Ratio-Based Efficiency Analysis for the Efficiency Evaluation of Healthcare Spending

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1 Introduction

An important problem in policy analysis is the question how efficiently a country spends its public resources. At this time when many countries have growing pressures on public balances, it is crucial that these resources be used as efficiently as possible. Even small changes in the efficiency of public spending can have a significant impact on GDP and on the attainment of the government’s objectives (Pang and Herrera 2005).

From a methodological point of view, a wide variety of approaches have been employed to study the efficiency of the use of public resources. On the one hand, there are parametric approaches such as, for example, panel data regression analysis that assume a production function that directly relates inputs to outputs (Baltagi 2005). On the other hand, there are non-parametric approaches such as data envelopment analysis (DEA; Charnes et al. 1978) that have achieved increasing popularity in recent times.

The popularity of the non-parametric approaches such as DEA stem from their empirical orientation and the absence of a need for the numerous assumptions that accompany other approaches. Requiring very few assumptions, DEA has also opened up possibilities for use in cases that are not amenable to other approaches due to complex or unknown nature of the relations between the multiple inputs and outputs involved in decision making units (DMUs). In recent years, DEA has been applied to the analysis of the efficiency of a diverse selection of performance entities such as, for example, hospitals, universities, cities, US Air Force, business firms, countries, and regions. (Cooper et al. 2011)

DEA approaches (e.g. CCR-DEA by Charnes et al. 1978; BCC-DEA by Banker et al. 1984) typically consider efficiency ratios in evaluating the efficiencies of DMUs. The efficiency score of a DMU is computed relative to an efficient frontier which is characterized by the most efficient DMUs. The efficient DMUs have an efficiency score of one by definition, whilst for inefficient DMUs the efficiency score will be between zero and one, depending on where the DMU lies relative to the efficient frontier.

However, there can be some problems associated with the application of DEA methods in certain types of efficiency analyses. One of these concerns arises when an outlier DMU is included in the DEA analysis. As the efficiency scores of DMUs are computed relative to an efficient frontier, the efficiency scores are sensitive to the selection of DMUs included in the analysis. Therefore, the inclusion of an exceptionally efficient DMU, for example, may shift the efficient frontier considerably and, hence, significantly change the efficiency scores of DMUs. (Salo and Punkka 2011)

Ratio-based efficiency analysis (REA; Salo and Punkka 2011) is a recent advance in the methods empirically measuring the productive efficiencies of
DMUs. It focuses on pairwise comparisons among the efficiency ratios of individual DMUs, thereby making the potential presence of outliers less disruptive and weakening some of the assumptions underlying traditional DEA approaches.

This study illustrates the utility of REA for the analysis of the efficiency of public spending, and specifically, the study of the efficiency in the use of healthcare resources. I begin with a brief review of the conventional DEA, highlighting some of the limitations associated with these approaches. I then outline the REA method. I conclude with an illustration of the practical usage of REA in the context of a reported DEA study which deals with the efficient use of healthcare resources across OECD countries.

2 Principles of DEA

2.1 Basic Methodology

Assume that there are \( K \) DMUs that consume \( M \) number of inputs and produce \( N \) number of outputs. Specifically, the \( k \)th decision making unit (DMU\(_k\)) consumes an amount of \( x_{mk} \geq 0 \) of the \( m \)th input and produces an amount of \( y_{nk} \geq 0 \) of the \( n \)th output. For DMU\(_k\) the input consumption and output production vectors are \( \mathbf{x}_k = [x_{1k}, \ldots, x_{Mk}] \) and \( \mathbf{y}_k = [y_{1k}, \ldots, y_{Nk}] \), respectively, and at least one positive input and one positive output value are assumed. (Charnes et al. 1978; Salo and Punkka 2011)

