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# Higher Education Productivity and Quality Modelling with Data Envelopment Analysis Methods

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**ABSTRACT**

Modelling and simulation of service production is a complex task and even harder for the special case of higher education research and teaching production due to the high complexity of throughput as well as definition problems for the outputs. This research contribution describes possible solutions based on DEA modelling and includes the additional problem of quality measurement and quality control in productivity analysis for the example of university service production.

## PROBLEM DESCRIPTION

Efficiency means preventing the waste of resources which is calculated through output to input ratio. There are a lot of various models used for calculating efficiency during recent years. These models can be divided into two general categories of quantitative-oriented and subjective models in operations research and it could be pointed out to MCDM (Multi Criteria Decision Making), DEA (Data Envelopment Analysis), Analytic-Hierarchy Process, Delphi method and nominal groups. Most of the efficiency analysis methods used to emphasize on differential production factors before 1957. Knowing such weak points and using a frontier production function, Farrel tried to estimate the utilization aspects of total production factors. In the same way, an organization could be regarded as an efficient one if it is capable of producing as much as no other unit could do in the same situation, meaning that the output level cannot be realized with a lower input level. Later on, Rohdes tried to compare similar units with multiple input and output levels and constant returns to scale in 1976, using Farrel's efficiency analysis model and presenting his results as the CCR-(Charnes/Cooper/Rhodes) model. Afterwards, Banker, Charnes and Cooper introduced variable returns to scale and presented the BCC (Banker/Charnes/Cooper) model. The potentials of DEA-models have led to its utilization in various economic sectors as an appropriate evaluation tool. One of the major applications for this tool is measuring universities' performance (Fandel; Gutierrez; Johnes).

### Data Envelopment Analysis (DEA)

The Data Envelopment Analysis (DEA) is a set of methods to measure the relative efficiency of production activities between homogeneous organizational units such as universities (Ramanathan). Measuring the efficiency of a university's activities - as defined by the relation between the activities' inputs and its outputs - can give away useful information for the university's stakeholders in their pursue to increase the university's efficiency (Charnes/Cooper/Rhodes; Charnes/Cooper/Thrall). The methods of the Data Envelopment Analysis are all deterministic and non-parametric methods of efficiency measurement that can handle multiple input and output variables for the calculation of efficiency values while allowing subjective post-priori-weightings of efficiency indicators set by the users of the models (Banker/Charnes/Cooper; Lewis/Sexton; Zhu/Cook). The latter aspect makes the DEA useful for universities in particular, since these institutions cater to the interests of several and diverse social groups who have their own distinctive view on what universities should produce and therefore how efficiency can be achieved. Deterministic models assume, that a lack of efficiency originates from deficits in management, differentiating from the stochastic models' idea, that uncontrollable external circumstances that should not be attributed to the university itself might also influence the university's performance in a negative way. The parametric methods assume that a functional connection between inputs and outputs of the university's service provision exists and is known (Charnes et al.). Between the DEA models, the basic differentiation is made in regards to the orientation of the model in terms of whether an increase in efficiency should be defined through a minimization of used input, a maximization of produced output or a combination of both. The other differentiating factor is, whether the expected returns to scale of the production are constant or variable (Kleine; Gutierrez). The first DEA model was named after its inventors Charnes, Cooper and Rhodes (CCR model). It can be configured for an orientation on input minimization as well as output maximization and assumes constant returns to scale. The BCC model – first stated by Banker, Charnes and Cooper – is equally configurable for input-minimization or output-maximization and assumes variable returns to scale. The additive model as well as the slack-based model are both unoriented between input-minimization and output-maximization. While the additive model does not allow calculating a one-dimensional efficiency measure, the slack-based model is not translation invariant, meaning that transforming the inputs and outputs changes the problem as well as the optimal solution for it.

Figure 1: Basic DEA Models (Cooper/Seiford/Tone, p. 115)

The basic DEA models can be extended in order to describe

| Basic DEA Models | Constant ROS | Variable ROS |
|---|---|---|
| input oriented | CCR-I | BCC-I |
| output oriented | CCR-O | BCC-O |
| unoriented | ADD/SBM | ADD/SBM |

the situation in which the efficiency measurement takes place more accurate, thereby resulting in efficiency values that are closer to real situation universities work in and that are more valuable to the universities' stakeholders due to a better information quality. Examples of aspects that can be covered by extending the DEA model are the handling of non-discrete variables, the limitation of post-priori weighting between efficiency-relevant variables, the handling of unwanted outputs and the measurement of efficiency over multiple periods as been conducted for e.g. the health care sector (e.g. Banker/Conrad/Strauss; Felder/Schmitt; Ferrier/Rosko/ Valdmanis). Non-discrete variables can either be extracted by performing separate measurements between universities, that are being influenced by the non-discrete variables and those who aren't, attributing differences in the aggregated efficiency values to the non-discrete variables. Those differences can be considered in a second measurement (two-stage-approach). Alternatively, the non-discrete variables can be treated as regular inputs or outputs, ignoring the possibility of attributing only variables that the university can control to the measurement of its efficiency (one-stage-approach) (Thannasoulis/Portela/Despic). Another aspect of reality, that the model of choice should reflect is the limitation of subjective weightings, i.e.: If we consider teaching and research the two main activities of universities, giving the user the option to put emphasis on one of the two activities entirely, with the result being that a purely teaching or research focused university is considered to be the most efficient, misses the point of comparing units with similar fields of activities. This can be precluded by either defining lower or upper bounds for the weighting variables themselves or for the relation of input- and output-weighting variables to each other (assurance region). A survey among experts can determine where the upper or lower bounds should be set (Ueda/Amatatsu). Further extensions of the basic DEA models can be made in order to handle unwanted outputs. An example for this would be chemical waste that is created during chemical research. While unwanted outputs might be inseparable from the production process, an increase of such output should not be considered as an increase in efficiency (Hua/Bian). Depending on the research question that the DEA model is supposed to help answering, the researcher applying the DEA model might be interested in the development of one or more units' efficiency over a period of time. The window analysis method measures the efficiency of several decision making units relative to each other as well as the efficiency of every decision making unit relative to itself over time (Charnes et al.). As said before, there are four basic DEA models used in the present study. Static or dynamic nature of RTS is then investigated using the FLG model, stating (Cooper/Seiford/Tone, p. 172):

