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EFFICIENCY AND PRODUCTIVITY ANALYSIS OF UNIVERSAL SERVICE OBLIGATION: A CASE OF 29 DESIGNATED OPERATORS IN THE EUROPEAN COUNTRIES

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Abstract. The main aim of this paper is to perform efficiency and productivity analysis of Universal Service Obligation (USO) based on the Malmquist Productivity Indices (MPI) analysis. The study focuses on 29 Designated Operators (DOs) and two isolated periods, the years 2003 and 2017. There is a clear trend of workforce reduction (12%). Considering the postal services, the data confirm a general trend that the letter-post is in decline (30%) and the parcels are on the rise (52%). Considering the financial results, both costs and revenues are increased; however, there is a higher increase of revenue (33.13%) compared to the cost (32.61%). Further, the results of implemented methodology are twofold. Firstly, a progress is determined at the average level of all observed DOs according to the efficiency and productivity indicators. Among other, the results indicate the increase of productivity for both input MPI (3.5%) and output MPI (8%). However, there are significant variations of efficiency and productivity at the individual level. Secondly, the aim of research was also to examine the sources of productivity changes by considering postal market liberalization, ownership, marketing services and e-commerce. Our findings show that the last three specified variables contribute to the explanation of productivity change.

Keywords: efficiency, DEA, Malmquist productivity indices, designated operators, universal postal service obligation.

JEL Classification: C14, C54, C67, O14, O33, O38, O52.

Introduction

Postal services are considered as one of the drivers of the development of economy and society. The size of the postal market in the European Union (EU) is around 90 billion euros in 2016, compared to 84 billion euros in 2013. This equals to 0.52% and 0.55% of the total

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GDP in 2016 and 2013, respectively (Copenhagen Economics, 2018). Besides contributing to gross domestic product and employment as other businesses, the postal operators make the functioning of other economic entities easier. They speed up and facilitate the business activity by their services, such as transfer of goods between spatially separated production and consumption points, transfer of business documentation, warehousing, inventory management, communication services, various types of e-services, marketing services; they offer a possibility of connecting the national and world markets, contribute to developing of new forms of services like e-commerce, etc. On the other hand, the postal companies are considered as a factor of social and financial inclusion of citizens, particularly in rural areas due to a legal obligation to cover the entire state territory by affordable postal services. A set of postal services that should be provided to every person under the conditions defined by the state regulations is referred to as universal postal services or Universal Service Obligations (USO). Each state designates at least one postal operator to serve as a designated operator (DO).

Designated operators (DOs) in many European countries had a primary goal in the past to provide universal service and financial results of the postal company were less important. A philosophy of this concept lies in the importance of postal services for the state, economy and citizens. Therefore, a potential financial loss would be covered by the state. In the recent decades, the expectations from DOs have raised to a higher level. A question of efficiency and productivity is a constant preoccupation of nowadays. A challenge is even higher having in mind the changing conditions in which modern DOs operate. The postal market is completely liberalized in most European countries. Unlike in the past, the DOs should struggle with private companies for customers in the competitive market. Further, another threat comes from expansion of electronic communications as a substitution for some traditional postal services. However, although the new information and communication technologies bring to a higher efficiency of postal process and generate some additional services such as e-commerce, the decline in letter post is generally noted in the recent years. By adding the impact of universal service obligations to the previously described challenging conditions, having in mind that these obligations are very often driven by the political factors and as a rule with a negative financial balance which can be measured (see Kujacic et al., 2015). Frontier Economics (2013) prepared a study for the European Commission on the principles used by the national regulatory agencies to calculate the net cost of the USO. These calculations can be performed in different ways, as described by the CERP (2008). To reimburse the net costs, the possible financial mechanisms include the following: reserved area, compensation funds of various forms, state funding, pay-or-play (a tax where the entrant pays a fixed amount per each address it does not cover) and competitive tendering (Jaag, 2014; USPS, 2019). Reserved area as a funding mechanism is the traditional approach to funding the universal postal service in the European postal sector. However, by adopting the European Union (2008) Directive 2008/06/EC, the postal market is fully liberalized starting from the year 2013, which means that a reserved area is totally abolished. Having in mind the previously explained, it is clear that there is a very difficult task in front of DOs to operate in an efficient and productive way. This was exactly the motivation for authors to perform a study on efficiency and productivity of DOs with the aim to identify the examples of good practice and to propose certain policy directions in the postal sector.

Data envelopment analysis (DEA) and Malmquist based approach (MBA) measure the productivity change over time. MBA can be further decomposed into two components: efficiency change (EC) and technological change (TC). In this study, the aim of research is exactly to analyze EC and TC of observed DOs over time. Thus, the efficiency and productivity changes of 29 selected European DOs for the period 2003–2017 are performed by using DEA and MBA. DEA is a mathematical programming technique (Charnes et al., 1978) for measuring the relative efficiency of the decision making units such as DOs. The application of the MBA is convenient for the topic of postal efficiency and productivity change over time and was also used by other authors (Iturralde & Quiros, 2008).

In the literature, there are a number of studies that have measured efficiency of postal services. Some studies put emphasis on the efficiency of the postal network and branches of DOs (Horncastle et al., 2006; Cazals et al., 2008; Ralević et al., 2016). Further, the studies where efficiency and productivity of DOs in general are analysed can be found. Some examples of these are the papers (Perelman & Pestieau, 1994; Iturralde & Quiros, 2008; Quiros, 2011; Schuster, 2013; Ralević, 2014; Ralević et al., 2014, 2015; Tochkov, 2015).

The studies on efficiency and productivity can be also segmented according to the considered sample. Many of these analyze the postal services in a single country. For example, Grifell-Tatje and Lovell (2008) assessed the performance of DO in United States, Cazals et al. (2008) in UK, Mizutani and Uranishi (2003) in Japan, Filippini and Zola (2005) in Switzerland and Ralević et al. (2016) in Serbia. On the other hand, Perelman and Pestieau (1994) measured the efficiency of 16 DOs from Europe, Japan and Australia, Iturralde and Quiros (2008) of 17 DOs in the EU, Tochkov (2015) of 17 DOs from Central and Eastern Europe, Ralević et al. (2014) of 27 DOs from Europe, Ralević et al. (2015) of 26 DOs from Europe. An advantage of this study is the analysis of a considerable sample of 29 DOs. The larger sample brings to the benefits of three kinds: the first refers to the fact that efficiency frontier is defined more realistic, the second to the possibility of bringing more reliable conclusions about trends in the postal industry and finally, there is a higher probability of finding the best practice.

The studies on efficiency differs from the standpoint of used data. In the papers of Ralević et al. (2014) and Ralević et al. (2015) the static approach is implemented using cross-section data. Grifell-Tatje and Lovell (2008), Iturralde and Quiros (2008), Tochkov (2015) considered the dynamic approach with panel data. In this paper we use a dynamic approach and an additional advantage is that we assess both efficiency and productivity. By comparing the results of both approaches, we are in a position to realize the performance of considered DOs in a broader sense. To deepen the analysis, we identify the determinants of productivity change using multiple regression analysis. The effects of liberalization and ownership are considered as components of a state policy and also marketing and e-commerce services as part of a company policy.

The current article proceeds as follows. Section 1 refers to the methodological issues about efficiency measurement and Malmquist-based analysis of productivity growth. In Section 2 we describe data collection and used variables. In Section 3 we demonstrate the applicability of the proposed methodology on the sample of 29 DOs from Europe.

1. Methodology

In the economic theory, the performance of producers or service organizations could be described as efficient or productive, and in the literature, these are two interconnected concepts. Thus, the productivity means the ratio of what a company produces (output) to the resources it uses (input). In practice, the simplest example of productivity calculation is when a single input and single output are considered; this is the case of single-factor productivity. The task of productivity assessment becomes more complicated when there are multiple inputs and multiple outputs which refers to the total factor productivity (TFP). Unlike the productivity, the efficiency treats a comparison between observed and optimal values of output and/or input.