In the traditional DEA methodologies, the efficiency of a decision making unit is typically defined as the ratio of a weighted sum of outputs to a weighted sum of inputs. The inputs and outputs are weighted by nonnegative weights \( \mathbf{v} = [v_1, \ldots, v_M]^T \) and \( \mathbf{u} = [u_1, \ldots, u_N]^T \), respectively, which provide information about the relative values of inputs and outputs. These weights can be assumed to satisfy certain linear constraints. If, for instance, one unit of output 1 is known to be at least as valuable as two units of output 2 but not more valuable than four units of output 2, then a constraint \( 2u_2 \leq u_1 \leq 4u_2 \) is acquired. In the literature, there exist numerous methods for eliciting this sort of preference information from a decision maker (see e.g. Salo and Hämäläinen 1992, 2001). By collecting all preference information, it is possible to define the feasible regions (Podinovski 2001, 2005; Salo and Punkka 2011)

\[
S_v = \{ \mathbf{v} = [v_1 \ldots v_M]^T \neq 0 \mid v \geq 0, A_v \mathbf{v} \leq 0 \}, \tag{2.1}
\]

\[
S_u = \{ \mathbf{u} = [u_1 \ldots u_N]^T \neq 0 \mid u \geq 0, A_u \mathbf{u} \leq 0 \}, \tag{2.2}
\]

where \( A_v \) and \( A_u \) are coefficient matrices derived from decision maker’s preference statements.

Under the assumptions above, the efficiency ratio of DMU\(_k\) can be defined
where the numerator and denominator are called the virtual output and virtual input of DMU \(\kappa\), respectively. Without further assumptions, the efficiency ratio \(E_k\) can be unbounded. By making a common assumption of strictly positive virtual inputs and outputs and by rescaling the input and output weights such that
\[
E_k(u, v) = \frac{\sum_n u_n y_{nk}}{\sum_m v_m x_{mk}} \leq 1 \quad \text{for } k = 1, \ldots, K, \tag{2.4}
\]
the efficiency ratio of each DMU is strictly larger than zero and less than or equal to unity.

In the traditional CCR-DEA, efficiency scores for each DMU are computed relative to an efficient frontier. The efficient frontier is characterized by DMUs with highest efficiency ratios for some feasible input and output weights. To compute an efficiency score for a DMU, such input and output weights must be searched for that maximize the efficiency ratio of that DMU. An efficient DMU will have a score of one by definition. An inefficient DMU will have a score of less than one, and this efficiency score serves as a measure of how close a DMU lies to the efficient frontier when its inputs and outputs are most favorable to this DMU. (Cooper et al. 2011; Salo and Punkka 2011)

### 2.2 Limitations of the Traditional DEA

The literature has recognized some limitations associated with the use of the conventional DEA (e.g. Dyson et al. 2001). Specifically, Salo and Punkka (2011) discuss three kinds of concerns with DEA that the REA approach is able to deal with by focusing on pairwise comparisons between individual DMUs. I will next briefly discuss these concerns proposed by Salo and Punkka (2011) before moving on to introduce REA in Section 3.

First, in the traditional DEA, the efficiency score of a DMU is computed using input and output weights that are most favorable to this DMU. Accordingly, the efficiency scores of DMUs do not convey information about the efficiencies for other feasible input and output weights. This analysis is somewhat limited in that other feasible weights reflect relevant preference information as well.

Second, the conventional efficiency scores may be sensitive to which DMUs are included in the analysis. Assume, for instance, that an exceptionally efficient DMU is introduced into the analysis. The introduction of this DMU may shift the efficient frontier significantly and, accordingly, possibly cause a major change in the efficiency scores of the other DMUs (e.g. Seiford and Zhu 1998a,b; Zhu 1996).

Third, the computation of conventional efficiency scores calls for returns-to-scale assumptions which may be difficult to justify. In CCR-DEA, developed by Charnes et al. (1978), returns to scale are assumed constant. In constrast, in the
more recently developed versions of DEA, returns-to-scale may not be constant and, in general, they may be either increasing (IRS), constant (CRS), or decreasing (DRS) (Banker et al. 1984). Graphically, the different returns-to-scale assumptions are reflected in the shape of the efficient frontier. In an example of one output and one input, the three different returns-to-scale possibilities may be illustrated as in Figure 2.1.

