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Evaluating the comparative efficiency of the postal services in OECD countries using context-dependent and measure-specific data envelopment analysis

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Abstract

Purpose – In an effort to help policy makers develop competitive postal service strategies, the purpose of this paper is to evaluate the comparative operating efficiencies of postal services across the Organization for Economic Cooperation and Development (OECD) nations and then identify room for service improvement.

Design/methodology/approach – As a better alternative to the conventional data envelopment analysis (DEA) which requires the proportional improvements of inputs and outputs simultaneously, the authors propose the combined use of both context-dependent and measure-specific DEAs to measure the relative attractiveness and progress of the national postal operators of OECD countries.

Findings – Defying the conventional notion that public enterprises operate less efficiently than private enterprises, the author discovered that some state-owned public enterprises such as postal service operators could still be efficient if managed properly. Even inefficient postal services operators could significantly improve their service performances, once they identified the root causes of their service failures. Through a series of model experiments and testing, the authors found that proposed context-dependent and measure-specific DEA models were more useful for finding such causes than the conventional DEA model.

Practical implications – For public officials and policy makers, the proposed DEAs can pinpoint what it takes to become more efficient and what steps need to be taken to improve postal service operations gradually.

Originality/value – This paper is the first to combine the context-dependent DEA with measure-specific DEA to evaluate the comparative efficiency (or progress) and inefficiency (or regress) of the national postal operators of 25 OECD countries.

Keywords Performance measurement, Data envelopment analysis

Paper type Research paper

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1. Introduction

The notion that "public enterprises operate less efficiently than private enterprises" has long been defended by many politicians, administrators and economists as a way to

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persuade policy makers to privatize public or state-owned enterprises in many industrialized countries (Sueyoshi and Aoki, 2001). However, the opponents of privatization argue that public ownership still can sustain efficiency through well-planned competitive strategy. In fact, some researchers contend that a key factor affecting efficiency is the degree of competition, not the state ownership (Mizutani and Uranishi, 2003). After witnessing the recent financial struggle and budget shortfalls of postal services across the most of Organization for Economic Cooperation and Development (OECD) countries, the postal sector became the center of this debate. For example, in fiscal year of 2009, the US Postal Services (USPS) faced a decline of mail volume of 30 billion pieces, creating a budget deficit of more than $8 billion (Shein, 2011). In 2011, USPS lost money at a rate of approximately $3 billion per quarter (Orr, 2011). One of the culprits for the decline in postal services is the advancement in information and communication technologies including e-mails and text messages. Another to blame includes the increased competition from private companies such as United Parcel Services, FedEx and DHL which often duplicate the government run postal services. The question still remains why the public companies or state-owned enterprises cannot compete against private companies. Answering this fundamental question is especially important given that the 192 members of Universal Postal Union (UPU) are public entities.

To reverse this slide in postal services, the postal sector should reassess its current service offerings, operations and strategies and then find ways to utilize their resources more efficiently. This reassessment comes with unusual challenges of dealing with the complexity involved in multiple service offerings (e.g. mail delivery/pickup, parcel delivery, tracking, packaging, passport issuance/renewal, copying/printing, financial services) and multiple operating units (e.g. main post office, branch post office, contract postal unit, bulk-mail center, business mail entry unit, destination delivery unit, detached mail unit, processing and distribution center, priority mail processing center).

To cope with these challenges, we propose data envelopment analysis (DEA). The rationale being that DEA was designed to measure the operational efficiency of decision-making units (DMUs) utilizing multiple incommensurable inputs and outputs (Min *et al.*, 2009). In particular, DEA introduced by Charnes *et al.* (1978) did not require any priori assumption about production functions, whereas parametric efficiency measurement tools including statistical regression require such assumption and necessitate the conversion of multiple output measures into a single output measure (Zhu, 2000). To elaborate, DEA is generally referred to as a linear programming (non-parametric) technique that converts multiple incommensurable inputs and outputs of each DMU into a scalar measure of operational efficiency, relative to its competing DMUs. Herein, DMUs refer to the collection of private firms, non-profit organizations, departments, administrative units and groups with the same (or similar) goals, functions, standards and market segments. DEA is designed to identify the best-practice DMU without a priori knowledge of which inputs and outputs are most important in determining an efficiency measure (i.e. score) and assess the extent of inefficiency for all other DMUs that are not regarded as the best-practice DMUs (e.g. Charnes *et al.*, 1978). Since DEA provides a relative measure, it will only differentiate the least efficient DMU from the set of all DMUs. In other words, DEA splits the DMUs under evaluation into two groups, namely, efficient (with the score of "1") and inefficient (with the scores between 0 and 1). The efficient DMUs may continue to have a perfect efficiency score of 1, even if the performance of inefficient DMUs deteriorates or improves. However, the performance evaluation is often

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influenced by the context (or operational condition). For instance, the same DMU's performance will appear more attractive as compared to less attractive alternatives, whereas it will appear less attractive as compared to more attractive alternatives (Morita *et al.*, 2005). As such, this DEA framework can lead to unfair DEA evaluations.

