Assessing the efficiency of monitoring the environment quality – case study on preventing illegal cuttings

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**Abstract**

Implementing the public policies related to environmental issues is a difficult task and implies effort and coordination focused on controlling, checking and double-checking different aspects of the economic activities that might cover illegal actions. Therefore the extent to which the public authorities are using their resources in preventing or penalizing illegal activities in an efficient way is a very difficult task. Basically the article presents how the Data Envelopment Analysis (DEA) can be used in those situations when the number of inputs and outputs exceeds the number of decision-making units (DMU). The procedure consists of splitting the main problem into some sub-problems, combining a part of the inputs and a part of the outputs in a consistent and logical way, depending on the causal relationships between the two types of data (inputs and outputs). Each sub-problem yields a local efficiency index and, multiplying these indices it is possible to compute an overall efficiency, allowing for sensible ranking of DMU. The method was tested on a set of real data produced by the Romanian forest inspectorates (ITRSV) in the first semester of 2007, referring to the actions carried out for preventing illegal cutting.

**Key words**

Data Envelopment Analysis, forest management, benchmarking, and illegal logging

Assessing the effectiveness of the money spent on controlling and monitoring the environmental factors is quite difficult at least for the many distortion brought about by the market failures and the legal framework [25, 2]. In addition to that, most of the inputs and outputs cannot be assessed in monetary terms; therefore any common efficiency indicator cannot be used. All public institutions in charge with supervising, surveying or controlling the extent to which the legal framework is being observed have to make inspections, have to answer to complains coming from different stakeholders (NGOs, associations, municipalities and public authorities) and have to penalize the ones who are not obeying the legal provisions.

In Romania, the nine Territorial Inspectorates of Forest Regime and Hunting (ITRSV) are key institutions meant to supervise and control all activities carried out within the forests and sawmills. Their duties are complex and consist of a large variety of actions focused on the extent to which the harvesting operations obey the legal framework: they check the timber cruising, afforestation works, timber budgeting and so forth. The outcome of this activity is diversified, ranging from submitting fines and penalties, proceeding criminal records to attorneys, and advising managerial contracts between private forest owners and forest districts. Most of these inputs and outputs cannot be expressed in money and the only way to produce some sound hierarchies between these decision-making units (DMU) seems to be the data envelopment analysis (DEA), which is like a Swiss army knife in benchmarking.

The method was proposed more than four decades ago [10] and its theoretical support shall be sought in the concepts of technical and allocative efficiencies, launched and defined by another seminal paper published in 1957 [14]. Nowadays such a long evolution is paying off as suggested in literature [33][16][34]; the domains where this method has been used to differentiate the best performing DMU are more and more diversified: for instance, DEA was used to identify why some bank branches are underperforming [17], [39], in analyzing the effectiveness of the healthcare system [36][38][12], the effectiveness of logistic networks [15], in education [42], [3], in measuring rural and regional development [40, 8], appraising efficiency of the public sector [18] or the airplanes maintenance services [9], and, finally an interesting application ranked the nations according to the Olympic Games results [11].

In forestry, forest management and forest economics the method was introduced in the early nineties [22], [24] and rapidly has extended to analyzing the
efficiency of forest management considering multiple rotations [23], efficiency of forest reform [44], efficiency in wood industry [43][28][1][13][7], effectiveness of forestry extension services [20][4][41], sustainability of park management [5] or pest control [27].

As expected whenever a panacea has been discovered, some limitations and pitfalls have also been debated in literature [37, 19] one of them being the condition referring to the number of decision units, on the one hand, and the total number of inputs and outputs, on the other hand (see condition 6 in the next section). Whenever this condition is not abided by the data describing the problem, the best alternative is multi-criteria analysis.

Multi-criteria analysis, also known as multi-criteria decision methods (MCDM) have also been extensively used in forest management since sixties; their utility in forest management was summarized in literature [6][21][26][12] but, contrasting DEA, MCDM is not a single and accurate model but rather a puzzle of methods that can be combined in different manners; actually only two MCDMs can be considered “fixed recipes”: the Analytic Hierarchy Process (AHP), coined by the Nobel Price laureate Thomas Saaty [31, 32] and ELECTRE (ELimination Et Choix Traduisant la REalité), conceived by the French researcher Bernard Roy, who published the first version by the end of sixties [29, 30].

