | 0.894 | 0.179 |

***Table 5. Firms' Average Efficiency Scores of Windows***

| Firm | 2000-'02 | 2001-'03 | 2002-'04 | 2003-'05 | 2004-'06 | 2005-'07 | 2006-'08 | 2007-'09 | Mean |
|---|---|---|---|---|---|---|---|---|---|
| BC | 0.996 | 1 | 0.993 | 1 | 0.995 | 0.958 | 0.966 | 0.988 | 0.987 |
| BDZ | 0.884 | 0.894 | 0.954 | 0.840 | 0.826 | 0.823 | 0.834 | 0.841 | 0.862 |
| BLS | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| SBB CFF FFS | 0.966 | 0.983 | 0.965 | 0.973 | 0.968 | 0.973 | 0.993 | 0.995 | 0.977 |
| CAMRAIL | 0.963 | 0.976 | 0.930 | 0.890 | 0.917 | 0.897 | 0.866 | 0.842 | 0.910 |
| CD | 0.714 | 0.790 | 0.751 | 0.755 | 0.611 | 0.614 | 0.596 | 0.672 | 0.688 |
| CFL | 0.975 | 0.982 | 0.992 | 0.977 | 0.951 | 0.992 | 0.995 | 1 | 0.983 |
| CIE | 0.877 | 0.884 | 0.891 | 0.877 | 0.850 | 0.879 | 0.945 | 1 | 0.900 |
| CP | 0.996 | 0.987 | 0.981 | 0.894 | 0.930 | 0.972 | 0.997 | 1 | 0.970 |
| DB AG | 0.896 | 0.919 | 0.890 | 0.839 | 0.846 | 0.866 | 0.864 | 0.882 | 0.875 |
| FEVE | 0.687 | 0.750 | 0.699 | 0.615 | 0.578 | 0.576 | 0.567 | 0.586 | 0.632 |
| FGC | 0.990 | 0.987 | 1 | 0.997 | 0.996 | 1 | 1 | 1 | 0.996 |
| RENFE | 1 | 1 | 1 | 0.993 | 1 | 1 | 1 | 1 | 0.999 |
| FS | 1 | 1 | 0.997 | 0.996 | 1 | 0.997 | 0.992 | 0.997 | 0.997 |
| ÖBB | 0.815 | 0.870 | 0.867 | 0.795 | 0.776 | 0.801 | 0.810 | 0.836 | 0.821 |
| GySEV/RÖEE | 0.996 | 0.992 | 0.983 | 0.997 | 0.977 | 0.966 | 0.987 | 0.961 | 0.982 |
| HZ | 0.626 | 0.627 | 0.647 | 0.676 | 0.646 | 0.665 | 0.672 | 0.735 | 0.662 |
| JR | 1 | 1 | 0.999 | 0.996 | 0.995 | 0.995 | 1 | 1 | 0.998 |
| KORAIL | 1 | 1 | 0.999 | 0.995 | 0.979 | 1 | 0.983 | 0.995 | 0.994 |
| KTM | 0.961 | 0.968 | 0.894 | 0.877 | 0.899 | 0.953 | 0.904 | 0.884 | 0.917 |
| LG | 0.847 | 0.883 | 0.883 | 0.850 | 0.826 | 0.883 | 0.883 | 0.916 | 0.871 |
| ONCFM | 0.963 | 0.979 | 0.964 | 0.921 | 0.964 | 1 | 1 | 0.995 | 0.973 |
| PKP | 0.677 | 0.710 | 0.727 | 0.675 | 0.652 | 0.676 | 0.676 | 0.676 | 0.684 |
| SNCB/NMBS | 0.846 | 0.892 | 0.842 | 0.826 | 0.810 | 0.873 | 0.878 | 0.872 | 0.855 |
| SNCF | 0.995 | 0.997 | 0.993 | 0.985 | 0.995 | 1 | 0.999 | 1 | 0.996 |
| SZ | 0.783 | 0.856 | 0.886 | 0.824 | 0.814 | 0.845 | 0.851 | 0.828 | 0.836 |
| TCDD | 0.869 | 0.871 | 0.795 | 0.792 | 0.774 | 0.790 | 0.705 | 0.711 | 0.788 |
| TRA | 0.996 | 0.989 | 0.989 | 0.990 | 1 | 0.996 | 0.995 | 1 | 0.994 |
| VR | 0.954 | 0.982 | 0.989 | 0.934 | 0.932 | 0.983 | 0.989 | 0.980 | 0.968 |
| ZRS | 0.763 | 0.746 | 0.659 | 0.645 | 0.603 | 0.639 | 0.590 | 0.624 | 0.659 |
| ZSSK ZSR | 0.924 | 0.909 | 0.858 | 0.841 | 0.916 | 1 | 1 | 0.983 | 0.929 |
| **Mean** | 0.902 | 0.917 | 0.904 | 0.880 | 0.872 | 0.891 | 0.888 | 0.897 | |