To overcome the aforementioned shortcomings of the traditional DEA, Seiford and Zhu (1999) developed a context-dependent DEA technique where the set of DMUs is partitioned into several levels of efficient frontiers. Each efficient frontier provides an evaluation context for measuring the relative attractiveness, while the second-level efficient frontier is used as the evaluation context for measuring the relative attractiveness of the DMUs located on the first-level (original) efficient frontier (Chen *et al.*, 2005). Put simply, the context-dependent DEA allows us to improve the DMU performance gradually through the step-wise, successive improvement toward the efficient frontier. Also, notice that the traditional DEA assumes that both inputs and output are discretionary and thus the concurrent improvements of all inputs and outputs are possible. However, this assumption becomes invalid when all inputs or outputs cannot be improved in the same proportion because some of them are non-discretionary. To overcome this drawback of the traditional DEA, a measure-specific DEA was introduced by several scholars such as Banker and Morey (1986), Thanassoulis and Dyson (1992) and Zhu (2000) which assigns target values to only the specific subsets of inputs and outputs under consideration.

Considering the merits of both context-dependent and measure-specific DEAs, this paper is one of the first to combine the context-dependent and measure-specific DEAs and utilizes a hybrid DEA model to evaluate the relative efficiency or progress of the national postal operators of 25 OECD countries.

2. Relevant literature

Although there has been much study in the telecommunications sector, there has not been much research regarding postal services. Some studies regarding telecommunications sector are outlined below.

Yang *et al.* (2013), employed meta-frontier methodology, which can reflect differences in production functions, for the comparative efficiency analysis of 85 enterprises, 30 of which are from USA, 37 from European Union (EU) and 18 from Asia. In the study, net sales is considered as the output variable, and total assets, number of employees and capital expenditure (CAPEX) as the input variables. The results indicate that the USA has the highest meta-frontier efficiency in contrast to previous research findings.

Nigam *et al.* (2012) used DEA to measure comparative efficiencies of 126 mobile telecom companies operating in India. The input variables which were selected based on the literature research are expenditure in crores, call success rate (per 100), call drop rate (per 100) and voice quality while the output variables are service access delay (in seconds), complaints per 1,000 billion, number of subscribers and gross revenue in crores. As a result of the analysis, the older and established private utilities perform superior to their younger counterparts.

Giokas and Pentzaropoulos (2008), used combined AHP/DEA method to measure efficiency of OECD member states as regards telecommunications sector. In the study, number of access lines and total staff in telecom are treated as input variables and number of internet hosts, total number of subscribers and total telecom revenue are treated as output variables. According to the DEA results, 19 member countries

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evaluated as inefficient countries. Nine countries of this group are considered as the most problematic, being positioned far away from the overall efficiency frontier.

Tsai *et al.* (2006), reconciles diverse efficiency measures to characterize the productivity efficiency of 39 Forbes 2,000 ranked leading global telecom operators via DEA analysis.In the DEA application, they treated number of employee, CAPEX and total assets as inputs and revenue, EBITDA margin and operating profit as outputs. Empirical results show that about 20.5 percent of Forbes 2,000 telecom operators are operating on the best-practice frontier for CCR efficiency measure, while only 7.7 percent match the efficiency achievement measure criteria. This study also shows that Asia-Pacific telecom operators have better productivity efficiency than those in Europe and America but the differences are not significant.

The other studies in similar area with postal sector can be found in literature. Two of them are cited as an example below.

Lin and Liu (2010) applied integrated DEA and Activity-Based Costing methods to 14 Taiwanese open-market shipping companies for measuring costs and efficiency performance. This paper chooses operating expenses, fixed assets and receivable turnover in days as inputs of DEA while fixed assets turnovers ratio, assets turnovers ratio and returns on equity are utilized as outputs of DEA. The results of this paper show that a better performance management, including service planning and design, quality management and control, process design and improvement and work force management could achieve cost reduction and improvement of efficiency.

Reeves *et al.* (2006), run DEA to measure the efficiency of a consumer freight package delivery involving 15 DMUs. Model inputs include number of delivery and administrative employees, labor hours, operating costs and number of deliver vehicles. Outputs include number of packages delivered, percent on-time, percent lost, percent damaged, revenue per package and customer satisfaction. According to the DEA results, 11 of the 15 DMUs are classified as efficient.

Though the studies evaluating the efficiency of the postal sector are relatively scarce, there have been some pioneering attempts to gauge the operational efficiency and the progress or regress of state-owned postal services throughout the world. These attempts include.

Doble (1995) measured the efficiency of 1,281 post office counters of the UK in the year 1989 using DEA. In this study, the amount of work carried out by counter clerks, measured in hours was assigned as the input variables. As the output variable, the 190 different types of transactions conducted by counters were divided into nine categories and measured in basic transaction hours. Consequently, only 177 counters (13.82 percent) were considered to be technical efficient.

Unlike the earlier work of Doble (1995) which focussed on a single period measure, Sueyoshi and Aoki (2001) evaluated the efficiency shift of 12 Regional Administrative Agencies of Postal Services in Japan from 1983 to 1997 using the Window Malmquist Analysis which combines the DEA window analysis with the Malmquist index approach. The efficiency of each DMU is measured by two inputs and three outputs. The two inputs are the number of post offices and the number of employees. The three outputs are the number of mails; the total amount of postal savings; and the total amount of postal life insurance. One of the most intriguing results of this study is that larger postal establishments tended to be more efficient than the smaller ones.