Summarizing all these pieces of information, any benchmarking process can be carried out in two ways, as suggested in figure 1; whenever the number of DMUs is smaller than the number of inputs and outputs, DEA (described in the next section) will produce irrelevant results, for the reasons explained in the next section, and, consequently, MCDM is recommended. Yet this article describes a procedure to enlarge the scope of DEA in solving benchmarking problems when the inputs and outputs are even much more than the DMUs; in other words how to move the DEA above the 45° frontline that divides the two domains in figure 1. This procedure is presented in the third section while a case study is presented in the forth section. The conclusions are drawn in the final section.

**Short description of DEA**

The method relies on a linear programming approach, where the objective function can be input-oriented, output-oriented, or both. The bottom line of DEA is the efficiency coefficient ($\theta$), which is the ratio between the output and the input, as described by relation (1).

$$\theta = \frac{\text{output}}{\text{input}} = \frac{\sum_{j} t_j r_j}{\sum_{i} \beta_i w_i} \times 100\% \quad (1)$$

where $t_j$ is the relative weight (‘price’) of the $r_j$ output, and $w_i$ is the relative weight of the $\beta_i$ input. The efficiency cannot exceed 100% and this condition is further plugged into the system.

Usually, any optimization problems approached through linear programming is focused on optimizing the quantities, while the prices are given while a DEA problem resembles the dual of a regular optimization problem, aiming at maximizing the efficiency for one DMU, at least. The mathematical model for an output-oriented model is described by the objective function (2), subject to the constraints 3, 4, and 5, where the inequality (2) renders the condition priory stated (it implies that one or maybe some DMUs could reach 100% efficiency), the conditions (4) express the non-negativity conditions common in any linear
programming model and the condition (5) conveys the condition of using up all inputs.

\[ \max_k \sum_k n_k f_k \quad (2) \]

\[ W^T B - RT \geq 0 \quad (3) \]

\[ W \geq \varepsilon; T \geq \varepsilon \quad (4) \]

\[ \sum_k w_{kj} \beta_{kj} = 1 \quad (5) \]

\[ 1 \leq k \leq p, \; 1 \leq i \leq m, \; 1 \leq j \leq n \]

An input-oriented model has a different objective function, with different arguments, that is \[ \min_k \sum_i \beta_{ik} w_{ik} \] all other constraints being the same.

The key problem refers to the number of DMU and the total number of inputs and outputs; if the number of DMU is smaller than the total number of inputs and outputs, more DMU will have 100% efficiency, which is useless from the analytical point of view. This bias occurs because the system of equations conveyed by the condition (3) will be ‘forced’ to have solutions although the system itself is mathematically undetermined (the number of variables exceeds the number of equations); therefore to the initial constraints another one shall be added, which is

\[ k \in m + n \quad (6) \]

where \( k \) stands for the number of decision units, \( m \) is the number of inputs and \( n \) is the number of outputs.

**Overcoming the shortcoming: iterative DEA**

The case study presented in the next section is a benchmark analysis carried on a set of data that do not match the rationale condition described above; nine ITRSV shall be analyzed against a much greater number on inputs and outputs collected from the quarterly reports each ITRSV has to submit to the forestry department. These reports are structured on nine chapters and contain 90 indicators (summarized in table 1) that can be classified into four categories: uncontrolled input (conditions, like the total forest area an ITRSV has to cover), inputs, outputs and unwanted outputs (like illegally harvested wood and )

<table>
<thead>
<tr>
<th>Chapter 1 Forest administration</th>
<th>Total forest area broken down on types of ownership Number of operating licenses canceled due to mal praxis, Infringements, felonies and total value of fines Field surveillances</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chapter 2. Illegal cuttings</td>
<td>Illegal use of marking hammers Felonies for tree cuttings Cut and abandoned trees Non-imputable illegal cuttings Total value of damages produced by illegal cuttings</td>
</tr>
<tr>
<td>Chapter 3 Overgrazing</td>
<td>Felonies and misdemeanors Total value of fines applied for overgrazing Unjustified damages</td>
</tr>
<tr>
<td>Chapter 4 Forest fires</td>
<td>Felonies and misdemeanors for setting fire Total value of fines</td>
</tr>
<tr>
<td>Chapter 5 Forest completeness</td>
<td>Felonies and misdemeanors for illegal use of land within the forests (buildings, access roads) Total fines applied for illegal use of forest land</td>
</tr>
<tr>
<td>Chapter 6. Checking the wood flow</td>
<td>Surveillances, felonies, misdemeanors and fines for transporting timber without having legal forms.</td>
</tr>
<tr>
<td>Chapter 7 Sawmills checking</td>
<td>Surveillances, felonies, misdemeanors and fines for chopping and processing timber without having legal forms.</td>
</tr>
<tr>
<td>Chapter 8 Inspections finalized with internal memos and reports</td>
<td>Total number of inspections carried for different reasons, including complains submitted by different authorities or natural persons</td>
</tr>
<tr>
<td>Chapter 9 Administrative and disciplinary sanctions</td>
<td>Withdrawn and suspended operating licenses and labor contracts, penalties (number and value)</td>
</tr>
</tbody>
</table>