The Figure 1 gives the efficiency averages of five least efficient and the average of all firms during the given period along the windows. It appears that efficiencies of these five firms started to decline after the range of Win4-Win5 (2004-06) and shows a recovery to a degree in the last window. While efficiency value for HZ of Croatia was 0.625, it increased to 0.735 in Win8. However, efficiency values of the other four firms have shown a trend of reduction. Efficiency score of these five firms is in the range of 0.763-0.586. However, looking at the efficiency average of all firms, it is seen that average efficiency score in the range of Win4-Win5 (2003-06) reduced, but started to increase subsequently. Still, average efficiency score has never dropped below 0.871. Basing on this result, it may be claimed that a stable process prevails in the railway operation.

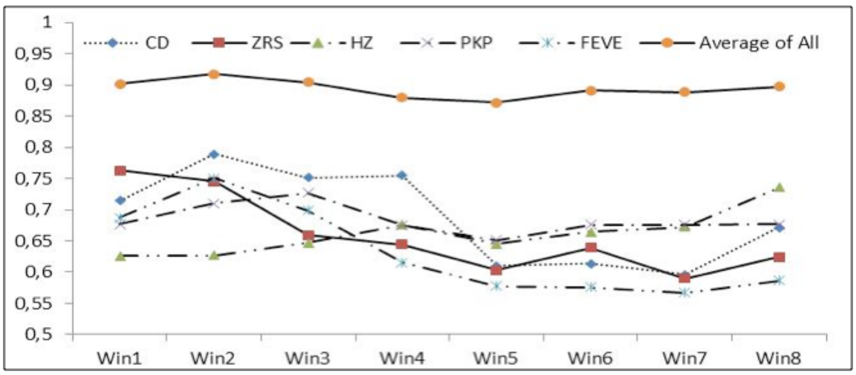


***Figure 1. Window Averages of 5 Inefficient Firms Relative to the Sample Average***

Looking at the information given about these five firms in the Table 1, the data about total cost, total revenue, the number of personnel and the number of transported passengers can be seen. The table includes values given both for the beginning and the end of the period. These five inefficient firms appear quite small scale ones. In the year 2000, these five firms account for nine in a thousand (9‰) of the total expenses and seven in a thousand (7‰) of the total revenue. Besides, these firms account for 21% of the personnel, 17% of the length of railway and 3.4% of the number of transported passengers. At the end of the period, in 2009, the expenses went down to five in a thousand (5‰) and the revenue to four in a thousand (4‰). Again, the number of personnel working in 2009 reduced to 15%, length of lines to 16% and number of transported passengers to 2.9%. Looking at the data in question, it is observed that the railways have suffered significant loss in the period of ten years. Another matter is that the number of personnel is very high, but the number of transported passengers reduces day after day. Of these five firms having low efficiency, HZ of Croatia has significantly increased revenue and the number of passengers.