Nikali (2002) measured an annual average productivity growth for the Finnish postal operator in the period 1980-2000, of nearly 1 percent by utilizing a constant

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elasticity of substitution function. In addition, the technical development increased by an average of 7 percent per annum. In this study, the number of postal items was taken as the output variable, while both labor (changes in the wage bill) and capital (cumulative sum of annual investments less depreciation) were regarded as the input variables.

Mizutani and Uranishi (2003) checked to see whether the competition factor affects cost reduction and total factor productivity (TFP) growth in the parcel delivery market in Japan for the period of 1972 through 1998. In this study, they selected the post office, the government-owned operator, and five private carriers of Japan as DMUs. In their DEA model, the sum of labor, material and capital costs comprised the total costs where the total number of freight items transported including letters, cards, parcels and other business goods were considered output measures. They found that competition indeed contributed to cost reduction and TFP growth in the case of private companies but not in the case of the state-owned post office.

Borenstein *et al.* (2004) explored the efficiency levels of 113 postal stores of the Brazilian Postal and Telegraph Company (ECT) for the year 2000 by using DEA. The DEA application is carried out with seven inputs and ten outputs. Consequently, 50 stores were found to be efficient and the average efficiency levels of the DMUs turned out to be 87.1 percent.

Flippini and Zola (2005) estimated a Cobb-Douglas cost frontier function for a sample of 47 small local post offices operating in the Italian-speaking part of Switzerland in 2001. Their results showed that approximately 50 percent of the postal offices included in the sample operated close to the regional standard for efficiency, achieving scores of 12 percent or lower, in terms of cost difference.

Iturralde and Quiros (2008) investigated the TFP change of 17 EU countries postal operators by using the Malmquist TFP Index between the years 1999 and 2003. In their model, three input and three output variables were used. The input variables are work force as the number of full-time workers, the capital as the value of amortization allowance and the intermediate consumption as subtracting labor costs and depreciation from the total operating costs. The output variables are the volume of letters and parcels processed by postal operators and area. The area is measured as the number of square kilometers of the country belonging to each operator who provides a postal distribution service. The findings indicate the possibility of 9 percent average reduction in inputs given the level of output.

As this literature reveals, all but Iturralde and Quiros (2008) dealt with the domestic postal service sector of a particular country which was confined to country-specific issues. Also, all of these studies used more conventional DEAs or the Cobb-Douglas function which still could result in misleading performance evaluations. To go beyond these earlier studies, this paper adopted newer DEA techniques and considered postal sectors covering multiple countries across the multiple continents (i.e. Europe, Asia, North-America and South-America).

3. Research methodology

As noted earlier, the conventional DEA suffers from some theoretical flaws despite its popularity. As a better alternative, we propose the context-dependent DEA to measure the relative attractiveness and progress of the national postal operators of OECD countries. In addition, we propose the measure-specific DEA models to calculate the level of potential improvement-specific inputs and/or outputs associated with inefficient DMUs. The detailed rationale for using the hybrid, context-dependent and measure-specific DEA models are provided below.

3.1 Context-dependent DEA

In the conventional DEA, the performances of the inefficient DMUs are assessed with respect to the best-practice frontier which is determined by efficient DMUs. However, one cannot determine which efficient DMU acts as a better referent for inefficient DMUs since each of them takes a score of "1." Although the super-efficiency DEA models can be used for ranking the efficient DMUs, the evaluation context changes from one evaluation to another and the efficient DMUs are not evaluated against the same reference set (Morita *et al.*, 2005). By utilizing the context-dependent DEA, the relative attractiveness is measured when DMUs with the worse performance are chosen as the evaluation context, and the relative progress is measured when DMUs with the better performance are chosen as the evaluation context (Seiford and Zhu, 2003). The context-dependent DEA is outlined as below (Chen *et al.*, 2005).

Let us assume that we have n DMUs yielding s outputs by utilizing m inputs. Let $J^1 = \{\mathrm{DMU}_j, j=1, \ldots, n\}$ be the set of all DMUs. The sequences of J^l and E^l are defined iteratively as $J^{l+1} = J^l - E^l$ where $E^l = \{\mathrm{DMU}_o \in J^l | \theta \times (l,o) = 1\}$ and $\theta \times (l,o)$ is the optimal value of the following linear programming model:

$$
\begin{aligned}
\theta^*(l,o) = \max_{\lambda_j, \theta(l,o)} \theta(l,o) & \\
\text{s.t.} \quad \sum_{j \in F(J^l)} \lambda_j y_{rj} \geqslant \theta y_{ro} & \quad r = 1, \ldots, s \\
\sum_{j \in F(J^l)} \lambda_j x_{ij} \leqslant x_{io} & \quad i = 1, \ldots, m \\
\lambda_j \geqslant 0 & \quad j \in F\left(J^l\right)
\end{aligned} \tag{1}
$$

where x_{io} and y_{ro} represents the ith input and rth output of DMU_o, respectively, and $j \in F(J^l)$ means $\mathrm{DMU}_j \in J^l$, i.e. $F(.)$ represents the correspondence from a DMU set to the corresponding subscript index set.