At the first glance, such a great amount of data cannot be processed at once and certainly it should not. The basic idea of dealing with these types of data is to split the whole benchmarking problem into many sub-problems, each sub-problem being solved independently. Each benchmarking sub-problem yields for each DMU a ‘local’ efficiency, noted with \( e_{kj} \). Multiplying all these ‘local’ efficiencies for a given DMU one might have a global efficiency, which finally can be compared with others global efficiencies.
Basically, the final efficiency of the \( k \)th DMU (\( E_k \)) is given by relation (7)

\[
E_k = \prod_{l=1}^{L_k} e_{k,l}\quad (7)
\]

where \( e_{k,l} \) stands for the \( l \)th sub-problem, each chapter of the reporting form mentioned ahead.

This is the theoretical approach. From a practical point of view, whatever benchmarking problem is to be solved with DEA, the most important condition the input data shall abide is the ‘non-zero value clause’ meaning that each DMU shall have positive values for all inputs and outputs; otherwise, the ‘virtual prices’ assigned to any zero-value will be infinite. In order to fit the initial data to this condition, all columns with at least one zero value shall be erased from the very beginning, or all zero values are replaced with very small values; having done this operation, the benchmarking sub-problems can be conceived, separating the uncontrolled inputs (conditions), the inputs, and the unwanted outputs and the outputs. So, there is no rule apart from the rule-of-thumb of not having zero values in the data panel.

**Case study – ITRSV benchmarking**

The input data were collected by the mid of 2007 and refer to all ninety indicators reported by each forest inspectorates. In order to disclaim any tentative to use these results elsewhere, in whatever purpose, the real names of ITRSV were replaced with letter, from A to J. The input data consists of a bunch of 10 inputs, outputs, uncontrolled inputs (conditions), and unwanted outputs. Table 2 presents the input data where a zero value (column 5, line 2) was left on purpose in order to highlight the risk of overlooking some precious information, like the felonies for illegal cuttings, reported by all forest inspectorates in the first semester of 2007, excepting for the ‘B’ ITRSV. The data were processed with Frontier Analyst® software, which has the option to replace all zeros with very small values that make sense for the mathematical model; however when these zeros occur quite often in the input data, the final results will be altered.

Two observations about the options at hand in Frontier Analyst® shall be carefully considered before starting the data processing. The first comment refers to appropriate selection of variables. The columns of the input data matrix shall be divided into inputs (at least one) and outputs (at least one, too). The inputs can be controlled (resources) and uncontrolled (conditions) while the outputs can be wanted (results) or un-wanted (negative side-effects). For our data set, the conditions were the total forest area and the public forest area. In our study, the unwanted outputs are the forest area without administration and the illegal cuttings; these two aspects are strongly correlated, and hardly can be controlled by ITRSV; yet, they are not conditions. The number of controls, inspections and surveillances are inputs in preventing illegal cuttings and the number of felonies, misdemeanors, as well as the total value of penalties applied, are outputs. The total value of damages produced by illegal logging is also an output, being correlated with the effort carried out in the field by ITRSV inspectors.

The second commentary refers to the two options for data processing: constant or decreasing return to scale, and the type of optimization (input oriented, or output oriented). Considering the inspections as input and the penalties – whatever they are – as outputs, it’s clear that double effort won’t produce double output, which means that there’s no constant return to scale, but a decreasing one. As for the second option, one should take into account that any well-planned monitoring aims at minimizing the inputs, not maximizing the outputs, that is the penalties; forest inspectors shall check and double check those areas where illegal cuttings are more likely to occur, and these inspections are meant to discourage all illegal activities, not to penalize people who already had made illegal activities; in other words, forest inspector shall prevent illegal cuttings first, and secondly penalize illegal activities already done. This is the reason why the model shall be set on minimizing the input, not maximizing the output.
A sample of the input data used for ITRSV benchmarking