In the efficiency analysis conducted by CCR and BCC models above, it is seen that the four firms transporting more than one million passengers a year have high average efficiency score as seen in the window analysis. Except for AG of Germany, three firms have efficiency score of about "1". On the other hand, the average efficiency scores of five firms having the lowest AE, except for ZRS of Bosnia-Herzegovina, have efficiency score in the range of 0.825 to 0.867.

In the efficiency analyses conducted by DEA Window model, whether by CCR or BCC method, SNCF of France is always the most efficient firm and ZRS of Bosnia-Herzegovina is always the least efficient firm. Besides, in all analytical techniques, it is observed that the categories of the efficient and inefficient firms do not change.

Efficiency scores by years and periodical averages of the railways are given in Table 6. As described above, again five firms with the lowest efficiency score and efficiency averages of all firms by years in the respective period is given. It appears that the efficiency of four firms has reduced by the end of the period; but a certain increase is observed in the efficiency of one firm, HZ of Croatia. While efficiency score of this firm was 0.826 in 2000, it went down to 0.567 in 2009. For these five firms, the efficiency score in the given period was 0.826-0.556. When these five firms are considered together, there is a downward trend but, there are no noticeable signs of instability.

***Table 6. Firms' Average Efficiency Scores of Years***

| Firm | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|
| BC | 1 | 0.994 | 0.993 | 1 | 0.995 | 0.984 | 0.939 | 1 | 0.982 | 1 | 0.989 |
| BDZ | 0.931 | 0.862 | 0.896 | 0.892 | 0.914 | 0.806 | 0.809 | 0.879 | 0.841 | 0.766 | 0.859 |
| BLS | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| SBB CFF FFS | 1 | 0.971 | 0.967 | 0.974 | 0.934 | 0.975 | 0.989 | 1 | 0.992 | 1 | 0.980 |
| CAMRAIL | 0.960 | 0.999 | 0.911 | 0.945 | 0.913 | 0.875 | 0.926 | 0.883 | 0.834 | 0.856 | 0.910 |
| CD | 0.704 | 0.778 | 0.713 | 0.781 | 0.715 | 0.657 | 0.613 | 0.646 | 0.592 | 0.690 | 0.689 |
| CFL | 1 | 0.989 | 0.979 | 0.978 | 1 | 0.943 | 0.985 | 0.987 | 1 | 1 | 0.986 |