The major challenge in calculating TFP is to determine a method to aggregate outputs and inputs. The traditional way approximates total inputs and outputs by using information on costs and revenues, respectively, based on parametric formulas or Price Index Numbers (PINs). Laspeyres, Paasche, Fisher, Törnqvist indices are the examples of the mentioned method for TFP measurement (Laspeyres, 1871; Paasche, 1874; Fisher, 1922; Törnqvist, 1936). The Törnqvist has been the most popular TFP index; this approach is also known as the Hicks-Moorsteen method which defines productivity index simply as the ratio of output and input index numbers. The other approach for calculation of TFP introduces the production function (technology) which was the contribution of Solow (1957). He showed that technical change could be measured as the difference of the change in observed output and the change in multiple inputs.

Caves et al. (1982) provided a relationship between a theoretical index of productivity based on technology and the Törnqvist index. In the literature, this is known as the Malmquist productivity indices (MPIs). Malmquist (1953) proposed a comparison of the same inputs in two different time periods where it should be examined if the inputs in the first period could be reduced wherein the unit would produce the same performance in the second period. By introducing these indices, a framework for another group of productivity indices that are based on the distance functions is provided. Nishimizu and Page (1982) carried out an empirical study of the Malmquist productivity index using the frontier production function model developed by Aigner and Chu (1968). This enables the assessment of productivity change based on its decomposition on the efficiency change (EC) and technological change (TC). The two main techniques to determine these components are the stochastic frontier analysis (SFA) and DEA as shown in Färe et al. (1994). MPIs are mainly used in the production sector; however, Keh and Chu (2003), Odeck (2006) and Kortelainen (2008) shown the possibility of their implementation in other areas as well. For example, Keh and Chu (2003) investigated the retail productivity and scale economies at the firm level by using a DEA approach. Odeck (2006) extended a DEA-based Malmquist index to measure productivity growth in target achievements of the operational units of the Norwegian Public Roads Administration (NPRA) charged with traffic safety services. Kortelainen (2008) applied DEA and MPI on the sample of 20 member states of the European Union considering eco-efficiency change in 1990–2003.

1.1. Efficiency measurement

There are two broad techniques for efficiency measurement. The first is a parametric (econometric) approach, and the second is nonparametric (programming) approach for efficiency analysis known as DEA. Both cases involve a comparison of actual performance with optimal performance located on the relevant approximated frontier.

In this research we used the CCR DEA model for efficiency measurement. This model is the original model of DEA for evaluating the relative efficiency for a group of Decision Making Units (DMUs) proposed by Charnes et al. (1978). The CCR stands for Charnes, Cooper and Rhodes which are the last names of this model creators. Suppose there is a set (A) of DMUs where each DMU_j ($j \in A$) uses m inputs x_{ij} (i = 1, 2, 3, …, m) to produce s outputs y_{rj} (r = 1, 2, 3, …, s). The CCR model evaluates the relative efficiency of a specific DMU_o, $o \in A$, with respect to a set of CCR frontier DMUs defined $E_o = \{ j \mid \lambda_j > 0$ for some optimal solutions for $DMU_o\}$. One formulation of a CCR model aims to minimize inputs while satisfying at least the given output levels, i.e., the CCR input-oriented model. Another formulation of a CCR model aims to maximize outputs without requiring more of any of the observed input values, i.e., the CCR output-oriented model.

1.2. A Malmquist-based analysis of productivity growth

In this study we analyzed the DOs as multiple inputs and multiple outputs units which implies the problem of the TFP measurement. To aggregate outputs and inputs we used the Malmquist productivity index. MPI consists of two components, efficiency change (EC) and technological change (TC), as shown in Eq. (1). EC (known as Catch-up) refers to the level to which a unit improves or worsens its efficiency between two considered time periods. It investigates if the technical efficiency has the impact on the productivity change. TC (known Frontier-shift) reflects the changes in efficiency frontiers between the two periods, i.e. measure the contribution of technology to the productivity change.

$$MPI = EC \times TC \,. \tag{1}$$

Let we notice a set of n DMUs in two different time periods where the each DMU_j (j = 1, 2, 3, …, n) use m inputs x_{ij}, $x_{ij} > 0$ (i = 1, 2, 3, …, m) to produce s outputs y_{rj}, $y_{rj} > 0$ (r = 1, 2, 3, …, s) during the both time periods. In the following text, the variables related to the first or the second period will be denoted by upper index 1 or 2, respectively.

EC is defined by Eq. (2). The marks $\theta^1((x_0, y_0)^1)$ and $\theta^2((x_0, y_0)^2)$ represent the relative efficiency scores which an observed DMU_0 $j_0 \in \{1,2,3,...,n\}$, achieved using technology 1 in the first period and technology 2 in the second period, respectively. If EC > 1 it means there is a positive impact of technical efficiency on the productivity change, namely the progress is noted between two periods. If EC < 1 there is a negative impact of technical efficiency on the productivity change; in other words, the regress is noted. EC = 1 indicates the lack of technical efficiency influence on the productivity change.

$$EC = \frac{\theta^2((x_0, y_0)^2)}{\theta^1((x_0, y_0)^1)} \,. \tag{2}$$

TC is defined by Eq. (3). The mark $\theta^2((x_0,y_0)^1)$ denotes the relative efficiency score in the first period for DMU_0 which is measured in relation to the efficiency frontier from the second period (technology 2). The efficiency score $\theta^1((x_0,y_0)^2)$ refers to the second period, and in Eq. (3) it is calculated in relation to the efficiency frontier from the first period (technology 1). Thus, TC > 1 indicates the positive effect of using technology 2 comparing to technology 1, TC < 1 indicates the negative effect, while TC = 1 indicates that there is no effect.

$$TC = \sqrt{\frac{\theta^1((x_0,y_0)^1)}{\theta^2((x_0,y_0)^1)} \times \frac{\theta^1((x_0,y_0)^2)}{\theta^2((x_0,y_0)^2)}}. \tag{3}$$

To perform the TFP measurement it is necessary to calculate MPI according to Eq. (4). The functional form for the calculation of this indicator is obtained using relations that are shown in Eqs (2) and (3). The result of this deriving is Eq. (4) which gives a final judgment on the productivity over time by sublimating both the technical and technological changes. Thus, the productivity of a unit from the first period to the second period is enhanced if MPI > 1. If MPI < 1 it indicates a deterioration in productivity, and finally, MPI = 1 means that there is no change in productivity:

$$MPI = \sqrt{\frac{\theta^1((x_0,y_0)^2)}{\theta^1((x_0,y_0)^1)} \times \frac{\theta^2((x_0,y_0)^2)}{\theta^2((x_0,y_0)^1)}}. \tag{4}$$

According to Eq. (4) the problem of quantification of MPI for observed DMU_0 comes down to determining the numerical values $\theta^1((x_0,y_0)^1)$, $\theta^2((x_0,y_0)^2)$, $\theta^1((x_0,y_0)^2)$ and $\theta^2((x_0,y_0)^1)$. These efficiency scores can be obtained by various methods, for example by using the input and output oriented radial data envelopment analysis (DEA) method as shown in the work by Färe et al. (1994). The results on MPI derived by input orientation and those obtained using the output orientation have to lead us to the same conclusions. In this study we use a mark ϕ ($\phi^1((x_0,y_0)^1)$, $\phi^2((x_0,y_0)^2)$, $\phi^1((x_0,y_0)^2)$ and $\phi^2((x_0,y_0)^1)$) to denote the efficiency score in output oriented radial DEA. The output MPI (MPI^*) and its corresponding components (EC^* and TC^*) are presented in Eqs. (5), (6) and (7). It is useful to note that an interpretation of the output MPI and its components is opposite to the case of the input MPI except when they are equal to 1:

$$MPI^* = \sqrt{\frac{\phi^1((x_0,y_0)^2)}{\phi^1((x_0,y_0)^1)} \times \frac{\phi^2((x_0,y_0)^2)}{\phi^2((x_0,y_0)^1)}}; \tag{5}$$

$$EC^* = \frac{\phi^2((x_0,y_0)^2)}{\phi^1((x_0,y_0)^1)}; \tag{6}$$

$$TC^* = \sqrt{\frac{\phi^1((x_0,y_0)^1)}{\phi^2((x_0,y_0)^1)} \times \frac{\phi^1((x_0,y_0)^2)}{\phi^2((x_0,y_0)^2)}}. \tag{7}$$

Beside the radial approach, for this purpose could be used the non-radial DEA and non-radial and non-oriented DEA models which are introduced, among others, in the papers of Zhu (1996), Tone (2001, 2002), Chen (2003), Tone and Tsutsui (2009).