<table>
<thead>
<tr>
<th></th>
<th>ITRSV</th>
<th>Forest area (ha)</th>
<th>Public forests (ha)</th>
<th>Forests without administration (ha)</th>
<th>Number of felonies for illegal cuttings</th>
<th>Number of misdemeanors for tree cuttings</th>
<th>Total value of damages produced by illegal cuttings</th>
<th>Number of surveillances and inspections</th>
<th>Illegal cuttings (m$^3$)</th>
<th>Confiscated timber (m$^3$)</th>
<th>Number of surveillances in harvested tracts</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1020796</td>
<td>300054</td>
<td>45710</td>
<td>27</td>
<td>1145</td>
<td>1846</td>
<td>3693</td>
<td>44737</td>
<td>7294</td>
<td>3230</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>178731</td>
<td>164554</td>
<td>5632</td>
<td>0</td>
<td>306</td>
<td>780</td>
<td>2227</td>
<td>6210</td>
<td>425</td>
<td>478</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>822108</td>
<td>356103</td>
<td>50224</td>
<td>40</td>
<td>1344</td>
<td>1954</td>
<td>6249</td>
<td>16106</td>
<td>3551</td>
<td>6806</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>577621</td>
<td>385020</td>
<td>48059</td>
<td>80</td>
<td>621</td>
<td>1403</td>
<td>2670</td>
<td>10095</td>
<td>1184</td>
<td>7796</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>563918</td>
<td>269841</td>
<td>40164</td>
<td>16</td>
<td>627</td>
<td>1124</td>
<td>3201</td>
<td>7926</td>
<td>1341</td>
<td>8242</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>417957</td>
<td>324277</td>
<td>26772</td>
<td>12</td>
<td>2474</td>
<td>2095</td>
<td>3369</td>
<td>15755</td>
<td>2957</td>
<td>278</td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>800823</td>
<td>469571</td>
<td>105947</td>
<td>39</td>
<td>1146</td>
<td>1962</td>
<td>5395</td>
<td>13981</td>
<td>668</td>
<td>3418</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>1115260</td>
<td>840575</td>
<td>65219</td>
<td>299</td>
<td>1210</td>
<td>6075</td>
<td>6493</td>
<td>43295</td>
<td>4739</td>
<td>7117</td>
<td></td>
</tr>
<tr>
<td>J</td>
<td>812701</td>
<td>599947</td>
<td>85729</td>
<td>111</td>
<td>143</td>
<td>3112</td>
<td>3405</td>
<td>17635</td>
<td>502</td>
<td>5371</td>
<td></td>
</tr>
</tbody>
</table>

Uncontrolled inputs: 1,2 unwanted outputs: 3,8, inputs: 7,10, outputs: 4,5,6,8

As already mentioned in the prior section, the input data were split into three groups: uncontrolled variables (conditions), unwanted output (the forest area without administration contracts), inputs (number of surveillances, controls, and inspections) and outputs (number of felonies and misdemeanors). Because the number of inputs and outputs exceeds the number of DMU, the problem is further decomposed in five sub-problems, each of them being a combination of 5 inputs and outputs. The outcome of these stepwise DEA is presented in table 3.