When $l=1$, model (1) turns out to be the original output-oriented constant returns to scale (CRS) DEA model and E^1 consists of the first-level efficient DMUs. We obtain the second-level efficient frontier for $l=2$ after the exclusion of the first-level efficient DMUs. In this way, we can identify several sub-efficient frontiers. Then, we refer to E^l the lth-level efficient frontier. The algorithm that characterizes these efficient frontiers by using Model (1) can be summarized as follows:

- Step 1: evaluate the efficiency of the entire DMU set J^1 via model (1) by setting $l=1$ and obtain the first-level efficient frontier, E^1.
- Step 2: exclude the preceding efficient DMUs from the entire DMU set for future DEA runs. $J^{l+1} = J^l - E^l$ (If $J^{l+1} = \phi$, then stop).
- Step 3: evaluate the efficiency of the new subset of J^{l+1} via model (1) to determine the new set of efficient DMUs, E^{l+1}.
- Step 4: let $l = l+1$.Go to Step 2.
- Stopping rule: $J^{l+1} = \phi$, the algorithm stops.

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In addition, one can attain the same stratification by conducting the input-oriented form of model (1).

3.1.1 Attractiveness and progress scores. Based upon these evaluation contexts $E^l(l=1,\ldots,L)$, the relative attractiveness measure of DMUs can be acquired by using the following context-dependent DEA (Cook and Zhu, 2005):

$$\begin{aligned} &\Omega_q^*(d) = \max \Omega_q(d) \quad d = 1, \ \ldots \ , L - l_0 \\ &\sum_{j \in F(E^{l_0+d})} \lambda_j y_{rj} \geqslant \Omega_q(d) y_q \\ &\sum_{j \in F(E^{l_0+d})} \lambda_j x_{ij} \leqslant x_q \\ &\lambda_j \geqslant 0 \quad j \in F\left(E^{l_0+d}\right) \end{aligned} \tag{2}$$

where $\text{DMU}_q = (X_q, Y_q)$ is from a specific level E^{l_0}, $l_0 \in \{l=1,\ldots,L-1\}$.

Definition 1. $A_q^*(d) \equiv 1/\Omega_q^*(d)$ is defined as (output-oriented) d-degree attractiveness of DMU_q from a specific level E^{l_0}. The larger the value of $A_q^*(d)$ the more attractive the DMU_q is.

In model (2), each efficient frontier of E^{l_0+d} represents an evaluation context for measuring the relative attractiveness of DMUs in E^{l_0}. That is, degree 1 attractiveness scores denotes the scores of Level 1 DMUs where the evaluation context is Level 2 DMUs. By using their attractiveness scores we can rank the DMUs to determine the best one(s).

By solving the following linear programming model, one can calculate the progress score of a specific $\text{DMU}_q \in E^{l_0}, l_o \in \{2, \ \ldots \ , L\}$:

$$\begin{aligned} &P_q^*(g) = \max_{\lambda_j, P_q(g)} P_q(g) \quad g = 1, \ \ldots \ , l_o - 1 \\ &\sum_{j \in F(E^{l_0-g})} \lambda_j y_{rj} \geqslant P_q(g) y_q \\ &\sum_{j \in F(E^{l_0-g})} \lambda_j x_{ij} \leqslant x_q \\ &\lambda_j \geqslant 0 \quad j \in F\left(E^{l_0-g}\right) \end{aligned} \tag{3}$$

Definiton 2. The optimal value of $P_q^*(g)$ is defined as the output-oriented g-degree progress DMU_q from a specific level E^{l_0} (Ulucan and Atıcı, 2010).

For a larger value of $P_q^*(g)$ more progress is required for DMU_q. Each efficient frontier, E^{l_0-g}, provides a possible target for a specific DMU in E^{l_0} to improve its performance.

3.2 Measure-specific DEA models

In the conventional DEA framework, proportional improvements of inputs and outputs are required simultaneously for inefficient DMUs to achieve the target values to

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become efficient. In some instances, it may be difficult for a DMU to achieve its targets concurrently or managers may have a priority framework over the improvements of different inputs (outputs) when assessing inefficient DMUs (Zhu, 2002). In such cases, the measure-specific DEA ~~models~~ that takes into account-specific inputs and outputs is more suitable for measuring operational efficiencies of DMUs than the conventional DEA.

Let $I \subseteq \{1,2, \ldots ,m\}$ and $O \subseteq \{1,2, \ldots ,s\}$ denote particular inputs and outputs of interest, respectively. A set of measure-specific models can be obtained based on the envelopment DEA models where only the inputs related to I or output associated with O are optimized (Cook and Zhu, 2005). The aforementioned measure-specific models are shown in Table I (Zhu, 2002).

Note that, both the envelopment and the measure-specific DEA models give the same efficient production frontier.

4. Model applications and experiments

To validate the usefulness and practicality of the proposed DEA models, we applied them to evaluate the operational efficiencies (progress) or inefficiency (regress) of the postal service operations of OECD countries. To further verify the robustness of the proposed DEA models, the models were experimented with the actual secondary data. The detailed experimental results are described below.