2. Data collection and description of variables

In this study we performed the efficiency measurement and Malmquist-based analysis of 29 DOs for a time period of 15 years. The sample consists of the DOs from European Union, Switzerland and Serbia. The total list of observed countries and their abbreviations, as well the official names of corresponding DOs are presented in Appendix A (Table A.1). The research involved the data from two periods: the year 2003 (first period) and 2017 (second period). For both periods and for all DOs in the sample, we used the same data source which is a website of the Universal Postal Union (2019).

The production activity of observed DOs was defined by three input and three output variables which are presented in Appendix A, Tables A.2 and A.3, respectively. To optimize the size of the following tables, we used the international labels instead of the full names of countries and DOs. The input variables are related to work, capital factor and financial investments. Work factor is determined by the total number of employees (x_1). This number includes both full and part time employees. Although our intention was to consider these two types of workers as two separate variables, the lack of definition consistency of part time employees across the countries forced us to use just one variable which covers both categories. For example, in some countries part-time workers are employed shorter time during a working day (e.g. three or four hours), while there are cases where part-time workers work full-time during the day, however they are not permanently employed in the company. The capital factor is illustrated by the number of permanent post offices (x_2). Besides the observed variable, there are other variables that affect the capital factor such as the number of vehicles and other equipment. Herein, the unavailability of these additional data did not significantly influenced the validity of the research since the main capital factor of DOs was used. Finally, financial investments are observed through the operating cost (x_3). The values of this variable are originally expressed in SDR currency (Special Drawing Rights); however, in the research all SDR values are converted into euros because of better comprehension (1 SDR = 1.1790 EUR for 31.12.2003; 1 SDR = 1.1936 EUR for 31.12.2017).

We identify the performance outcomes of DOs based on provided postal services and achieved revenue. A service portfolio of an ordinary DO is much diversified, besides traditional postal services, there are also commercial services, such as: express, financial, marketing, electronic services, etc. Since the aim of this paper is to examine the efficiency changes of DOs in the field of USO providing, we have focused on traditional postal services as output variables. Each country from the consider sample in this study has the possibilities to define the scope of USO at the national level. However, some general rules of UPU and EU should be followed, which means that in all countries letter-post and parcels are the main part of USO. This involves postal services of both regimes ordinary, as well as value added services – registered and insured letters and parcels. Therefore, we employed two output variables to quantify the provided postal services: the number of letter-post items, domestic services (y_1) and the number of parcels (y_2). Finally, we took into consideration just domestic services because the number of international postal services is negligible in the total number of services. The third output is the operating revenue (y_3) which is expressed in euros, the same as in the case of cost.

Table 1. Average descriptive statistics for input variables (source: calculated by the authors based on data from Universal Postal Union (2019))

Variable	2003				2017			
	Min	Max	Mean	SD	Min	Max	Mean	SD
Employees	665	383173	57339	89411	650	472208	50552	95902
Post Offices	50	16992	3990	4862	68	17100	3896	4891
Cost (mil. €)	12.99	38326.27	3232.34	7675.35	22.52	58530.17	4286.43	11455.62

Table 2. Average descriptive statistics for output variables (source: calculated by the authors based on data from Universal Postal Union (2019))

Variable	2003				2017			
	Min	Max	Mean	SD	Min	Max	Mean	SD
Letters (mil.)	38.51	20840	3325.23	5929.02	13.2	18457	2346.49	4481.75
Parcels (mil.)	6.1×10^{-5}	1531	79.22	284.10	2.87×10^{-4}	1323	121.58	324.78
Revenue (mil. €)	16.96	41307.59	3415.70	8181.43	25.99	62249.22	4547.61	12167.46

Table 3. Percentage changes of input and output variables for the period 2003–2017 (source: calculated by the authors based on data from Universal Postal Union (2019))

Variable	Change [%]		
	Min	Max	Mean
Employees	–2.26	23.24	–11.84
Post Offices	36.00	0.64	–2.36
Cost (mil. €)	73.36	52.72	32.61
Letters (mil.)	–65.72	–11.43	–29.43
Parcels (mil.)	370.49	–13.59	52.47
Revenue (mil. €)	53.24	50.70	33.14

By analyzing the average values of observed input (Table 1) and output (Table 2) variables and percentage changes (Table 3) in two considered periods, we are in a position to perceive general development trends in the postal sector. Thus, there is a clear trend of workforce reduction. At the level of 29 European countries the average number of employees was 57339 in the year 2003, compared to 50552 in the year 2017, which is a decrease of 6787 employees (11.84%). The most remarkable exceptions are DOs from Germany and Switzerland where the number of employees is increased from 383183 to 472208 and 54543 to 59369, respectively. According to the general expectations, the postal network is reduced which is reflected in a smaller number of post offices. However, the postal network is relatively stable because this reduction is just 2.36% during the fifteen years period. When it comes to the number of services, the data confirm a general trend that the letter-post is in decline (29.43%), while the parcels are on the rise (52.47%). The explanation of this phenomenon might be in rising electronic communications, which affect letters and development of e-commerce, which generates additional parcels. Finally, considering the financial results, both cost and revenue are increased. It is interesting that there is a higher increase of revenue (33.14%) compared to the cost (32.61%).

3. Empirical results and discussion

3.1. Efficiency and productivity estimates

In this research, the efficiency and productivity of each observed DO were determined. For the efficiency measurement, the original CCR DEA model is used on cross-section data for the years 2003 and 2017, while the productivity analysis is performed using the Malmquist indices based on panel data for the same period. The analytical results are presented in Table 4.

Table 4. Efficiency scores and productivity changes (source: calculated by the authors based on data from Universal Postal Union (2019))

Country	CCR Score (2003)	CCR Score (2017)	Malmquist indices		Components			
			MPI* (MPI)		EC* (EC)		TC*(TC)	
AUS	0.90358	1.00000	0.51566	(1.93925)	0.90358	(1.10671)	0.57069	(1.75226)
BGR	0.92528	0.75388	1.28548	(0.77792)	1.22735	(0.81476)	1.04736	(0.95478)
CRO	0.78720	0.97200	0.90468	(1.10537)	0.82273	(1.21547)	1.09960	(0.90942)
CYP	1.00000	1.00000	1.13578	(0.88045)	1.00000	(1.00000)	1.13578	(0.88045)
CZE	1.00000	0.90097	1.43991	(0.69449)	1.10991	(0.90097))	1.29732	(0.77082)
DNK	0.99470	0.81878	0.93976	(1.06411)	1.14220	(0.87551)	0.82276	(1.21542)
EST	0.94291	0.89251	1.01815	(0.98217)	1.05746	(0.94566)	0.96283	(1.03861)
FIN	0.89180	0.90071	0.99987	(1.00013)	0.98910	(1.01102)	1.01089	(0.98922)
FRA	0.82937	0.94843	0.89788	(1.11374)	0.87248	(1.14615)	1.02910	(0.97172)
DEU	1.00000	1.00000	0.81714	(1.22377)	1.00000	(1.00000)	0.81714	(1.22377)
GBR	1.00000	1.00000	0.56622	(1.76611)	1.00000	(1.00000)	0.56622	(1.76611)
GRC	0.82201	0.88874	1.01824	(0.98208)	0.92609	(1.07981)	1.09951	(0.90949)
HUN	0.88366	0.90408	0.96231	(1.03917)	0.97847	(1.02200)	0.98348	(1.01680)
IRL	0.82258	0.88695	0.91585	(1.09188)	0.90923	(1.09984)	1.00729	(0.99277)
ITA	0.83731	0.97988	0.93140	(1.07366)	0.85992	(1.16290)	1.08312	(0.92325)
LVA	0.79505	0.90756	1.00198	(0.99803)	0.89411	(1.11844)	1.12065	(0.89234)
LTU	0.80197	0.88711	1.01736	(0.98293)	0.91112	(1.09755)	1.11661	(0.89557)
LUX	0.93984	0.94559	0.93052	(1.07467)	0.97721	(1.02332)	0.95222	(1.05018)
MLT	1.00000	0.97374	1.13690	(0.87958)	1.00000	(1.00000)	1.13690	(0.87958)
NLD	1.00000	1.00000	0.90134	(1.10946)	1.00000	(1.00000)	0.90134	(1.10946)
POL	0.88259	0.87011	1.06875	(0.93567)	1.02300	(0.97752)	1.04472	(0.95719)
PRT	0.87984	0.94935	1.00827	(0.99180)	0.92803	(1.07755)	1.08646	(0.92042)
ROU	1.00000	0.88958	1.04417	(0.95770)	1.12413	(0.88958)	0.92887	(1.07658)
SVK	1.00000	0.89176	1.12606	(0.88806)	1.13478	(0.88122)	0.99231	(1.00775)
SVN	1.00000	1.00000	0.78138	(1.27979)	1.00000	(1.00000)	0.78138	(1.27979)
ESP	1.00000	1.00000	1.04710	(0.95502)	1.00000	(1.00000)	1.04710	(0.95502)
SWE	1.00000	0.93041	0.81481	(1.22728)	1.00000	(1.00000)	0.81481	(1.22728)
SUI	0.92893	1.00000	0.91545	(1.09236)	0.92893	(1.07651)	0.98549	(1.01472)
SRB	0.71760	0.96974	0.81927	(1.22060)	0.74427	(1.34360)	1.10078	(0.90845)
Avg	0.91677	0.93317	0.96420	(1.08025)	0.98152	(1.02987)	0.98423	(1.05135)