| CIE | 0.891 | 0.885 | 0.870 | 0.855 | 0.913 | 0.829 | 0.849 | 1 | 1 | 1 | 0.909 |
| CP | 0.989 | 1 | 1 | 0.928 | 0.935 | 0.921 | 0.978 | 0.999 | 0.999 | 1 | 0.975 |
| DB AG | 0.909 | 0.921 | 0.901 | 0.856 | 0.860 | 0.858 | 0.866 | 0.873 | 0.870 | 0.876 | 0.879 |
| FEVE | 0.663 | 0.747 | 0.729 | 0.670 | 0.627 | 0.581 | 0.585 | 0.589 | 0.559 | 0.556 | 0.631 |
| FGC | 1 | 0.965 | 1 | 1 | 1 | 0.993 | 1 | 1 | 1 | 1 | 0.996 |
| RENFE | 1 | 1 | 1 | 1 | 0.993 | 1 | 1 | 1 | 1 | 1 | 0.999 |
| FS | 1 | 1 | 1 | 0.993 | 1 | 1 | 1 | 0.992 | 0.992 | 1 | 0.998 |
| ÖBB | 0.798 | 0.797 | 0.883 | 0.854 | 0.806 | 0.779 | 0.802 | 0.828 | 0.808 | 0.844 | 0.820 |
| GySEV/RÖEE | 1 | 1 | 0.971 | 0.995 | 0.996 | 0.957 | 0.977 | 1 | 1 | 0.882 | 0.978 |
| HZ | 0.688 | 0.658 | 0.561 | 0.588 | 0.716 | 0.690 | 0.650 | 0.709 | 0.707 | 0.717 | 0.668 |
| JR | 1 | 1 | 0.999 | 0.998 | 0.993 | 0.995 | 1 | 1 | 1 | 1 | 0.998 |
| KORAIL | 1 | 1 | 1 | 0.994 | 0.979 | 1 | 1 | 0.978 | 1 | 1 | 0.995 |
| KTM | 1 | 0.981 | 0.939 | 0.916 | 0.829 | 0.931 | 0.900 | 0.913 | 1 | 0.775 | 0.918 |
| LG | 0.842 | 0.870 | 0.866 | 0.847 | 0.870 | 0.861 | 0.875 | 0.914 | 0.880 | 0.869 | 0.869 |
| ONCFM | 0.918 | 0.963 | 0.973 | 0.939 | 0.933 | 0.998 | 1 | 1 | 0.991 | 1 | 0.971 |
| PKP | 0.717 | 0.640 | 0.687 | 0.745 | 0.688 | 0.648 | 0.677 | 0.708 | 0.653 | 0.644 | 0.681 |
| SNCB/NMBS | 0.874 | 0.885 | 0.847 | 0.862 | 0.793 | 0.844 | 0.855 | 0.892 | 0.877 | 0.843 | 0.857 |
| SNCF | 0.996 | 0.991 | 1 | 0.981 | 0.991 | 1 | 0.999 | 1 | 1 | 1 | 0.996 |
| SZ | 0.787 | 0.806 | 0.810 | 0.885 | 0.867 | 0.795 | 0.854 | 0.879 | 0.822 | 0.756 | 0.826 |
| TCDD | 1 | 0.934 | 0.746 | 0.878 | 0.767 | 0.752 | 0.763 | 0.752 | 0.690 | 0.702 | 0.798 |
| TRA | 1 | 0.994 | 1 | 0.968 | 1 | 1 | 1 | 0.991 | 1 | 1 | 0.995 |
| VR | 0.949 | 0.977 | 0.971 | 0.966 | 0.955 | 0.941 | 0.974 | 0.999 | 0.980 | 0.950 | 0.966 |
| ZRS | 0.827 | 0.786 | 0.719 | 0.644 | 0.556 | 0.758 | 0.576 | 0.613 | 0.623 | 0.567 | 0.667 |
| ZSSK ZSR | 1 | 0.965 | 0.886 | 0.795 | 0.789 | 1 | 1 | 1 | 1 | 0.950 | 0.939 |
| **Mean** | 0.917 | 0.915 | 0.897 | 0.894 | 0.882 | 0.883 | 0.885 | 0.904 | 0.893 | 0.879 | |