### 3 Ratio-Based Efficiency Analysis

Ratio-based efficiency analysis proposed by Salo and Punkka (2011) addresses the limitations of the traditional DEA presented in Section 2.2 by focusing on pairwise comparisons between the efficiency ratios among DMUs. Focusing on such pairwise comparisons is beneficial for a number of reasons. First, pairwise comparisons account for all feasible input and output weights compared to only weights that are the most favourable to a DMU. Second, pairwise comparisons are less sensitive to outlier DMUs. Third, pairwise comparisons do not call for assumptions about returns-to-scale beyond the DMUs that are included in the analysis (Galagedera and Silvapulle 2003; Dyson et al. 2001). (Salo and Punkka 2011)

REA evaluates the efficiencies of DMUs using three ratio-based efficiency measures – ranking intervals, dominance relations, and efficiency bounds – as discussed below based on the study of Salo and Punkka (2011).
3.1 Ranking Intervals

For each DMU, an efficiency ratio can be calculated using each feasible input and output weight. Accordingly, the DMUs can be also ranked by their efficiency ratios in each point of the feasible region.

The ranking interval of a DMU is defined by its best and worst rankings among DMUs over all feasible input and output weights. One major benefit from assessing ranking intervals is robustness: When a single DMU is introduced or removed from the analysis, the bounds of ranking-intervals can change by one at most. Another major benefit is that by assessing ranking intervals, no feasible input or output weight is ignored.

To mathematically formulate the definition of a ranking interval, the following two sets are defined:

\[
\begin{align*}
R_k^> (u, v) &= \{ l \in \{1, \ldots, K\} \mid E_l(u, v) > E_k(u, v) \}, \\
R_k^\geq (u, v) &= \{ l \in \{1, \ldots, K\} \setminus \{k\} \mid E_l(u, v) \geq E_k(u, v) \}.
\end{align*}
\]

The sets \(R_k^>\) and \(R_k^\geq\) contain the indices of the DMUs that have strictly higher (the set \(R_k^>\)) or at least as high (the set \(R_k^\geq\)) an efficiency ratio as DMU \(k\). Under these definitions, the ranking interval for DMU \(k\) can be defined as \([r_{k, \text{min}}, r_{k, \text{max}}]\), where \(r_{k, \text{min}}\) and \(r_{k, \text{max}}\) are defined as

\[
\begin{align*}
r_{k, \text{min}} &= \min_{u \in S_u, v \in S_v} (1 + |R_k^>(u, v)|), \\
r_{k, \text{max}} &= \max_{u \in S_u, v \in S_v} (1 + |R_k^(\geq)(u, v)|),
\end{align*}
\]

where \(|\cdot|\) denotes the cardinality of a set, i.e. the number of elements of a set.

3.2 Dominance Relations

The concept of efficiency dominance builds on the concepts used by the domain of preference programming (e.g. Salo and Hämäläinen 1992, 2001). Within REA, DMU \(k\) is called to dominate DMU \(l\), i.e. DMU \(k \succ DMU_l\), if and only if the following two conditions hold:

\[
\begin{align*}
E_k(u, v) &\geq E_l(u, v) \text{ for all } (u, v) \in (S_u, S_v), \\
E_k(u, v) &> E_l(u, v) \text{ for some } (u, v) \in (S_u, S_v).
\end{align*}
\]

Accordingly, DMU \(k\) dominates DMU \(l\) if the efficiency ratio of DMU \(k\) is larger than or equal to the efficiency ratio of DMU \(l\) for all feasible input and output weights and strictly larger for some weights.