The results from Columns 2 and 3 (Table 4) indicate the increase of average efficiency at the level of all observed DOs from 0.91677 for the year 2003 to 0.93317 for 2017. Further, based on efficiency scores we can identify DOs which may be considered as the examples of good practice. DOs from Cyprus, Germany, Great Britain, Netherlands, Slovenia and Spain achieved the best results, which include the highest ratings in both periods. In addition, DOs from Austria and Switzerland could be joined to the previous group since they achieved a progress, which results in the full efficiency in 2017. Further, there are DOs that improved their performance to certain extent, such as Croatia, Finland, France, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxemburg, Portugal and Serbia. However, the general positive trend does not apply to all DOs individually because three are cases of negative efficiency change. These are DOs from Bulgaria, Czech Republic, Denmark, Estonia, Malta, Poland, Romania, Slovakia and Sweden.

The results from the Column 4 and 5 of Table 4 show that the average productivity change is positive for both input and output Malmquist indices. According to the output MPI, an increase in productivity at the level of all observed DOs reaches 8.03% (1.08025) for the considered period of time, while the input MPI (MPI^*) indicates the rise of 3.58% (0.96420). In relation to this result, we should mention the work of Iturralde and Quiros (2008) who found that the increase in productivity of the postal sector in the European Union for the period 1999–2003 was 1.4% by using input MPI. Further, our finding indicates that this improvement is due to the rise in technical efficiency (Avg. EC^* = 0.98152 and Avg. EC = 1.02987) and technological change (TC^* = 0.98423 and TC = 1.05135). Both input and output MPI indicate that the progress in productivity is achieved at the total level. Furthermore, there are technical and technological progress revealed based on both input and output EC and TC indicators.

At an individual level of DOs, there are significant differences in the productivity changes over time. The values range from –30% to 94% (MPI) and –43% to 48% (MPI^*). DO from Czech Republic has the largest average decrease of productivity (MPI = 0.69449 and MPI^* = 1.4391), while the DO from Austria has the largest average increase (MPI = 1.93925 and MPI^* = 0.51566).

The decomposition of MPI to its components, EC (EC^*) and TC (TC^*) (see the Columns 6–9 of Table 4), identified large differences in the technical and technological changes at the level of DOs. Thus, for example, the DOs from Austria, Croatia, France, Ireland, Italy, Latvia and Serbia achieved the growth of technical efficiency by more than 10% in 2017 compared to 2003. Conversely, it can be seen that some DOs did not make significant technical changes in the observed period. This statement particularly stands for the DOs from Finland, Greece, Hungary, Lithuania, Luxemburg, Portugal and Switzerland. The results which indicate the productivity change in the technological sense relate to TC indicator. The greatest technological progress, with increase of more than 20%, is achieved in Austria, Germany, Great Britain, Slovenia and Sweden.

The interesting conclusions can be derived based on comparing the results of efficiency and productivity. In this regard, there are DOs which achieved progress in efficiency, i.e. CCR Score (2017) > CCR Score (2003), but their productivity decreased ($MPI^* > 1$ or MPI < 1). These are DOs from Greece, Latvia, Lithuania and Portugal. Conversely, DOs from Denmark and Sweden have CCR Score (2017) < CCR Score (2003), but $MPI^* < 1$ or MPI > 1. Finally,

DOs from Germany, Great Britain, Netherland and Slovenia achieved the highest efficiency scores in both periods and at the same time increased productivity. On the other hand, DO from Cyprus and Spain decreased their productivity even though they were fully efficient in both periods.

To test the robustness of the CCR efficiency scores, sensitivity analysis by Zhu (2003) is performed. The results are shown in Table 5. It can be noticed that there is no significant differences between CCR efficiency scores and CCR efficiency sensitivity for both periods 2003 and 2017. The exceptions are DOs from Czech Republic and Germany for the year 2003, and DOs from Austria, Germany and Great Britain for 2017.

Table 5. Efficiency scores and productivity changes (source: calculated by the authors based on data from Universal Postal Union (2019))

Country	2003			2017		
	CCR Score	CCR Score Sensitivity	Difference	CCR Score	CCR Score Sensitivity	Difference
AUS	0.90358	0.90358	0.00000	1.00000	2.10403	–1.10403
BGR	0.92528	0.92528	0.00000	0.75388	0.75388	0.00000
CRO	0.78720	0.78720	0.00000	0.97200	0.95682	0.00000
CYP	1.00000	1.04602	–0.04602	1.00000	1.01721	–0.01721
CZE	1.00000	1.50036	–0.50036	0.90097	0.90097	0.00000
DNK	0.99470	0.99470	0.00000	0.81878	0.87086	0.00000
EST	0.94291	0.94291	0.00000	0.89251	0.89168	0.00000
FIN	0.89180	0.89180	0.00000	0.90071	0.90163	0.00000
FRA	0.82937	0.82937	0.00000	0.94843	0.95058	0.00000
DEU	1.00000	2.70505	–1.70505	1.00000	1.65471	–0.65471
GBR	1.00000	1.13974	–0.13974	1.00000	2.05399	–1.05399
GRC	0.82201	0.82201	0.00000	0.88874	0.88762	0.00000
HUN	0.88366	0.88366	0.00000	0.90408	0.90310	0.00000
IRL	0.82258	0.82258	0.00000	0.88695	0.90470	0.00000
ITA	0.83731	0.83731	0.00000	0.97988	0.97371	0.00000
LVA	0.79505	0.79505	0.00000	0.90756	0.88922	0.00000
LTU	0.80197	0.80197	0.00000	0.88711	0.88020	0.00000
LUX	0.93984	0.93984	0.00000	0.94559	0.96176	0.00000
MLT	1.00000	1.08472	–0.08472	0.97374	1.02637	–0.02637
NLD	1.00000	1.18215	–0.18215	1.00000	1.05595	–0.05595
POL	0.88259	0.88259	0.00000	0.87011	0.86275	0.00000
PRT	0.87984	0.87984	0.00000	0.94935	0.94808	0.00000
ROU	1.00000	1.11352	–0.11352	0.88958	0.88958	0.00000
SVK	1.00000	1.02800	–0.02800	0.89176	0.88122	0.00000
SVN	1.00000	1.26527	–0.26527	1.00000	1.30757	–0.30757
ESP	1.00000	1.14915	–0.14915	1.00000	1.02338	–0.02338
SWE	1.00000	1.23200	–0.23200	0.93041	1.03989	–0.03989
SUI	0.92893	0.92893	0.00000	1.00000	1.01321	–0.01321
SRB	0.71760	0.71760	0.00000	0.96974	0.96417	0.00000

3.2. Calculating the determinants of productivity change by the multiple regression analysis

There may be a numerous factors which affect the efficiency and productivity. For example, Tochkov (2015) considered and determined the influence of internet and mobile-phone use, customs procedures, population density, competition policy, reform progress in the postal and telecommunication sector, profits and price of a standard letter. We chose four independent variables to test in a multiple regression analysis. These are: liberalization of the postal market, ownership of the DOs, marketing services offered by DOs and the state in the field of e-commerce. The first two variables describe some of the most important policy questions in the postal sector. The other two are related more directly to the postal company as the services with a huge potential for replacement of some outdated postal services in the digital age. A dependent variable refers to the achieved Malmquist scores in this research.