4.1 Sample and variables

The first stage in a DEA application is to form the DMU set to be evaluated. We aimed to include all OECD countries as the evaluation basis in our study, but the limited availability of data has forced us to reduce the sample from 34 to 25 countries. The data

Frontier type	Input oriented	Output oriented
CRS	$\min\theta-\varepsilon\left(\sum_{i=1}^{m}s_i^-+\sum_{r=1}^{s}s_r^+\right)$ st. $\sum_{j=1}^{n}\lambda_j x_{ij}+s_i^- = \theta x_{io} \quad i \in \mathrm{I}$ $\sum_{j=1}^{n}\lambda_j x_{ij}+s_i^- = x_{io} \quad i \notin \mathrm{I}$ $\sum_{j=1}^{n}\lambda_j y_{rj}+s_r^+ = y_{ro} \quad r = 1,2,\ldots,s$ $\lambda_j \geqslant 0 \quad j = 1,2,\ldots,n$	$\max\theta-\varepsilon\left(\sum_{i=1}^{m}s_i^-+\sum_{r=1}^{s}s_r^+\right)$ st. $\sum_{j=1}^{n}\lambda_j x_{ij}+s_i^- = x_{io} \quad i = 1,2,\ldots,m$ $\sum_{j=1}^{n}\lambda_j y_{rj}-s_r^+ = \theta y_{ro} \quad r \in O$ $\sum_{j=1}^{n}\lambda_j y_{rj}-s_r^+ = y_{ro} \quad r \notin O$ $\lambda_j \geqslant 0 \quad j = 1,2,\ldots,n$
VRS	Add $\sum_{j=1}^{n}\lambda_j = 1$	
NIRS	Add $\sum_{j=1}^{n}\lambda_j \leqslant 1$	
NDRS	Add $\sum_{j=1}^{n}\lambda_j \geqslant 1$	

Table I.
Measure-specific models

used in the study is obtained from the web site of UPU (www.upu.int). The sample is exhibited in Table II.

As summarized in Table II, 20 out of 25 DMUs in the evaluation set are public entities, while Chile, Denmark and Poland's operators have independent boards. On the other hand, the Deutsche Post (Germany) is a partial public company of which 56 percent of shares are held by the state. Similarly, 90 percent of the share capital of ELTA (Greece), a limited liability company, is owned by the state.

Since there is no standard procedure, the DEA technique is highly sensitive to the selection of input and output set. Inclusion or exclusion of an important variable from the model could dramatically alter the results when performing DEA. Although a modern postal operator provides various types of services including delivery of postal items such as letters, parcels, periodicals (newspapers, magazines, etc.), financial services (money orders, postal savings, etc.) and postal life insurance, we focussed on the delivery of letters and parcels in this study in line with the prior literature. Accordingly, we determined the number of letters and parcels as two output variables in our DEA model. In addition, we utilized the area factor, measured as the number of square kilometers of the country belonging to each operator, as the third output (non-discretionary) variable. This variable is considered a proxy of the geographical distribution capacity of the network of each postal operator (Iturralde and Quiros, 2008). The two input variables used in the model are the number of full-time staff and the number of permanent post offices, given the labor-intensive nature of postal service operations. Since it contains multiple operating units as mentioned above, the number of permanent post offices is treated as a non-discretionary variable.

Universal postal operator	Country	Status
Australia Post	Australia	Public
Empresa de Correos de Chile	Chile	Public (autonomous)
Česká pošta	Czech Republic	Public
Post Denmark	Denmark	Public (autonomous)
Eesti Post	Estonia	Public
Itella Corporation	Finland	Public
Deutsche Post	Germany	Public (56%)
ELTA	Greece	Public (90%)
Magyar Posta	Hungary	Public
Israel Postal Company Ltd	Israel	Public
Poste Italiane	Italy	Public
Japan Post Service Co Ltd	Japan	Public
Korea Post	Korea	Public
Posts and Telecoms Corporation	Luxembourg	Public
Correos de México	Mexico	Public
Norway Post	Norway	Public
Polish Post	Poland	Public (autonomous)
CTT – Correios	Portugal	Public
Slovenská pošta	Slovak Republic	Public
Pošta Slovenije	Slovenia	Public
Posten Sverige	Sweden	Public
Swiss Post	Switzerland	Public
Directorate-General of PTT	Turkey	Public
Royal Mail Group	UK	Public
US Postal Service (USPS)	USA	Public

Table II.
Illustrative samples

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The descriptive statistics of the relevant variables for the year 2010 are demonstrated in Table III.

4.2 The standard output-oriented CRS-DEA model

The first step of our application is to run output-oriented CRS-DEA model for the 25 postal operators to obtain original DEA frontiers. The overall efficiency scores calculated and reference set for benchmarking are exhibited in Table IV.