The possible presence of a dominance relation can be checked by considering what values the pairwise efficiency ratio defined by

\[
D_{k,l}(u, v) = \frac{E_k(u, v)}{E_l(u, v)}
\]

7
can take. Clearly, if the pairwise efficiency ratio is larger than or equal to one for all feasible $u$ and $v$ and strictly larger than zero for some $u$ and $v$, then DMU$_k$ dominates DMU$_l$.

The maximum and minimum values of the pairwise efficiency ratio are denoted with symbols $\overline{D}_{k,l}$ and $\overline{D}_{k,l}$, respectively. The values of $\overline{D}_{k,l}$ and $\overline{D}_{k,l}$ provide information on how efficient DMU$_k$ can be relative to DMU$_l$ across all feasible input and output weights. If, for instance, $\overline{D}_{k,l}$ equals 1.23, then the efficiency ratio of DMU$_k$ can be at most 23% larger than the efficiency ratio of DMU$_l$ across all feasible weights. Conversely, if $\overline{D}_{k,l}$ equals, for example, 0.95, then the efficiency ratio of DMU$_k$ is not lower than 5% than the efficiency ratio of DMU$_l$ across all feasible weights.

### 3.3 Efficiency Bounds

The concept of dominance can be applied to the pairwise comparisons between the efficiency ratios of two individual DMUs. However, in order to compare the efficiency ratio of a DMU to the efficiency ratios of a group of DMUs, hereafter referred to as DMU$_L$ = \{DMU$_l$ | $l \in L \subseteq \{1, \ldots, K\}\}$, the analysis presented in Section 3.2 needs to be expanded.

The ratios defined by equations

$$ D_{k,L}(u,v) = \frac{E_k(u,v)}{\max_{l \in L} E_l(u,v)} = \min_{l \in L} \frac{E_k(u,v)}{E_l(u,v)}, \quad (3.8) $$

$$ D_{k,L}(u,v) = \frac{E_k(u,v)}{\min_{l \in L} E_l(u,v)} = \max_{l \in L} \frac{E_k(u,v)}{E_l(u,v)} \quad (3.9) $$

indicate how efficient DMU$_k$ is relative to DMU$_L$ for different values of input and output weights. Specifically, equation (3.8) indicates how efficient DMU$_k$ is relative to the most efficient DMUs in DMU$_L$, whereas equation (3.9) indicates how efficient DMU$_k$ is relative to the least efficient DMUs in DMU$_L$. Similarly as with dominance relation, the minimum and maximum values of (3.8) and (3.9) over feasible input and output weights are denoted with symbols $\overline{D}_{k,L}$, $\overline{D}_{k,L}$, and $\overline{D}_{k,L}$. If the set $L$ contains all DMUs, then the maximum value of $\overline{D}_{k,L}$ is 1, and it, moreover, equals DMU$_k$’s CCR-DEA efficiency score.

### 4 Efficiency of Healthcare Spending in OECD Countries

I next illustrate the use of REA for the analysis of the efficiency of healthcare spending by revisiting the study of Joumard et al. (2008).
4.1 Background

Joumard et al. (2008) examine how healthcare spending and other determinants contribute to the health status of the population, and whether or not healthcare resources produce similar value for monetary expenses across OECD countries. To analyze countries’ relative efficiencies in utilizing healthcare resources, Joumard et al. (2008) conduct analyses using two different methods: Panel data regression analysis and DEA. It is worth noting that DEA has been widely utilized in healthcare efficiency analysis also in numerous other studies (see Hollingsworth 2003).

Joumard et al. (2008) mainly focus on output-oriented DEA\(^1\), because it is conceptually closer to the production function approach they use in their panel data regression analyses. They also assume that returns-to-scale decrease beyond a certain level in the production of health.

To keep the number of inputs and outputs sufficiently low relative to the size of the sample, Joumard et al. (2008) restrict the number of outputs to one and inputs to three. They do not elicit preference information about the relative values of the input or output weights.