Not so long ago, the traditional postal services were reserved just for a state owned postal company. Since it was expected from competition to bring higher efficiency of DOs, new forms of services, higher quality and lower prices for customers, the process of postal market liberalization started in many countries. To describe the first variable, we categorized the countries according to the moment of postal market liberalization. The data were obtained at the web site of the European Commission (2019). In the first group was countries which opened their market by their own decision, before 2003. This was done by Sweden in 1993 and Finland in 1994. The member states of the European Union had to liberalize their market according to the Directive 2008/6/EC (European Union, 2008). The states that accomplished this goal even before the law forced them, but after the year 2003, are: Great Britain, Germany, Netherlands and Estonia. Under the third postal directive, the third group of states had to open their postal markets fully by the end of 2010: Austria, Denmark, France, Ireland, Italy, Portugal, Slovenia and Spain. The remaining twelve countries completed the liberalization process by the end of 2012: Croatia, Czech Republic, Greece, Cyprus, Latvia, Lithuania, Luxembourg, Hungary, Malta, Poland, Romania and Slovakia. In the final group are Switzerland and Serbia retaining a reserved area for their DOs, which covers the letters up to 50 grams. To quantify the status of these two countries in the calculation process, the year of liberalization for them was taken as 2017 because this is the last year in the examined period (Table 6).

To address very much discussed issue related to the DOs' ownership, we investigated whether a private or public governance impacts the efficiency change. The following countries introduced a model of private capital entry in the DOs in the observed period: Austria, Germany, Great Britain, Malta, Netherlands and Portugal. These data are partially taken from WIK (2012). In the calculation process, the DOs that have certain involvement of private capital are market with 1, while the fully state-owned enterprises are marked with 2 (Table 6).

There are opinions that due to the expansion of e-communications, the postal operators do not have a bright future. This might be partially true if we notice a general trend of decline in the letter post. However, on the other hand the new technologies generate new business possibilities. The high expectations are related to the marketing services and e-commerce.

The postal companies could offer various types of marketing services. Having in mind an extensive network of branches all over the country, the advertisements on digital screens

or in the physical form could be exposed. A huge potential of this kind is confirmed by a research carried out by the Post of Slovenia in 2010, resulting in a data that around 80% of adult population visit a postal branch at least once a month. Another way of advertisement is by using personalized stamps and envelopes which contributes to establish a strong brand identity. Finally, the most effective marketing tool provided by the postal operators is a direct marketing, or more precisely direct mail. Its main characteristic is contacting targeted clients for whom it is expected that should be interested in the offered product. Therefore, the creation of comprehensive and updated customer databases is the essential prerequisite for offering a direct marketing service (Dobrodolac et al., 2016).

The integral direct mail service should consist of several services that can be offered by a DO. The first refers to the identification of specific market segments within a larger audience to be targeted by the campaign. The criteria for segmentation could be various, depending on the advertised product, such as the age, personal income, rural or urban area, distance from the point of interest, etc. To be effective, a direct mail should be properly designed. This could be the second service. Generally, DOs possess the sophisticated printing machines enabling them to offer high quality printing services. Since the direct mail is usually ordered in a huge number, envelope inserting may be lasting and demanding job. DOs mainly use the machines to insert letters, leaflets, brochures etc. into an envelope. However, it should be kept in mind that direct mail includes both items with and without an envelope. Finally, in this process a traditional job of DOs should be performed, a delivery of mail to the addressee.

A huge potential of marketing services offered by postal operators is confirmed in a research carried out by the Institute for the Future (2003). According to the results, consumers identified a traditional mail as the preferred way to receive messages from businesses, comparing it with the modern information channels such as web, e-mail, television, radio and telephone. Particularly interesting is that consumers with higher levels of education are more likely to identify mail as the preferred means of receiving messages from companies. Bearing in mind the capacity of marketing services to bring to the progress of DOs, we took them into consideration as third independent variable. Data on marketing services provided by DOs in the year 2003 and 2017 were collected from the Universal Postal Union (2019) database. A percentage level of change between two periods was taken as the third independent variable (Table 6).

Another great hope for the postal operators is a rapid expansion of e-commerce, since its final phase includes a traditional postal service. In describing e-commerce as an independent variable, we used two categories of data. The first relates to the number of Courier, Express and Parcel (CEP) item since the goods order over the Internet are mainly transferred by this type of postal service. The percentage change between the years 2003–2017 is calculated based on Universal Postal Union (2019) database. The second category describes the level of e-commerce development in each considered country. Data about the share of consumer using Internet that shop online are obtained from Ecommerce Europe (2019) and presented in Table 6.

To investigate a relationship between the mentioned phenomena, we implemented the multiple regression analysis. It implies to find the appropriate coefficients in the Eq. (8) where y is dependent or criterion variable, while x_i (i = 1, 2, 3, …, n) are independent or predictor variables that affects the y variable, while b_i are the corresponding regression coefficients and b_0 is the intercept. In our case Eq. (8) reflects to the Eq. (9), where y is productivity change

and independent variables x_1, x_2, x_3, and x_4 represent a moment of postal market liberalization, DO ownership, the change in volumes of marketing services offered by DO and the level of E-commerce development, respectively. Input data for the multiple regression analysis are shown in Table 6.

$$y = b_0 + b_1 x_1 + b_2 x_2 + \ldots + b_n x_n; \tag{8}$$

$$y = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_4 x_4. \tag{9}$$

Table 6. Input data for the calculation of determinants of efficiency change (source: Calculated by the authors based on data from Universal Postal Union (2019), WIK (2012) and Ecommerce Europe (2019))

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Country	Year of postal market liberalization (x_1)	Ownership (x_2)	Change in marketing services, 2003–2017 [%] (x_3)	Change in CEP – courier, express and parcels volume [%]	Share of customers shopping online [%]	$\frac{(5)\times(6)}{100}$ (x_4)
AUS	2011	1	73	122	69	84
BGR	2011	2	–23	7	31	2
CRO	2013	2	57	64	47	30
CYP	2011	2	–89	7	38	3
CZE	2013	2	–23	–30	67	–20
DNK	2011	2	–97	54	86	47
EST	2009	2	20	71	68	48
FIN	1994	2	11	77	70	54
FRA	2011	2	16	25	75	19
DEU	2008	1	–18	–6	82	–5
GBR	2006	1	56	184	87	160
GRC	2013	2	–37	–24	49	–12
HUN	2013	2	30	122	52	63
IRL	2011	2	42	–53	70	–37
ITA	2011	2	33	–21	47	–10
LVA	2013	2	3	106	53	56
LTU	2013	2	–9	20	54	11
LUX	2013	2	7	378	82	310
MLT	2013	1	–64	61	66	40
NLD	2009	1	–12	39	84	32
POL	2013	2	–13	2	60	1
PRT	2011	1	5	–97	49	–48
ROU	2013	2	–18	–41	26	–11
SVK	2012	2	7	40	54	21
SVN	2011	2	75	401	53	213
ESP	2011	2	5	12	62	7
SWE	1993	2	15	118	84	99
SUI	non-liberal.	2	87	5	88	4
SRB	non-liberal.	2	90	286	46	132

To interpret the results of multiple regression analysis, one of the most important parameters to notice is a P-value for overall F-test. This test examines the validity of the entire model in sense that it examines the null hypothesis which says that all beta coefficients are equal to zero. If the P-value would be higher than 0.05, the null hypothesis would be confirmed, and this would mean there are no relationships between the considered variables and productivity change. However, in our case, P-value is 3.98×10^{-5} which confirms the validity of the proposed model. The second significant parameter is the value of R^2. In this model $R^2 = 0.6409$, which means that around 64% of variability in the productivity change can be explained by the proposed model. This is in accordance with the general expectations, because, as stated in the beginning of this subsection, the productivity change can be affected also by some other factors.