Similarly, by looking at the yearly efficiency averages of five firms with the least efficiency and of all firms during the investigated period, a slightly downward trend is observed as seen in the Figure 2. However, there is a stable attitude in the efficiency; while average efficiency score of all firms at the beginning of the period was 0.917, it went down to 0.878 at the end of period.

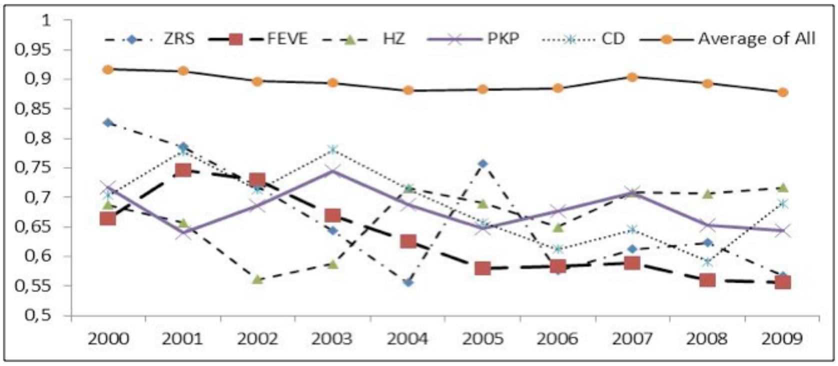


***Figure 2. Yearly Averages of 5 Inefficient Firms Relative to the Sample Average***

***Table 7. Average by Term***

| DMU | Window Average | Year Average | Window Difference | Year Difference | Standard Deviation |
|---|---|---|---|---|---|
| BC | 0.9869 | 0.9887 | 0.1017 | 0.1017 | 0.0150 |
| BDZ | 0.8619 | 0.8594 | 0.2343 | 0.1362 | 0.0424 |
| BLS | 1 | 1 | 0 | 0 | 0 |
| SBB CFF FFS | 0.9769 | 0.9803 | 0.0671 | 0.0671 | 0.0111 |
| CAMRAIL | 0.9101 | 0.9102 | 0.1779 | 0.1142 | 0.0428 |
| CD | 0.6878 | 0.6889 | 0.4431 | 0.1654 | 0.0705 |
| CFL | 0.9830 | 0.9861 | 0.1018 | 0.1018 | 0.0147 |
| CIE | 0.9003 | 0.9091 | 0.1988 | 0.0830 | 0.0453 |
| CP | 0.9695 | 0.9748 | 0.1208 | 0.1044 | 0.0357 |
| DB AG | 0.8751 | 0.8788 | 0.1944 | 0.0909 | 0.0250 |
| FEVE | 0.6322 | 0.6306 | 0.2477 | 0.0905 | 0.0653 |
| FGC | 0.9961 | 0.9957 | 0.0406 | 0.0122 | 0.0049 |
| RENFE | 0.9992 | 0.9993 | 0.0197 | 0.0197 | 0.0022 |
| FS | 0.9974 | 0.9977 | 0.0134 | 0.0115 | 0.0025 |
| ÖBB | 0.8212 | 0.8199 | 0.1363 | 0.0926 | 0.0317 |
| GySEV/RÖEE | 0.9821 | 0.9778 | 0.1181 | 0.0716 | 0.0125 |
| HZ | 0.6616 | 0.6684 | 0.2451 | 0.1557 | 0.0331 |
| JR | 0.9980 | 0.9984 | 0.0160 | 0.0160 | 0.0023 |
| KORAIL | 0.9939 | 0.9951 | 0.0627 | 0.0627 | 0.0077 |
| KTM | 0.9174 | 0.9183 | 0.2246 | 0.1149 | 0.0344 |
| LG | 0.8713 | 0.8694 | 0.1438 | 0.1052 | 0.0265 |
| ONCFM | 0.9730 | 0.9714 | 0.1396 | 0.1396 | 0.0247 |
| PKP | 0.6835 | 0.6806 | 0.1507 | 0.0913 | 0.0220 |
| SNCB/NMBS | 0.8549 | 0.8571 | 0.1382 | 0.0645 | 0.0267 |
| SNCF | 0.9955 | 0.9958 | 0.0349 | 0.0349 | 0.0048 |
| SZ | 0.8360 | 0.8258 | 0.1687 | 0.0938 | 0.0288 |
| TCDD | 0.7884 | 0.7983 | 0.3178 | 0.1320 | 0.0577 |
| TRA | 0.9944 | 0.9953 | 0.0334 | 0.0141 | 0.0043 |
| VR | 0.9678 | 0.9660 | 0.0754 | 0.0616 | 0.0225 |
| ZRS | 0.6586 | 0.6668 | 0.3192 | 0.1013 | 0.0592 |
| ZSSK ZSR | 0.9288 | 0.9385 | 0.2526 | 0.0987 | 0.0575 |

Table 7 evaluates the firms whether they are stable in terms of efficiency. The fourth column in the table gives the largest difference among the efficiencies in windows of a DMU. This difference for BDZ of Bulgaria equal to the difference between the value of 2004 in Window 3 and the value of 2009 in Window 8, that is, 1 – 0.7657=0.2343. The fifth column in the table signifies the highest difference taken by each DMU as given in window table for the same date. Difference for ZSSK of Slovakia is, for example, 0.8460-0.7473=0.0987. It may be considered that the higher these differences are, the more the variability is, that is, it may be considered as a sign that impairs stability. The last column gives standard deviations of the average efficiency scores. There is a relation between the standard deviation and efficiency values and that the standard error of DMU with low efficiency would be high (Carnes,1995).