Joumard et al. (2008) use life expectancy at birth of the total population as the output variable. The inputs represent the three main dimensions of health outcome production and, accordingly, they include a health resources variable, a proxy of socioeconomic environment, and a lifestyle (diet) variable in their inputs. Since the DEA and REA methods assess how efficient the countries are in turning the three inputs into the one output, the analyses do not explicitly measure countries’ efficiencies in turning just health resources into life expectancy.

Joumard et al. (2008) measure health resources by healthcare spending per capita, expressed in 2000 US dollars adjusted for purchasing power. As a proxy of socioeconomic environment, they use the PISA index of economic, social, and cultural status (ECSC) which is derived from subindices based on the highest occupational status of a student’s parent, the highest education of parents, and an index based on educational resources at home and the number of books at home. The yearly per capita consumption of fruits and vegetables (in kgs) is used as the lifestyle variable.

In their DEA analyses, Joumard et al. (2008) use data from 30 OECD countries from year 2004, or from the latest year available. In the REA analyses of this study, the same dataset was employed. The data along with the corresponding country rankings is presented in Table 4.1. The first three columns in the table – under the headings healthcare spending per capita, ESCS, and consumption of fruits and vegetables – contain input data, and the last column – under the heading life expectancy at birth – contains output data.

\(^1\)Output-oriented DEA seeks to maximize the levels of outputs given the levels of the inputs, whereas input-oriented DEA aims at minimizing the levels of inputs given the levels of outputs. The results of CCR-DEA are independent of the selection of this orientation. (Cooper et al. 2011)
4.2 Results

The DEA results of Joumard et al. (2008) are presented in Figure 4.1. In addition to the conventional DEA efficiency scores, the results also contain bias-corrected estimates and confidence intervals that are computed using bootstrapping (see e.g. Simar and Wilson 1998).

Based on the DEA results presented in Figure 4.1, Joumard et al. (2008) suggest that population health status, measured by life expectancy at birth, could be significantly raised in all examined countries, whilst, however, the variations in the efficiencies of individual countries are quite large. According to the results, life expectancy at birth could be raised by 2–8 percentage points in each country.

The results of the REA analyses were calculated using REA-Solver software (Guerfi 2009) using the data presented in Table 4.1. The REA-Solver software allowed for the estimation of each country’s best and worst efficiency rankings, dominance relations, and CCR-DEA efficiency bounds. The numerical results from the REA analyses are summarized in Table 4.2.

Dominance relations are shown in Figure 4.2, where country $X$ dominates $Y$ if and only if there is a directed path from $X$ to $Y$. In Figure 4.2, the abbreviated names of the countries were used as specified in Table 4.2.

According to the results, there are four non-dominated countries: Japan, Mexico, Poland, and Slovak Republic. Among these, Mexico dominates more

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Figure 4.1. DEA Efficiency Scores of the Original Study. (Joumard et al. 2008, p. 37)

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2 Joumard et al. (2008) provide DEA results also for a few other alternative model specifications, but the focus in this study is on the specification presented in Section 4.1.
Table 4.1. Explanatory Variables, Outcome Variable, and Country Rankings.\textsuperscript{a}