To assess the determinants of productivity change by the multiple regression analysis, we should consider the beta coefficients and individual t-test for each considered variable. In Table 7, there are values for all four considered variables; however, based on P-value, not all of them can be accepted as significant for the explanation of productivity change. By analyzing the results from the last column of Table 7, there are three variables that have P-value less than 0.05 and based on this, they significantly participate in the explanation of dependent variable. Therefore, the results show that a moment of postal market liberalization does not significantly affect the productivity. However, the ownership, level of marketing services and e-commerce development can be seen as drivers of productivity.

The question of DOs ownership is one the crucial dilemmas of states related to the postal sector. On one hand, there is a widespread opinion that a state is not a good owner and business manager and that higher efficiency can be reached by involvement of private investments. This standpoint can be explained by the fact that the state-owned enterprises are often managed by the people being close to the government structures and by this their business decisions are sometimes driven by the political issues rather than by the phenomenon of efficiency and productivity. On the other hand, the state-owned DOs sometimes achieve higher service volumes due to the state support, which results in higher efficiency and productivity. There are many examples of this kind in the postal industry. In the Post of Serbia citizens could apply for state aid or the distribution of stocks of the state-owned companies. Besides, some types of correspondence is reserved just for the DO, such as tax letters, letters from the courts, invitation for elections, etc. It is similar in Poland where Tax Office issues 10 million certificates a year, while the National Court Register and the National Criminal Register issue about 4 million official documents a year, offering "significant" potential for Polish Post (Post & Parcel, 2019). There is a possibility of issuance of various types of certificates in posts, such

Table 7. Multiple regression analysis results for the determinants of efficiency change (source: calculated by the authors based on data from Universal Postal Union (2019))

Independent variable	Beta coefficients	P-value
Liberalization	–0.007483	0.201850
Ownership	–0.179231	0.019182
Marketing	0.002983	0.000165
E-commerce	0.000842	0.049271

as birth, citizenship, marriage certificate, the certificates from land registration organizations, etc. A special benefit could be the possible delivery of all these documents at the home or business address. Therefore, although there are many privatization advocates, good results can be achieved also by DOs governed by a state. A fact that also should be kept in mind is that a private capital in the DOs may have a negative impact for the society in terms of universal postal service quality level decrease (Schuster, 2013).

The result which confirms that the increase in provided marketing services corresponds to increase of productivity is expected. The countries where DOs increased the number of marketing services for more than 50% in the period 2003–2017 are the following: Austria, Croatia, Great Britain, Slovenia, Switzerland and Serbia. The examples of good practice in this field could be find in the countries with the highest number of provided services. DOs which realized more than a billion marketing services are from: Czech Republic, Finland, France, Germany, Great Britain, Italy, Netherlands and Switzerland. In the absolute value, the first is France with around 13 billion services in 2017, while in relative relation considering the number of inhabitants in the country, the DO from Netherlands is at the top with 532 marketing services per person in 2017.

E-commerce is a segment of economy which offers a great opportunity for growth to postal operators. We are witnesses of exponential increase in volumes over the past years, and predictions for the future are optimistic as well. As stated by the International Post Corporation (2019) growth is being driven by mobile e-commerce, social media and, increasingly, cross-border e-commerce as consumers gain more and more confidence in online shopping and search for goods abroad that are either cheaper or unavailable in their home market. This is the reason why postal operators should take the advantage of this phenomenon. The main expectations from postal operators are to guarantee a day-certain delivery at home or business address and possibility of flexible solutions for parcel pick-up, for example using 24 hours a day, 7 days a week available parcel lockers.

Beside delivery, having in mind the huge confidence in DOs, there are some other opportunities. For example, postal operators can form virtual shopping center which visitors would access over the web site of the postal company. Beside sales channel and delivery service, the DOs can provide other logistic services to vendors, such as warehousing, inventory management, handling customs procedures etc. An example of good practice can be found in the DO from Slovenia. The postal operator takes care about the complete distribution process of a reputable beer producer, to each store or coffee shop in the country. The same DO handles all the on-line orders of a kitchen and home appliances manufacturer.

Conclusions

In this paper we illustrated the analysis of efficiency and productivity of designated operators (universal postal service providers) by using DEA method and Malmquist indices. The research focused on two time periods, the years 2003 and 2017. The results of efficiency analysis of 29 DOs from Europe suggest that there are at least 6 DOs that are excellent in operation for both considered periods and as such represent good examples for other DOs. The mentioned DOs are from Cyprus, Germany, Great Britain, Netherlands, Slovenia and Spain.

Productivity analysis was performed on the same sample of DOs. The results indicate an increase in average productivity in the postal sector for the period 2003–2017, both by the input (about 3.5%) and output (about 8%) Malmquist indicators. On the individual level, there are significant differences in productivity change during the observed period. The DOs from Austria, Croatia, France, Germany, Great Britain, Netherland, Slovenia, Sweden, and Serbia achieved a growth in productivity higher than 10% from 2003 to 2017. Furthermore, according to the output MPI, the results show that the increase in average productivity (around 8%) in the postal sector is more dependent on technological progress (around 5%) than on technical efficiency improvement (around 3%).

Although the task to determine the sources of efficiency and productivity growth can be considered as a very complex, we implemented a multiple regression analysis to assess the impact of postal market liberalization, ownership, services related to marketing and e-commerce. The results of the proposed model show that the postal market liberalization did not significantly affect the level of productivity change. On the other hand, the ownership and rising services of DOs related to marketing and e-commerce contribute to the productivity change. Although these results indicate certain policy directions both from the standpoint of a state and DO, further investigation about the sources of efficiency and productivity growth and the examples of good practice would be welcome.

Based on the results of this research and assessed trends, we might be optimistic about the future of DOs, despite all challenges imposed to them. It seems that the new information and communication technologies brought both positive and negative consequences; however, the DOs have caught their benefits in a proper way. Finally, we believe this type of studies might inspire policy makers in making decisions, which would lead toward efficient and productive DOs of the future.

Author contributions

Predrag RALEVIĆ and Momčilo DOBRODOLAC designed a methodology of the research. Predrag RALEVIĆ and Dragana ŠARAC were responsible for calculation of efficiency and productivity indices and presentation of corresponding results. Libor ŠVADLENKA and Momčilo DOBRODOLAC investigated the determinants of productivity change, gathered the data to be used in the multiple regression analysis, performed the calculations and presented the strategical results for the postal sector. Dejan ĐURIĆ chose the sample of designated operators to be analyzed, gathered the data about them and prepared the literature review from the considered field.

Disclosure statement

The authors state that they do not have any competing financial, professional, or personal interests from other parties.