As it may be seen from the table, YD and WD values are also high for the firms with the lowest efficiency score. CD of Czech Republic, one of the four firms with the lowest average efficiency score, for example, has a maximum window difference of 44.3% and the year difference of about 16.5%. Standard deviation of the average efficiency, 0.0705, shows the highest standard deviation of all firms. The least efficiency four firms take place among the firms with the highest window difference and standard deviation. It appears that if Window Difference (WD) of a firm is high, Year Difference (YD) and standard deviation are also high for that firm but, WD may never be less than YD.

## Total Factor Productivity Analysis with Malmquist Index

Productivity scores and parameter estimations of the firms are obtained separately in terms of total factor productivity (TFP) Analysis with an output-oriented MI. In this analysis, values for TFP Change (tfpch), Technical Change (techch), Efficiency Change (effch), Pure Efficiency Change (pech), and Scale Change (sech) belonging to these firms were estimated.

***Table 8. Annual Efficiency Averages of Malmquist Index***

| Year | effch | techch | Pech | sech | tfpch |
|---|---|---|---|---|---|
| 2001 | 1.021 | 0.943 | 1.019 | 1.002 | 0.962 |
| 2002 | 0.979 | 1.006 | 0.987 | 0.992 | 0.985 |
| 2003 | 1.007 | 1.017 | 1.011 | 0.996 | 1.024 |
| 2004 | 0.993 | 1.035 | 1.004 | 0.990 | 1.028 |
| 2005 | 0.991 | 1.056 | 0.990 | 1.000 | 1.047 |
| 2006 | 0.983 | 1.042 | 0.994 | 0.988 | 1.024 |
| 2007 | 1.032 | 0.982 | 1.020 | 1.012 | 1.013 |
| 2008 | 0.999 | 0.979 | 1.000 | 0.999 | 0.978 |
| 2009 | 0.995 | 0.973 | 0.998 | 0.996 | 0.968 |
| **Mean** | 1.000 | 1.003 | 1.002 | 0.997 | 1.003 |