<table>
<thead>
<tr>
<th>Country</th>
<th>Healthcare Spending per Capita\textsuperscript{b}</th>
<th>ESCS\textsuperscript{c}</th>
<th>Consumption of Fruits and Vegetables\textsuperscript{d}</th>
<th>Life Expectancy at birth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>2844.96</td>
<td>10</td>
<td>13.23</td>
<td>197.3</td>
</tr>
<tr>
<td>Austria</td>
<td>3048.31</td>
<td>6</td>
<td>12.60</td>
<td>227.6</td>
</tr>
<tr>
<td>Belgium</td>
<td>2854.80</td>
<td>9</td>
<td>12.94</td>
<td>199.5</td>
</tr>
<tr>
<td>Canada</td>
<td>2934.86</td>
<td>8</td>
<td>14.08</td>
<td>239.5</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>1223.54</td>
<td>24</td>
<td>12.99</td>
<td>151.4</td>
</tr>
<tr>
<td>Denmark</td>
<td>2729.68</td>
<td>12</td>
<td>13.13</td>
<td>248.7</td>
</tr>
<tr>
<td>Finland</td>
<td>2055.62</td>
<td>20</td>
<td>13.30</td>
<td>162.6</td>
</tr>
<tr>
<td>France</td>
<td>2960.88</td>
<td>7</td>
<td>12.08</td>
<td>238.4</td>
</tr>
<tr>
<td>Germany</td>
<td>2760.03</td>
<td>11</td>
<td>12.98</td>
<td>203.7</td>
</tr>
<tr>
<td>Greece</td>
<td>2373.46</td>
<td>16</td>
<td>11.81</td>
<td>422.7</td>
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<tr>
<td>Hungary</td>
<td>1196.57</td>
<td>25</td>
<td>12.12</td>
<td>188.1</td>
</tr>
<tr>
<td>Iceland</td>
<td>3189.69</td>
<td>5</td>
<td>14.97</td>
<td>162.3</td>
</tr>
<tr>
<td>Ireland</td>
<td>2474.73</td>
<td>15</td>
<td>12.06</td>
<td>219.7</td>
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<tr>
<td>Italy</td>
<td>2298.12</td>
<td>17</td>
<td>11.95</td>
<td>309.3</td>
</tr>
<tr>
<td>Japan</td>
<td>2140.11</td>
<td>19</td>
<td>12.09</td>
<td>159.4</td>
</tr>
<tr>
<td>Korea</td>
<td>1051.97</td>
<td>26</td>
<td>12.00</td>
<td>275.1</td>
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<tr>
<td>Luxembourg</td>
<td>4529.64</td>
<td>2</td>
<td>13.07</td>
<td>227.5</td>
</tr>
<tr>
<td>Mexico</td>
<td>593.02</td>
<td>29</td>
<td>8.12</td>
<td>178.7</td>
</tr>
<tr>
<td>Netherlands</td>
<td>2670.77</td>
<td>13</td>
<td>12.74</td>
<td>255.5</td>
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<tr>
<td>New Zealand</td>
<td>1983.43</td>
<td>21</td>
<td>13.18</td>
<td>244.6</td>
</tr>
<tr>
<td>Norway</td>
<td>3752.10</td>
<td>3</td>
<td>14.66</td>
<td>190.7</td>
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<tr>
<td>Poland</td>
<td>746.16</td>
<td>28</td>
<td>11.62</td>
<td>147.9</td>
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<tr>
<td>Portugal</td>
<td>1804.56</td>
<td>23</td>
<td>10.00</td>
<td>297.2</td>
</tr>
<tr>
<td>Slovak Republic</td>
<td>929.81</td>
<td>27</td>
<td>12.06</td>
<td>129.7</td>
</tr>
<tr>
<td>Spain</td>
<td>1817.23</td>
<td>22</td>
<td>11.25</td>
<td>256.0</td>
</tr>
<tr>
<td>Sweden</td>
<td>2662.82</td>
<td>14</td>
<td>13.33</td>
<td>193.6</td>
</tr>
<tr>
<td>Switzerland</td>
<td>3540.11</td>
<td>4</td>
<td>12.15</td>
<td>201.1</td>
</tr>
<tr>
<td>Turkey</td>
<td>575.59</td>
<td>30</td>
<td>8.68</td>
<td>338.1</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>2246.17</td>
<td>18</td>
<td>12.84</td>
<td>207.4</td>
</tr>
<tr>
<td>United States</td>
<td>5516.00</td>
<td>1</td>
<td>13.49</td>
<td>237.0</td>
</tr>
<tr>
<td>Average</td>
<td>2384.83</td>
<td>12.38</td>
<td>223.7</td>
<td>78.4</td>
</tr>
</tbody>
</table>