The outcome of stepwise DEA performed on data presented in table 2

<table>
<thead>
<tr>
<th>Uncontrolled input</th>
<th>1:2</th>
<th>1:2</th>
<th>1:2</th>
<th>1:2</th>
<th>1:2</th>
<th>1:2</th>
<th>E_k</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unwanted output</td>
<td>3:8</td>
<td>3:8</td>
<td>3:8</td>
<td>3:8</td>
<td>3:8</td>
<td>3:8</td>
<td></td>
</tr>
<tr>
<td>Input</td>
<td>7:10</td>
<td>7:10</td>
<td>7:10</td>
<td>7:10</td>
<td>7:10</td>
<td>7:10</td>
<td></td>
</tr>
<tr>
<td>Output</td>
<td>4:5</td>
<td>6:9</td>
<td>4:6</td>
<td>4:9</td>
<td>5:6</td>
<td>5:9</td>
<td></td>
</tr>
<tr>
<td>ITRSV</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>1</td>
<td>0.747</td>
<td>0.837</td>
<td>1</td>
<td>1</td>
<td>0.747</td>
<td>0.625</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1.000</td>
</tr>
<tr>
<td>C</td>
<td>1</td>
<td>0.471</td>
<td>0.474</td>
<td>0.508</td>
<td>0.524</td>
<td>0.471</td>
<td>0.059</td>
</tr>
<tr>
<td>E</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.896</td>
<td>1</td>
<td>0.896</td>
</tr>
<tr>
<td>F</td>
<td>0.775</td>
<td>0.764</td>
<td>0.75</td>
<td>0.723</td>
<td>0.749</td>
<td>0.764</td>
<td>0.310</td>
</tr>
<tr>
<td>G</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1.000</td>
</tr>
<tr>
<td>H</td>
<td>0.564</td>
<td>0.559</td>
<td>0.556</td>
<td>0.504</td>
<td>0.495</td>
<td>0.559</td>
<td>0.078</td>
</tr>
<tr>
<td>I</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.416</td>
<td>1</td>
<td>0.416</td>
</tr>
<tr>
<td>J</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.654</td>
<td>1</td>
<td>0.654</td>
</tr>
</tbody>
</table>
The second column of table 3 shows the efficiencies considering all inputs and outputs; discrimination between the nine DMU is poor (only two ITRSV have poor scores, F and H) and such fake results occurs whenever there are more inputs and outputs than DMU. The next four columns present partial efficiencies resulted from narrower analyses, considering combinations of two outputs brought about by the two types of inspections.

These combinations between the two inputs and various outputs are justified because whenever the inspectors show up in the field, nobody really knows the reason why they are there, and its obvious that nobody can tell what kind of output will occur. Performing four partial analyses on these combinations the inefficiency is better highlighted and, finally, only two ITRSV seem to be very efficient in preventing illegal cuttings.

Actually all partial analyses were performed in a region which quite close to the line drown in figure 1 because in all partial analyses as much as eight variables were considered; consequently, each analysis was also distorted to some extent, and the most severe one seems to be the forth one, which has shown ‘only’ the three best ITRSV.

**Discussions and Conclusions**

The numerical example presented in this article shows the virtues and limits of DEA in handling factual data provided by current activities carried out in order to prevent illegal cuttings, or whatever illegal activities that imply a great deal of effort which cannot be assessed in pure economic terms. Although the method has a sound and consistent mathematical support – the relative prices are localized for each specific problem, in order to produce a clear hierarchy of decision units – in some specific situations it cannot be applied or, if applied, it will produced a faked result. So, if the number of inputs and outputs exceeds the number of decision units, it recommended to analyze smaller bunches of data, each package being considered a distinct problem. Doing so it is possible to get a much more accurate picture of what makes the difference between all decision units.

This study has considered the outcomes produced in the fist semester of 2007; for such a short period of time the final hierarchy would not be so relevant, because illegal cuttings usually occur by the end of autumn, when the demand for fuel wood increases. So, more relevant results would be produced when the data refer to longer periods of time, one year at least. But the outcome depends to a much greater extent to what we have considered to be uncontrolled inputs, or conditions; in this study we have considered just two such conditions: the total forest area and the forest area owned by the state. Definitely, these working conditions are much complex, they cannot be abridged to the forest area; for instance, the density of the transportation network is equally important for both illegal activities and control but, having a large variation for this parameter across and within ITRSV it is quite doubtful to consider the road density as another uncontrolled input. The same discussion holds for the protected areas too, for unemployment and a lot of socio-economic indicators that make the difference between the forest inspectorates. But any analyst is prone to consider all these inputs unless s/he will abide the condition expressed by relation (6).

This example pinpointed another general problem of any informational system meant to collect data from real life: how detailed shall be this information system in order to grasp only what really matters for an effective management. The data sample processed in this study contains two separate columns: felonies and misdemeanors for illegal tree cuttings. According to the new Forest Act, enforced in 2008 [45], any illegal cutting is considered a felony, which simplifies somehow further analyses carried out on this methodological basis.

In spite of all DEA disadvantages discussed here or in literature, for effective management this analytical tool provides very precious information not mentioned yet: DEA indicates which area a DMU needs to address in order to improve its global efficiency. From this perspective, any practical use of DEA will provide valuable information not to the best DMU, but to all other DMU, who underperformed; the ‘winner’ gets nothing but good news, while all other DMU get some clues about what shall be better done. Therefore DEA can be regarded as an effective instrument meant to improve the overall efficiency of a network of similar DMU, with similar goals and resources, which perfectly match any monitoring and/or extension service provided by state agencies.

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