The result summarized in Table IV showed that only three universal postal operators (i.e. Australia, Japan and USA) turned out to be most efficient under the CRS

Table III. Descriptive statistics of data set

Variable	Mean	SD	Maximum	Minimum
Inputs				
No. of full-time staff	71,511	138,504	583,908	1,062
No. of post offices	6,653	8,959	30,771	1,016
Outputs				
No. of letters (in millions)	103.65	10,365.32	160,728	35.75
No. of parcels (in millions)	233.13	677.82	3,318	0.42
Area (1,000 km^2)	974.52	2,371	9,629	2.586

Table IV. CRS-efficiency scores for the sample

Sl. no.	DMUs	Overall efficiency	Reference set	Peer count
1	Australia	1.000	Australia	12
2	Chile	0.851	Australia	0
3	Czech Republic	0.362	Japan, USA	0
4	Denmark	0.459	Japan, USA	0
5	Estonia	0.074	Australia, Japan, USA	0
6	Finland	0.396	Australia, Japan, USA	0
7	Germany	0.593	Japan, USA	0
8	Greece	0.191	Australia, USA	0
9	Hungary	0.113	Australia, USA	0
10	Israel	0.464	USA	0
11	Italy	0.146	USA	0
12	Japan	1.000	Japan	15
13	Korea	0.508	Japan, USA	0
14	Luxembourg	0.580	Japan, USA	0
15	Mexico	0.309	Australia	0
16	Norway	0.575	Australia, Japan, USA	0
17	Poland	0.048	Australia, Japan, USA	0
18	Portugal	0.299	Australia, USA	0
19	Slovak Rep.	0.197	Australia, Japan, USA	0
20	Slovenia	0.587	Japan, USA	0
21	Sweden	0.491	Australia, Japan, USA	0
22	Switzerland	0.691	Japan, USA	0
23	Turkey	0.163	Australia, Japan, USA	0
24	UK	0.639	Japan, USA	0
25	USA	1.000	USA	20
	Mean	0.469		

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assumption. USA proved to be a benchmark target with highest peer count of 20 for inefficient DMUS. USA is followed by Japan and Australia. Potential improvement rates for the five lowest inefficient scored DMUs are shown in Table V.

As shown in Table V, Poland should increase the volume of letter and parcel delivery by 1,985.46 percent to become an efficient DMU. In real life, it is almost impossible for Poland to increase the volume of letter and parcel by the required level in the short term. By the same token, the other four inefficient DMUs face similar conditions like Poland.

4.3 Context-dependent DEA model

In the case of unrealistic improvement targets the inefficient DMUs facing above, the context-dependent DEA is more relevant to obtain more achievable targets for inefficient DMUs in the short run. For this purpose, we ran models (2) and (3) to calculate the relative attractiveness and progress scores, respectively. First, by running model (1) for $l = 1$, we obtained the first-level efficient frontier that is identical to the original CRS-DEA frontier calculated above. By repeating this process, we attained six efficiency levels as shown in Table VI.

Our results indicated that the postal services of Estonia (5) and Turkey (23) that were rated as the highest inefficient DMUs with respect to the original CRS efficient frontier are now third-level efficient DMUs and they serve as an evaluation context for the efficient DMUs in level 4, 5 and 6.

4.3.1 Attractiveness and progress scores. Having obtained the efficiency levels, the next step of context-dependent DEA is the computation of attractiveness and progress scores of DMUs. For this purpose, by running model (2) and model (3), respectively, we have obtained relative attractiveness scores and progress scores for the DMUs for each degree. Results are shown in Table VII.

DMUs	Eff. scores	Staff	Letter	Parcel
Poland	0.048	0	1,985.46	1,985.46
Estonia	0.074	0	1,255.95	1,255.95
Hungary	0.113	0	783.58	1,486.59
Italy	0.146	0	584.64	4,067.63
Turkey	0.163	0	514.35	514.35

Table V. Potential improvement rates (%) for inefficient postal operators

	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
DMUs	1,12,25	2,7,13,16,22, 24	4,5,15,20,21,23	3,6,14	8,10,19	9,11,17,18
CCR-score range	1	0.508-0.851	0.074-0.587	0.362-0.580	0.191-0.464	0.048-0.299

Table VI. Efficiency levels

DMUs	Degree 1	Degree 2	Degree 3	Degree 4	Degree 5
Australia	3.025	11.111	20.121	28.130	52.690
Japan	7.861	19.250	25.830	69.260	137.900
USA	2.383	3.070	3.933	8.754	18.710

Table VII. Attractiveness scores for the first-level efficient DMUs

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Herein, degree 1 means the DMUs in E^1 are being evaluated with respect to the second efficient frontier represented by E^2. The other four degree scores are to be interpreted in the same way. If the DMUs in E^3 are chosen as the evaluation context, we obtain the second degree attractiveness scores for the first-level DMUs. As can be seen from the table easily, Japan is the most attractive one (best performer) among the first-level DMUs since it has the highest attractiveness scores for all degrees. Relying on the attractiveness scores, we can rank the first-level DMUs as Japan > Australia > USA.

In Table VIII, Korea is the second best attractive DMU with score of 2.519 according to degree 1 attractiveness scores (where the evaluation context is Level 3 DMUs). However, when we investigate degrees 3 and 4 attractiveness scores (where the evaluation context is Level 4 and 5 DMUs, respectively) Korea is the fourth best-performer DMU. Here, we can conclude that when the evaluation context alters, the ranking of DMUs may alter.

The attractiveness scores of the remaining DMUs of the other five levels are shown in Tables IX-XI.

Wenow take a look at to the progress scores for the sixth-level DMUs exhibited in Table XII.