$$\theta^*_{CCR} \leq \theta^*_{BCC}$$

| Seiford and Zhu Model | | RTS | CCR Model |
|---|---|---|---|
| 1. $If\ \theta^*_{CCR} = \theta^*_{BCC}$ | | Constant | $\sum \lambda^*_j = 1$ |
| 2. $If\ \theta^*_{CCR} \neq \theta^*_{BCC}$ | Then | | |
| 3. $If\ \sum \lambda_j < 1$ | | increasing | $\sum \lambda^*_j < 1$ |
| 4. $If\ \sum \lambda_j < 1$ | | Decreasing | $\sum \lambda^*_j > 1$ |

It should be noted, that one unit may be efficient in the BCC model, in accordance with FLG proposition however it might reveal inefficient performance with regard to the CCR model. Therefore, it is required to compare the BCC and CCR scores. The CCR model would organize the constant return to scale in production possibility sets, that is, radial expansion and contraction of all units and their possible non-negative combinations, hence the CCR score is called the global technical efficiency. On the other hand, the BCC model assumes a convex combination of the observed units and the BCC score is known as the local, pure technical efficiency. Various units which have achieved a 100% score as their efficiency level are being called globally efficient while other units which got the 100% score for their BCC level but didn't reach efficiency in accordance with the CCR model are operating at locally efficiency instead of being globally efficient (Cooper/ Seiford/Tone, p. 173).

## CASE STUDY

This research paper provides a comparison of DEA models based on data from 28 German universities in order to show the comparative characteristics of different DEA models and possibilities for the integration of quality control measures into university efficiency analysis and simulation. Selecting appropriate input and output parameters for the efficiency analysis of universities has always been the most controversial scientific issue, because the selection of measurable factors in education and research programs is a difficult task and at the same time, there are some factors that could be evaluated as both input and output parameters, making it increasingly difficult to assign them to one group. Input and output parameters in the present study are as follows: Input parameters include the total budget and the staff count of each university. Output parameters include the number of PhD graduates, third-party funds and the number of publications in a year. The efficiency analysis results for 28 German universities are as being displayed in table 1.

Table 1: Efficiency scores of 28 German universities

| Unit name | Efficiency Score | |
|---|---|---|
| | CCR-Model | BCC-Model |
| Johannes Gutenberg University Mainz | 100 | 100 |
| Technical University of München | 100 | 100 |
| University of Freiburg | 100 | 100 |
| University of Kiel | 100 | 100 |
| University of Erlangen-Nürnberg | 99.09 | 100 |
| Heidelberg University | 92.03 | 100 |
| University of Bielefeld | 86.69 | 100 |
| University of Hamburg | 70.78 | 100 |
| Aachen University | 59.35 | 100 |
| University of Münster | 54.89 | 100 |
| Ludwig Maximilian University of Munich | 46.89 | 100 |
| University of Kassel | 45.67 | 100 |
| Friedrich-Schiller-University of Jena | 75.89 | 97.85 |
| Frankfurt University | 61.64 | 94.87 |
| Dresden University of Technology | 84.94 | 92.71 |
| Georg-August-University of Goettingen | 64.02 | 84.98 |
| University of Karlsruhe | 76.52 | 81.14 |
| University of Leipzig | 53.6 | 75.76 |
| Freie University of Berlin | 66.29 | 74.38 |
| Humboldt-University of Berlin | 65.85 | 74.28 |
| Berlin University of Technology | 68.21 | 74.25 |
| University of Bonn | 53.75 | 72.44 |
| University of Regensburg | 53.48 | 68.53 |
| University of Stuttgart | 60.03 | 68.36 |
| Leibniz University of Hannover | 46.76 | 49.72 |
| Dortmund University of Technology | 48.19 | 48.47 |
| University of Düsseldorf | 37.15 | 45.97 |
| University of Hohenheim | 19.85 | 24.44 |

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## Discussion

Which DEA model is more appropriate for the performance analysis of the data in this study? Regarding this study's findings and a literature review, the BCC-O model seems to be the best option, because an output-oriented approach for the evaluation of educational systems is based on each universities' experiences and research made in this field of study to boost the performance efficiency. In addition, considering the constant lack of finances for higher education programs, managers prefer increasing output levels instead of decreasing input levels. Besides, the lack of universities' control and supervision on some of the inputs such as total budget might be another reason for choosing an output-oriented approach. On the other hand, the results of two DEA models (BCC and CCR) and the utilization of data in the FLG model revealed, that the RTS has been a variable factor. As stated in the proposition of FLG, some of the universities investigated in the present study, such as the Ludwig Maximilian University of Munich and the University of Kassel revealed to be efficient ones according to the BCC model, their performance in the CCR model is not efficient and qualifies only for local, pure technical efficiency. However, there are 4 universities that have acquired a 100% performance score, making them globally efficient.

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## BIOGRAPHY

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