***Table 9. Efficiency Averages of Firms' Malmquist Index***

| Firm | effch | techch | Pech | sech | Tfpch |
|---|---|---|---|---|---|
| BC | 1.000 | 1.075 | 1.000 | 1.000 | 1.075 |
| BDZ | 0.990 | 0.993 | 0.994 | 0.996 | 0.983 |
| BLS | 1.000 | 1.070 | 1.000 | 1.000 | 1.070 |
| SBB | 1.000 | 1.005 | 1.000 | 1.000 | 1.005 |
| CAMRAIL | 0.985 | 1.049 | 1.000 | 0.985 | 1.033 |
| CD | 1.008 | 1.000 | 1.008 | 1.000 | 1.009 |
| CFL | 1.000 | 0.895 | 1.000 | 1.000 | 0.895 |
| CIE | 1.013 | 1.056 | 1.013 | 1.000 | 1.070 |
| CP | 1.000 | 1.015 | 1.000 | 1.000 | 1.015 |
| DB AG | 1.005 | 0.998 | 1.000 | 1.005 | 1.003 |
| FEVE | 0.992 | 0.986 | 1.013 | 0.979 | 0.978 |
| FGC | 1.000 | 0.929 | 1.000 | 1.000 | 0.929 |
| RENFE | 1.000 | 1.034 | 1.000 | 1.000 | 1.034 |
| FS | 1.000 | 0.999 | 1.000 | 1.000 | 0.999 |
| ÖBB | 1.017 | 0.994 | 1.020 | 0.997 | 1.011 |
| GySEV/RÖEE | 1.000 | 1.007 | 1.000 | 1.000 | 1.007 |
| HZ | 1.019 | 1.000 | 1.018 | 1.000 | 1.019 |
| JR | 1.000 | 1.011 | 1.000 | 1.000 | 1.011 |
| KORAIL | 1.000 | 1.056 | 1.000 | 1.000 | 1.056 |
| KTM | 0.987 | 0.995 | 1.000 | 0.987 | 0.982 |
| LG | 1.011 | 0.988 | 1.019 | 0.992 | 0.998 |
| ONCFM | 1.007 | 1.038 | 1.005 | 1.002 | 1.046 |
| PKP | 1.004 | 0.994 | 0.989 | 1.015 | 0.998 |
| SNCB/NMBS | 0.997 | 0.993 | 0.996 | 1.001 | 0.990 |
| SNCF | 1.000 | 1.022 | 1.000 | 1.000 | 1.022 |
| SZ | 1.007 | 0.988 | 1.014 | 0.993 | 0.995 |
| TCDD | 0.976 | 0.962 | 0.983 | 0.993 | 0.939 |
| TRA | 1.000 | 0.982 | 1.000 | 1.000 | 0.982 |
| VR | 1.006 | 0.990 | 1.006 | 1.000 | 0.996 |
| ZRS | 0.970 | 0.993 | 1.000 | 0.970 | 0.963 |
| ZSSK | 1.000 | 0.999 | 1.000 | 1.000 | 0.999 |
| **Mean** | 1.000 | 1.003 | 1.002 | 0.997 | 1.003 |

The results related to the constant return to scale and input oriented TFP are shown in Table 8. In the second, third, and last two years, the TFP change is less than one. In 2001, the TFP change is at its lowest level, by a reduction of 3.8% and in the relevant years, the TFP increased to its highest level in 2005 by an increase of 4.7%.

TFP and other efficiency changes of the firms are investigated below in the Table 9 by MI. There are 16 firms with their TFP average less than one. When the averages of all firms are considered, the scale efficiency change is below the initial value by 0.3% and the TFP has increased only by 0.3%. When the efficiency averages of all firms are concerned, all firms, except one, have shown increases at level of thousandths. Atkinson and Cornwell (1998) obtained a similar result in their study on 12 railways in the United States for the period of 1951-75 where the annual averages of the firms had an efficiency increase about 0.3%. Change rate in the TE and TFP was the same, 17 firms with the TE scores less than 1 also had the TFP values below one. As it may also be seen from the table, BC of Belarus is at the highest level with a TFP of 7.5% and CFL of Luxemburg is at the lowest level with a decrease of 10.5%.

In order to see the relation between the total factor efficiency and window efficiency analysis, a further look at the values given in Table 9 is needed. In the table, total factor efficiency change for CFL of Luxembourg is at the lowest level. With respect to TE and AE of the same firm conducted by CCR model, it is understood that no inefficiency is encountered till 2004 and after that, a quick fall especially in the AE is observed. However, in the analysis made by BCC model, it has a complete efficient score in the AE and TE during the period. Average efficiency score obtained according to the windows and years is in the range of 0.983 – 0.986. Besides, YDch and WDch values are also the same. Since TFP does not change much, it seems the firm has a very stable efficiency score with reflection of AE on MI. In Window analysis, no negative aspect is noticeable in relation to inefficiency of the firm.

As seen from the Figure 3, trends of changes in window average and year average seem to be similar. Another interesting point is that as the higher the TFP level, the lower the window average, and year average changes. In another word, as TFP gets higher in value, deviations in window and year averages decline.