As mentioned earlier, due to the expected improvement level for an inefficient DMU, smaller progress scores are desired. Degree 1 scores refer to the scores obtained when the fifth-level efficient frontier is considered as the evaluation context while degree 5

Table VIII. Attractiveness scores for the second-level efficient DMUs

DMUs	Degree 1	Degree 2	Degree 3	Degree 4
Chile	6.567	9.462	17.711	38.760
Germany	1.296	2.251	19.046	23.980
Korea	2.519	3.283	14.837	18.656
Norway	1.676	2.014	7.977	10.352
Switzerland	2.259	2.866	16.390	20.618
UK	2.323	2.942	12.195	15.290

Table IX. Attractiveness scores for the third-level efficient DMUs

DMUs	Degree 1	Degree 2	Degree 3
Denmark	1.754	14.925	27.100
Estonia	1.272	1.965	2.703
Mexico	6.211	8.264	13.193
Slovenia	1.349	4.504	4.608
Sweden	1.821	4.425	6.579
Turkey	1.669	3.706	5.305

Table X. Attractiveness scores for the fourth-level efficient DMUs

DMUs	Degree 1	Degree 2
Czech Rep.	3.067	5.208
Finland	9.009	10.649
Luxembourg	2.586	5.714

scores refer to the scores attained when the first-level efficient frontier is considered as the evaluation context.

According to the analysis results, Italy should fulfill greater improvement than the other three DMUs to catch the fifth-level efficient frontier. At this point, it is obvious that degree 1 progress of Italy is a lower value (2.054), where for degree 5 which is more difficult for this DMU to obtain has a higher progress score of 6.846. Poland has the largest improvement potential when the first level (degree 5) is taken as the evaluation context. This result is to be expected since Poland has the worst performance (the most inefficient DMU) according to the original CRS model.

The progress scores of the DMUs of the remaining five levels are shown in Tables XIII-XVI.

4.3.2 Measure-specific performance of the postal operators. Measure-specific models enable decision-makers to further characterize the performance of inefficient DMUs by taking into account a particular input or output. By doing so, one can specify the maximum potential decrease of an input (input surplus) and increase of an output (output shortfalls), while other inputs and outputs remain at the current levels

DMUs	Degree 1
Greece	2.399
Israel	3.125
Slovak Rep.	2.300

Table XI. Attractiveness scores for the fifth-level DMUs

DMUs	Degree 1	Degree 2	Degree 3	Degree 4	Degree 5
Hungary	1.824	3.074	4.642	5.432	8.836
Italy	2.054	3.058	3.812	4.191	6.846
Poland	1.077	3.896	4.566	13.540	20.855
Portugal	1.092	1.220	1.812	2.057	3.348

Table XII. Progress scores for the sixth-level DMUs

DMUs	Degree 1	Degree 2	Degree 3	Degree 4
Greece	1.152	1.992	2.845	5.242
Israel	1.086	1.231	1.302	2.156
Slovak Republic	1.875	2.728	2.991	5.077

Table XIII. Progress scores for the fifth-level DMUs

DMUs	Degree 1	Degree 2	Degree 3
Czech Republic	1.181	1.723	2.763
Finland	0.637	1.837	2.524
Luxembourg	1.007	1.060	1.724

Table XIV. Progress scores for the fourth-level DMUs

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(Zhu, 2000). Table XVII exhibits the efficiency scores obtained by running input and output-oriented CRS measure-specific models.

In our measure-specific model, we treated the number of post offices and area variables as non-discretionary factors and leave them out of the assessment. Only three

Table XV.
Progress scores for the third-level DMUs

DMUs	Degree 1	Degree 2
Denmark	1.202	2.180
Estonia	4.500	13.560
Mexico	1.370	3.237
Slovenia	1.044	1.704
Sweden	1.146	2.038
Turkey	2.813	6.143

Table XVI.
Progress scores for the second-level DMUs

DMUs	Degree 1
Chile	1.175
Germany	1.685
Korea	1.967
Norway	1.738
Switzerland	1.447
UK	1.564

Table XVII.
Measure-specific efficiency scores

Sl. no.	DMU	Staff	Letter	Parcel
1	Australia	1	1	1
2	Chile	0.851	0.851	0.851
3	Czech Republic	0.185	0.078	0.356
4	Denmark	0.459	0.361	0.246
5	Estonia	0.027	0.067	0.073
6	Finland	0.396	0.334	0.278
7	Germany	0.593	0.471	0.363
8	Greece	0.097	0.048	0.191
9	Hungary	0.069	0.023	0.126
10	Israel	0.182	0.035	0.464
11	Italy	0.077	0.012	0.146
12	Japan	1	1	1
13	Korea	0.506	0.368	0.490
14	Luxembourg	0.285	0.071	0.579
15	Mexico	0.040	0.309	0.309
16	Norway	0.488	0.331	0.568
17	Poland	0.047	0.036	0.047
18	Portugal	0.071	0.023	0.299
19	Slovak Republic	0.078	0.036	0.195
20	Slovenia	0.385	0.134	0.583
21	Sweden	0.347	0.189	0.490
22	Switzerland	0.691	0.502	0.625
23	Turkey	0.137	0.117	0.162
24	UK	0.504	0.317	0.627
25	USA	1	1	1

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DMUs, Australia, Japan and USA proved to be efficient as expected since they were found efficient in classical DEA model. These efficiency scores illustrate the maximum potential decrease of a particular input and an increase of a specific output, while keeping other inputs and outputs at current levels.