References

Aigner, D. J., & Chu, S. F. (1968). On estimating the industry production function. *The American Economic Review*, *58*(4), 826–839. https://www.jstor.org/stable/i331496

Caves, D. W., Christensen, L. R., & Diewert, W. E. (1982). The economic theory of index numbers and the measurement of input, output, and productivity. *Econometrica*, *50*(6), 1393–1414. https://doi.org/10.2307/1913388

Cazals, C., Dudley, P., Florens, J. P., Patel, S., & Rodriguez, F. (2008). Delivery offices cost frontier: A robust nonparametric approach with exogenous variables. *Review of Network Economics*, *7*(2), 294–308. https://doi.org/10.2202/1446-9022.1150

CERP. (2008). *Guidelines for calculating the net cost of the universal service obligations*. http://www.cept.org/files/1049/documents/List%20of%20documents%20(history)/Guidelines%20Calculation%20net%20costs%20USO.pdf

Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision making units. *European Journal of Operational Research*, *2*(6), 429–444. https://doi.org/10.1016/0377-2217(78)90138-8

Chen, Y. (2003). Non-radial Malmquist productivity index with an illustrative application to Chinese major industries. *International Journal of Production Economics*, *83*(1), 27–35. https://doi.org/10.1016/S0925-5273(02)00267-0

Copenhagen Economics. (2018). *Main developments in the postal sector (2013–2016). Study for the European Commission, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs*. https://op.europa.eu/en/publication-detail/-/publication/d22799b5-bbb7-11e8-99ee-01aa75ed71a1/language-en

Dobrodolac, M., Lazarević, D., Švadlenka, L., & Živanović, M. (2016). A study on the competitive strategy of universal postal service provider. *Technology Analysis & Strategic Management*, *28*(8), 935–949. https://doi.org/10.1080/09537325.2016.1180357

Ecommerce Europe. (2019). *European Ecommerce Report*. https://www.ecommerce-europe.eu/wp-content/uploads/2019/07/European_Ecommerce_report_2019_freeFinal-version.pdf

European Commission. (2019). *Opening up the postal services markets*. http://ec.europa.eu/competition/sectors/postal_services/overview_en.html

European Union. (2008). *Directive 2008/6/EC of the European Parliament and of the Council of 20 February 2008*. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02008L0006-20080227

Färe, R., Grosskopf, S., Norris, M., & Zhang, Z. (1994). Productivity growth, technical progress, and efficiency change in industrialized countries. *The American Economic Review*, *84*(1), 66–83. https://www.jstor.org/stable/2117971

Filippini, M., & Zola, M. (2005). Economies of scale and cost efficiency in the postal services: Empirical evidence from Switzerland. *Applied Economic Letters*, *12*(7), 437–441. https://doi.org/10.1080/13504850500109709

Fisher, I. (1922). *The making of index numbers*. Houghton Mifflin.

Frontier Economics. (2013). *Study on the principles used to calculate the net costs of the postal USO – a report prepared for the European Commission*. http://ec.europa.eu/internal_market/post/studies/index_en.htm

Grifell-Tatje, E., & Lovell, C. (2008). Productivity at the post: its drivers and its distribution. *Journal of Regulatory Economics*, *33*(2), 133–158. https://doi.org/10.1007/s11149-007-9051-y

Horncastle, A., Jevons, D., Dudley, P., & Thanassoulis, E. (2006). Efficiency analysis of delivery offices in the postal sector using stochastic frontier and data envelopment analyses. In M. A. Crew, & P. R. Kleindorfer (Eds.), *Liberalization of the postal and delivery sector* (pp. 149–164). Edward Elgar.

Institute for the Future. (2003). *Changing communications strategies – new roles for mail*. http://www.iftf.org/uploads/media/SR785_B_ChangingCommStrategies.pdf

International Post Corporation. (2019). *Strategic perspectives on the postal market*. http://www.ipc.be/~/media/Documents/PUBLIC/Markets/Strategic%20Perspectives%202012%20FINAL.pdf

International Trade Statistics. (2019). *ISO 3166-1 alpha-3 Country Codes*. https://unstats.un.org/unsd/tradekb/knowledgebase/country-code

Iturralde, J. M., & Quiros, C. (2008). Analysis of efficiency of the European postal sector. *International Journal of Production Economics*, *114*(1), 84–90. https://doi.org/10.1016/j.ijpe.2008.03.001

Jaag, K. (2014). Postal-sector policy: From monopoly to regulated competition and beyond. *Utilities Policy*, *31*(SI), 266–277. https://doi.org/10.1016/j.jup.2014.03.002

Keh, H. T., & Chu, S. (2003). Retail productivity and scale economies at the firm level: A DEA approach. *Omega*, *31*(2), 75–82. https://doi.org/10.1016/S0305-0483(02)00097-X

Kortelainen, M. (2008). Dynamic environmental performance analysis: A Malmquist index approach. *Ecological Economics*, *64*(4), 701–715. https://doi.org/10.1016/j.ecolecon.2007.08.001

Kujacic, M., Blagojevic, M., Sarac, D., & Vesovic, V. (2015). The modified activity-based costing method in universal postal service area: Case study of the Montenegro post. *Inzinerine Ekonomika-Engineering Economics*, *26*(2), 142–151. https://doi.org/10.5755/j01.ee.26.2.2818

Laspeyres, É. (1871). Die Berechnung einer mittleren Warenpreissteigerung. *Jahrbücher für Nationalökonomie und Statistik / Journal of Economics and Statistics*, *16*, 296–314.

Malmquist, S. (1953). Index numbers and indifference surfaces. *Trabajos de Estatistica*, *4*(2), 209–242. https://doi.org/10.1007/BF03006863

Mizutani, F., & Uranishi, S. (2003). The post office vs. parcel delivery companies: Competition effects on costs and productivity. *Journal of Regulatory Economics*, *23*(3), 299–319. https://doi.org/10.1023/A:1023368327735

Nishimizu, M., & Page, J. M. (1982). Total factor productivity growth, technological progress and technical efficiency change: Dimensions of productivity change in Yugoslavia 1965–78. *The Economic Journal*, *92*(368), 920–936. https://doi.org/10.2307/2232675

Odeck, J. (2006). Identifying traffic safety best practice: an application of DEA and Malmquist indices. *Omega*, *34*(1), 28–40. https://doi.org/10.1016/j.omega.2004.07.017

Paasche, H. (1874). Ueber die Preisentwicklung der letzten Jahre nach den Hamburger Börsennotirungen. *Jahrbücher für Nationalökonomie und Statistik / Journal of Economics and Statistics*, *23*(2–4), 168–178. https://doi.org/10.1515/jbnst-1874-0113

Perelman, S., & Pestieau, P. (1994). A comparative performance study of postal services: A productive efficiency approach. *Annales d'Économie et de Statistique*, *33*, 187–202. https://doi.org/10.2307/20075942

Post & Parcel. (2019). *Polish Post seeks central role in e-government services*. http://postandparcel.info/54402/news/it/polish-post-seeks-central-role-in-e-government-services/

Quiros, C. (2011). Liberalization and efficiency in the European postal sector. *Applied Economics Letters*, *18*(12), 1155–1158. https://doi.org/10.1080/13504851.2010.528350

Ralević, P. (2014). *A model for designated operator resource optimization based on measuring the efficiency of postal services providing* (Doctoral dissertation). University of Belgrade, Faculty of Transport and Traffic Engineering, Serbia). http://nardus.mpn.gov.rs/bitstream/handle/123456789/4212/Disertacija119.pdf?sequence=1&isAllowed=y

Ralević, P., Dobrodolac, M., & Marković, D. (2016). Using a nonparametric technique to measure the cost efficiency of postal delivery branches. *Central European Journal of Operations Research*, *24*(3), 637–657. https://doi.org/10.1007/s10100-014-0369-0

Ralević, P., Dobrodolac, M., Marković, D., & Finger, M. (2014). Stability of the classifications of returns to scale in data envelopment analysis: A case study of the set of public postal operators. *Acta Polytechnica Hungarica*, *11*(8), 177–196. https://www.uni-obuda.hu/journal/Ralevic_Dobrodolac_Markovic_Finger_54.pdf

Ralević, P., Dobrodolac, M., Marković, D., & Mladenović, S. (2015). The measurement of public postal operators' profit efficiency by using data envelopment analysis (DEA): A case study of European Union member states and Serbia. *Inzinerine Ekonomika-Engineering Economics*, *26*(2), 159–168. https://doi.org/10.5755/j01.ee.26.2.3360

Schuster, P. B. (2013). One for all and all for one: Privatization and universal service provision in the postal sector. *Applied Economics*, *45*(26), 3667–3682. https://doi.org/10.1080/00036846.2012.727982

Solow, R. M. (1957). Technical change and the aggregate production function. *The Review of Economics and Statistics*, *39*(3), 312–320. https://doi.org/10.2307/1926047

Tochkov, K. (2015). The efficiency of postal services in the age of market liberalization and the internet: Evidence from Central and Eastern Europe. *Utilities Policy*, *36*, 35–42. https://doi.org/10.1016/j.jup.2015.09.004

Tone, K. (2001). A slacks-based measure of efficiency in data envelopment analysis. *European Journal of Operational Research*, *130*(3), 498–509. https://doi.org/10.1016/S0377-2217(99)00407-5