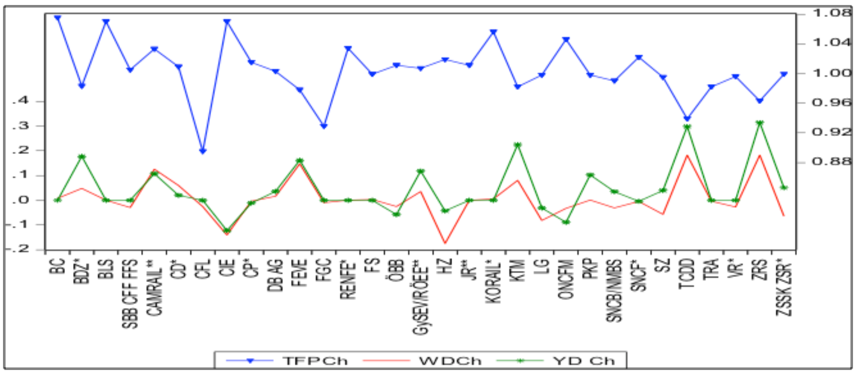


*Figure 3. Changes in TFP, Window Average, and Year Average*

Finally in the analysis performed by CCR, BCC, and DEA Window models, it has been mentioned that the efficient and inefficient firms bear similarity in all analytical models. Now, additionally, looking at the results obtained from the analyses conducted with MI, similar results are obtained in this analysis as well. In parallel to high efficiency scores of the four biggest railway firms mentioned above, it is seen that total factor efficiencies are above "1". In other words, efficiency of these firms seems to have increased during the period. However, total factor efficiencies of four small firms with low capacity and low efficiency have been below one (<1).

## Conclusion and Suggestions

In this study, TE and AE scores have been obtained in two different models by using DEA in a period of ten years, 2000-2009, for active 31 firms operating worldwide. In the analysis with the constant return to scale CCR model, 17 firms had TE at the beginning and at the end of the investigated period. While only two firms had AE for the first year, this figure goes down to one in the last year. In the analysis with the variable return to scale BCC model, the number of firms having TE in the beginning of the period is 20 and at the end, this figure rises to 24.

In the results related to the constant return to scale and input oriented TFP obtained by use of MI, the TFP is less than one in the second, third, and the last two years. There are 16 firms with their TFP average less than one. Considering the averages for all firms, the Scale Efficiency Change is below the initial value by 0.3%, and the TFP has increased only by 0.3%. Percentage change in the TE and TFP is the same.

However, looking at the efficiency average of all firms, it appears that average efficiency score declines in the range of Win4-Win5 and it starts to increase again. Despite of all, average efficiency score has never gone below 0.87. Considering this result, it might be said that there is a stable process prevailing in the railway operations. As mentioned in the article, five firms with the least efficiency are among the firms having the highest window difference and standard deviation values.

One of the most important findings obtained in this study is that small-scale railway firms established by a political, ethnical, or any other non-economic reason, as detailed in the text, are unproductive. The railway firms in Bosnia-Herzegovina and Spain may be given by way of example in this respect. The unproductivity of the railway firm in Luxemburg, which as a developed economy, stems, in our opinion, from the fact that the country is small and population is few. Another important point is that the railway firms have productivity only at the level of thousandths.

In the efficiency analyses conducted by DEA Window model, CCR or BCC model, SNCF of France always takes place in the most efficient firms and ZRS of Bosnia-Herzegovina is always in the list of firms with the least efficiency.

Furthermore, it was also observed in all applied analytical techniques, the efficient and inefficient firm categories remained the same. Additionally, looking at the analysis conducted with MI, it is seen that four biggest railway firms mentioned in the text have total factor efficiencies above “1” in parallel to their high efficiency scores. In other words, efficiency of these firms during the period has increased. On the other hand, four small firms with low capacity and low efficiency had total factor efficiency below one (<1) at the end of the period. Finally, a common point in all efficiency analyses should not be neglected that; in the analyses conducted with CCR, BCC, and DEA Window models, the efficient and inefficient firms had similarity in all analytical models and it is observed that this similarity corresponds to total factor efficiency defined by MI.

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