By calculating the measure-specific scores, we obtained target values for the inefficient DMUs to achieve to become efficient. Based on target values, one can easily calculate the required percentage change for each input/output of inefficient DMUs.

As shown in Table XVIII, Chile will become efficient in terms of staffing, if the number of the full-time staff is decreased by 52.97 percent. Similarly, if Chile seeks to become efficient in terms of letter delivery services, it should increase the delivery of letter by 129.73 percent. Besides, to become efficient in terms of parcel delivery services, Chile should increase the delivery of parcel by 909.47 percent, which is nearly impossible to achieve in the near future. That is to say, Chile will continue to have a difficulty in achieving efficient parcel delivery services. Similarly, almost half of the DMUs are in a similar situation to Chile in terms of parcel delivery efficiency. Likewise, there are several unachievable targets for inefficient DMUs in the letter-specific DEA model, but the improvement potentials are greater for inefficient DMUs with regards to staffing efficiency. As is seen from the table, the DMUs that are already efficient have 0 percentage change.

5. Conclusions and future research directions

In the wake of world-wide financial crisis and the subsequent chronic budget shortfall, this paper aimed to measure the performances of the universal postal operators of

No.	DMU	Staff	Letter	Parcel
1	Australia	0	0	0
2	Chile	−52.97	129.73	909.47
3	Czech Rep.	−63.80	11.62	7.62
4	Denmark	−83.30	0	0
5	Estonia	−92.62	1219.60	862.22
6	Finland	−83.80	28.25	0
7	Germany	−81.90	0	0
8	Greece	−80.92	230.68	1,264.72
9	Hungary	−88.70	239.45	1,323.33
10	Israel	−53.62	5.14	251.46
11	Italy	−85.40	190.16	4,067.63
12	Japan	0	0	0
13	Korea	−49.20	0	0
14	Luxembourg	−42	0	53.18
15	Mexico	−69.1	363.39	7,165.86
16	Norway	−42.46	0	0
17	Poland	−95.2	753.58	697.80
18	Portugal	−70.13	164.08	3,677.25
19	Slovak Rep.	−80.30	194.95	176.62
20	Slovenia	−41.32	0	7.27
21	Sweden	−50.90	0	79.17
22	Switzerland	−0.364	0	0
23	Turkey	−83.70	311.51	375.63
24	UK	−36.10	0	0
25	USA	0	0	0

Table XVIII. Potential improvement rates (%) for DMUs

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OECD countries by using newer DEA techniques. For comparative purposes, we initially performed conventional output-oriented CCR-DEA analyze. According to the initial results, only three postal operators were considered efficient. Besides, the average overall efficiency of the postal services under evaluation yielded a considerably low DEA score. To see if we can better gauge gradual improvement potentials, we conducted the context-dependent DEA analyses. We determined six efficient levels (frontier) the first of which is identical to the result obtained from the conventional DEA. Afterwards, we calculated the relative attractiveness scores for the efficient postal operators with respect to the sub-efficient frontiers as well as progress scores for inefficient postal operators with respect to upper-efficient frontiers to overcome unrealistic targets. Application of the context-dependent DEA model enabled inefficient DMUs became efficient at lower levels and acted as a referent DMU for the remaining DMUs at lower efficient frontiers. Besides, via calculation of attractiveness scores we ranked the DMUs at each level which is very practical for benchmarking purposes of managers.

In addition, unlike the conventional DEA, the efficient frontiers obtained via context-dependent DEA are changed by either excluding or including inefficient DMUs. This property makes the context-dependent DEA more flexible than the conventional DEA. In the next stage, we performed input and output-oriented measure-specific models to overcome another shortcoming of conventional DEA. After experimenting with the measure-specific models, we found that it is almost impossible to attain the letter and parcel delivery efficiency due to overwhelming performance gaps. This result may be a reflection of the huge differences in the volume of delivered letters and parcels between efficient and inefficient postal operators. Since it is not always possible to make progress in every input and output simultaneously we attained target values for each input or output via measure-specific DEA models.

To sum up, the main contributions of this study are:

(1) This study is one of the first, illustrating the viability of context-dependent and measure-specific DEA techniques in measuring the efficiency of the postal service sector.

(2) The experiments with both context-dependent and measure-specific DEA indicate that these techniques enabled us to rank efficient DMUs and then determine achievable short- and long-term targets for inefficient DMUs. From a managerial standpoint, this capability of the proposed DEAs helps policy makers what it takes to become more efficient and what steps need to be taken to improve postal service operations gradually. In particular, the target values obtained from the measure-specific DEA can pinpoint which inputs or outputs should be prioritized for further improvements. Given limited budgets, such information will greatly help the policy makers decide how those budgets should be properly allocated and better utilized without waste.

Despite aforementioned merits, this study has some limitations that mainly stem from the limited availability of data. If more data were available in the future, this paper can be extended to include multiple time periods and other nations which did not belong to OECD. Also, the proposed DEA models can be modified to perform cross-efficiency evaluations in the context-dependent DEA, while considering a slack-based context-dependent DEA. Furthermore, to further verify the robustness of the models, a series of sensitivity analyses can be conducted after altering some input and output parameters.

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