Tone, K. (2002). A slacks-based measure of super-efficiency in data envelopment analysis. *European Journal of Operational Research*, *143*(1), 32–41. https://doi.org/10.1016/S0377-2217(01)00324-1

Tone, K., & Tsutsui, M. (2009). Network DEA: A slacks-based measure approach. *European Journal of Operational Research*, *197*(1), 243–252. https://doi.org/10.1016/j.ejor.2008.05.027

Törnqvist, L. (1936). The bank of Finland's consumption price index. *Bank of Finland Monthly Bulletin*, *16*(10), 1–8. https://helda.helsinki.fi/bof/bitstream/handle/123456789/10834/Bofbul_1936-10.pdf?sequence=1

Universal Postal Union. (2019). http://pls.upu.int/pls/ap/ssp_report.main?p_language=AN&p_choice=BROWSE

USPS. (2019). *Funding the universal service obligation – RARC Report* (Report Number RARC-WP-16-005). United States Postal Services, Office of Inspector General. https://www.uspsoig.gov/sites/default/files/document-library-files/2016/RARC-WP-16-005.pdf

WIK. (2012). *Summary of postal privatization in Europe & key lessons*. http://www.wik.org/uploads/media/PLV_2012_04_06_Rutgers_Washington.pdf

Zhu, J. (1996). Data envelopment analysis with preference structure. *Journal of the Operational Research Society*, *47*(1), 136–150. https://doi.org/10.1057/jors.1996.12

Zhu, J. (2003). *Quantitative models for performance evaluation and benchmarking: Data envelopment analysis with spreadsheets and DEA excel solver*. Kluwer Academic Publishers. https://doi.org/10.1007/978-1-4757-4246-6

APPENDIX

Table A1. Sample (source: International Trade Statistics 2019)

Designated operator (DO)	Country	International label
Österreichische Post AG	Austria	AUS
Bulgarian Posts	Bulgaria	BGR
Hrvatska Pošta	Croatia	CRO
Cyprus Post	Cyprus	CYP
Česká pošta	Czech Republic	CZE
Post Denmark	Denmark	DNK
Eesti Post	Estonia	EST
Itella Posti Oy	Finland	FIN
La poste	France	FRA
Deutsche Post	Germany	DEU
Royal Mail Group plc	Great Britain	GBR
Hellenic Post ELTA	Greece	GRC
Magyar Posta	Hungary	HUN
An Post	Ireland	IRL
Poste Italiane	Italy	ITA
Latvijas Pasts	Latvia	LVA
Lietuvos paštas	Lithuania	LTU
P & T Luxembourg	Luxembourg	LUX
Malta Post	Malta	MLT
PostNL	Netherlands	NLD
Poczta Polska	Poland	POL
CTT – Correios	Portugal	PRT
Posta Romana	Romania	ROU
Slovenská pošta	Slovakia	SVK
Pošta Slovenije d.o.o	Slovenia	SVN
Correos y Telégrafos	Spain	ESP
Posten Sweden Post	Sweden	SWE
Swiss Post	Switzerland	SUI
JP "Pošta Srbije"	Serbia	SRB

Table A2. Input variables data (source: Universal Postal Union 2019)

Country	Inputs (2003)			Inputs (2017)		
	x_1	x_2	x_3 (Millions of euros)	x_1	x_2	x_3 (Millions of euros)
AUS	28,845	2,007	1558.93	19,191	1,802	1838.04
BGR	14,878	3,021	38.43	10,293	2,980	82.90
CRO	11,931	1,168	183.69	9,825	1,016	197.65
CYP	1,752	1,123	21.06	650	1,097	23.23
CZE	40,730	3,430	454.82	30,315	3,385	732.10
DNK	27,682	1,019	1209.10	8,605	1,112	877.09
EST	4,237	549	42.70	2,121	315	92.21
FIN	23,740	1,346	1091.41	16,201	873	1680.89
FRA	285,802	16,992	15413.68	226,672	17,100	22974.81
DEU	383,173	13,514	38326.27	472,208	12,502	58530.17
GBR	191,843	15,868	12123.60	141,000	11,650	10672.59
GRC	11,402	2,218	449.98	6,146	1,352	341.04
HUN	40,848	3,102	527.29	30,564	2,682	590.36
IRL	10,498	1,658	753.60	8,684	1,135	771.52
ITA	150,746	13,728	7317.37	128,049	12,822	8465.15
LVA	7,316	964	33.98	3,882	1,019	56.57
LTU	8,030	965	41.06	5,328	570	69.71
LUX	1,782	108	111.13	1,360	103	152.56
MLT	665	50	12.99	665	68	22.52
NLD	62,070	2,577	3101.58	59,280	1,670	3249.58
POL	100,760	8,304	1196.54	79,341	7,490	1421.42
PRT	15,273	3,537	591.59	12,163	2,366	663.63
ROU	35,436	6,840	133.30	24,725	5,746	237.21
SVK	17,252	1,617	155.28	13,677	1,577	311.89
SVN	6,094	554	163.78	5,688	494	212.97
ESP	59,822	3,343	1625.10	56,326	14,521	1312.96
SWE	46,589	1,720	2714.63	19,617	1,847	2268.44
SUI	54,543	2,722	4194.49	59,369	2,157	6272.37
SRB	19,104	1,671	150.32	14,055	1,530	184.97

Table A3. Output variables data (source: Universal Postal Union 2019)

Country	Outputs (2003)			Outputs (2017)		
	y_1	y_2	y_3 (Millions of euros)	y_1	y_2	y_3 (Millions of euros)
AUS	873,129,000	43,673,405	1605.58	5,520,000,000	97,000,000	2040.66
BGR	81,539,469	887,062	39.50	20,784,383	273,930	73.59
CRO	277,406,070	1,900,453	181.60	286,937,319	1,016,253	218.97
CYP	51,800,000	61	28.77	41,655,615	670	27.17
CZE	2,723,299,149	2,025,305	481.88	1,936,418,412	1,118,367	734.50
DNK	1,153,300,000	30,447,000	1418.05	305,000,000	47,200,000	782.68
EST	38,513,980	1,370,020	44.75	13,200,000	3,407,553	92.72
FIN	820,000,000	22,100,000	1165.27	703,000,000	40,100,000	1653.53
FRA	17,201,000,000	254,000,000	15554.98	10,603,000,000	318,000,000	2.981.41
DEU	20,840,000,000	1,531,000,000	41307.59	18,457,000,000	1,323,000,000	62249.22
GBR	20,749,000,000	109,500,000	12224.14	14,400,000,000	1,200,000,000	11454.06
GRC	527,922,600	2,105,647	470.99	22,079,636	1,555,934	341.67
HUN	1,149,701,323	8,992,722	540.11	596,898,000	20,460,000	604.67
IRL	635,400,000	7,168,000	710.62	477,592,000	3,400,000	776.37
ITA	6,343,522,000	22,977,000	7755.94	2,524,283,870	1,473,475	9240.63
LVA	46,456,755	101,907	35.79	25,201,667	66,149	59.39
LTU	40,927,280	117,750	43.45	38,433,214	140,999	71.82
LUX	106,700,000	4,300	124.35	94,321,787	2,056,265	158.50
MLT	43,000,000	214	16.96	29,417,161	287	25.99
NLD	5,384,000,000	40,000,000	3923.32	2,213,000,000	183,000,000	3501.23
POL	2,463,777,833	20,343,320	1235.08	1,664,022,545	20,806,739	1411.27
PRT	979,500,500	7,810,158	644.92	627,190,000	219,000	710.47
ROU	253,834,289	5,074,091	131.06	264,768,493	6,186,609	243.41
SVK	320,746,623	5,035,864	158.87	429,680,676	3,437,112	316.84
SVN	673,559,703	150,521	173.68	836,301,829	8,404,381	220.02
ESP	5,248,430,509	20,512,171	1769.58	2,000,000,000	22,919,828	1551.68
SWE	4,360,000,000	44,900,000	2711.76	1,637,000,000	97,700,000	2320.19
SUI	2,917,000,000	114,000,000	4418.36	2,001,900,000	122,000,000	6809.49
SRB	128,228,619	1,156,033	138.32	279,274,056	921,257	208.43