\textsuperscript{a} 2004 or latest year available. Country ranking expressed on the right side of the variable value.
\textsuperscript{b} Expressed in 2000 US dollars and PPP
\textsuperscript{c} PISA index of economic, social, and cultural status
\textsuperscript{d} Yearly average consumption per capita in kgs

Source: OECD
Figure 4.2. Efficiency Dominance Relations Among the Countries.
Figure 4.3. Best and Worst Efficiency Rankings for the Countries.

countries (23) than Japan, Poland, and Slovak Republic, which dominate 19, 17, and 14 countries, respectively. Considering the dominance relations, the United States is the worst performer as it is dominated by more countries (17) than any other country. The other least efficient countries in this respect are Canada, Denmark, and Luxembourg which are dominated by 13, 13, and 12 countries, respectively.

Compared to the original DEA results presented in Figure 4.1, the dominance relations provide some interesting new insights. First, all the non-dominated countries are among the 12 most efficient countries on the basis of the bias-corrected efficiency scores of the original DEA results, but none of them belongs to the seven top performers which are Spain, Korea, Portugal, Switzerland, Australia, Sweden, and Iceland. Second, although the United States, Luxembourg, and Denmark seem to be relatively inefficient countries also considering the original DEA results, Canada is relatively efficient. Third, Hungary which appears to be the least efficient country according to the original DEA results is dominated only by Mexico, Poland, and Slovak Republic.

In the computation of efficiency bounds, the REA-Solver© software includes all DMUs into the benchmark set $L$ by default, and, accordingly, the efficiency bounds $\bar{D}_{k,L}$ equal the CCR-DEA efficiency scores as discussed in Section 3.3. Therefore, these bounds provide few further insights into the uncorrected estimates presented in Figure 4.1, because the results are essentially DEA results of same sort that have been only computed using a somewhat different assumptions regarding returns-to-scale.

The ranking intervals presented in Figure 4.3 complement the efficiency
bound results. For instance, the CCR-DEA-efficient country Mexico is among the seven most efficient countries for all feasible input and output weights, whereas Slovak Republic is also CCR-DEA-efficient, but its ranking drops to 16 for some weights, indicating that its efficiency is sensitive to what input and output weights are selected.

Similar to the dominance relations results, Canada, Denmark, Luxembourg, and the United States appear to be among the least efficient countries also considering the ranking intervals. Canada, Denmark, and Luxembourg are not, however, ranked worst for any feasible weights, whereas Greece, Iceland, and Norway, in addition the United States, are ranked worst for some feasible input and output weights.

5 Conclusion

This study has considered ratio-based efficiency analysis for the study of public spending efficiency. The recently developed REA approach provides more robust results compared to the conventional DEA approaches by making the potential presence of outliers less disruptive, conveying information about the efficiencies for all feasible input and output weights, and making unnecessary the assumptions about what production possibilities there are beyond those DMUs included in the analysis.

This study has illustrated the practical usage of the REA methodology by revisiting a reported DEA study of the efficient use of healthcare resources. The results of the REA analyses are relatively well in line with the DEA results, but, nevertheless, provide some new insights.

Acknowledgements

I am grateful to Ahti Salo and Yrjänä Hynninen for introducing me to this topic, coaching with the methods, and help with the REA-Solver© software. I also wish to thank Yongjun Li for providing some insightful comments, and Antti Toppila for advising with the graphical presentation of the results. I gratefully acknowledge all support from OECD and, specifically, Raphaëlle Bisiaux and Christophe André.
Table 4.2. REA Results for the Comparison of Healthcare Spending Efficiency between OECD Countries.

<table>
<thead>
<tr>
<th>Country</th>
<th>$r_{\min}$</th>
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a Although the $D_{k,L}$ value of Japan is equal to 1.00 with the precision of two decimals, it does not equal to one, and, accordingly, Japan is not CCR-DEA efficient.
Bibliography


