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Measuring University Library Efficiency Using Data Envelopment Analysis

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In this paper we analyse the technical efficiency of 118 randomly selected university libraries from German-speaking countries (Austria, Germany, Switzerland) and English-speaking countries (the United States, Australia and Canada) using Data Envelopment Analysis (DEA). DEA efficiency scores are calculated using library staff, measured in full-time equivalents, and book materials held as inputs, and the number of serial subscriptions, total circulations, regular opening hours per week, and book materials added as outputs. Among the 118 university libraries analysed 10 are rated fully efficient. However, comparing group-specific efficiency scores, there are no significant differences between libraries from English-speaking and German-speaking countries or between small and large university libraries.

Introduction

Increasingly, scientific librarians are becoming aware of the importance of the managerial aspects in libraries. University librarians in particular are skilled as modern service providers aiming to meet user demands as well as possible. As regards performance assessment, library performance can be assessed by surveying library users' opinions (subjective component) and/or analysing library performance indicators (objective component). For more than twenty years, librarians, especially in the United States and Great Britain, have used performance indicators to analyse library performance, viz. Brophy (1989), King Research Ltd (1990), McDonald et al. (1994), Poll (1993) and Van House et al. (1990). Comparable studies in Austria, Germany or Switzerland are mostly confined to drawing up simple library statistics, viz. Boekhorst (1995), Deutsches Bibliotheksinstitut (1996) and Poll (1992).

As Austrian universities, and university libraries in particular, are increasingly confronted with limited resources, the pressure to provide library services efficiently is increasing rapidly. Therefore, it is interesting to see whether or not the performance of Austrian libraries is comparable – in terms of efficiency – to the performance of libraries from other countries. It is also interesting whether or not there are efficiency differentials between library groups, particularly between small and large libraries and between libraries in German-speaking countries (Austria, Germany and Switzerland) and English-speaking countries (the United States, Australia and Canada). The analysis of performance differentials between libraries from German- and English-speaking countries is motivated by the assumption that, due to different environmental conditions (e.g. more strongly developed "surrogate" market forces, continuous performance assessment, etc.), libraries from English-speaking countries (are forced to) perform better than libraries from German-speaking countries. As regards the comparison of libraries of different sizes, we assume that small libraries might be less efficient because of sub-optimal scale sizes. To check these assumptions, this study investigates library performance, particularly to provide information on the ranking of individual libraries, on potential benchmarks for less efficient libraries and on efficiency differentials between different library groups.

As the use of single factor productivity measures might be unsatisfactory because these meas-

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ures reflect only partial aspects of the library performance spectrum, we apply Data Envelopment Analysis (DEA) to be able to assess library performance using a measure which depicts total factor productivity. DEA has become established as a tool to judge performance, especially of non-profit institutions such as university libraries where profit measures are of little value, especially due to the absence of output prices. Analysing the potential of DEA, Shim (2000) found out that the DEA technology is a suitable tool to benchmark research libraries in the United States. The potential of DEA goes beyond the calculation of a scalar measure of efficiency: it is part of a continuous learning process, including the thorough analysis of the service production process to identify candidate measures of inputs and services at first, the calculation of efficiency measures based on the selected input / output measures, the discussion of efficiency results and finally the derivation of strategies to improve performance via learning from the best practice performer identified through DEA. Using DEA we therefore obtain a first insight into the efficiency differentials across single libraries and library groups.

Accordingly, this paper is organised as follows: The first two sections are dedicated to a brief introduction of DEA, a discussion of the sample and the model specification. The next section presents detailed results for those libraries which are rated above-average efficient and also group-specific average results. A discussion and conclusion is given in the last section.

Methodology

In this paper, library performance assessment is based on the Farrell (1957) concepts of a piecewise linear production frontier as an envelope to a production possibility set and efficiency measures calculated as radial movements from observations to the frontier. These concepts were popularised in Charnes et al. (1978) under the name of DEA. Since it is beyond the scope of this study to describe DEA in detail, we provide a brief overview and refer the particularly interested reader to the well-known textbooks of Cooper et al. (2000) or Thanassoulis (2001) for further details.

DEA can be seen as an extension of ratio analysis since it enables us to consider the use of multiple inputs to produce multiple outputs (services). The DEA efficiency score is defined as the ratio of the weighted sum of outputs to the weighted sum of inputs, where the weights are not defined ex ante but calculated by the DEA model itself. DEA provides detailed information about the libraries under assessment: It identifies those libraries as fully efficient which use the lowest input for a given level of services (input orientation) or which produce a maximum output (services) given their level of inputs (output orientation), it calculates the degree of relative efficiency for all other libraries in the sample and indicates which efficient library serves as a benchmark (peer) for inefficient libraries. DEA therefore has several advantages: First, it is suitable for assessing the efficiency of public sector non-profit organisations such as libraries where multiple services are produced using multiple inputs when no output price data are available. Second, it provides quantitative information on the extent of inefficiency and, subsequently, on the targets required to become efficient. Third, it identifies best-practice rather than average performance which may serve as a benchmark for inefficient service providers.

As libraries are increasingly confronted with the idea of output control, we use an output-oriented efficiency measure. Mathematically, the output-oriented efficiency index is derived by solving a set of linear programming problems, one for each library. Assume there are $j = 1,..., k,...,n$ libraries, where each library produces s outputs (denoted y_r, $r = 1,...,s$) using m inputs (denoted x_i, $i = 1,...,m$). Then, the technical efficiency of library k, TE_k, is calculated as the solution to the following linear program:

$$\frac{1}{TE_k} = \max \eta_k \qquad (1)$$

subject to

$$\sum_{n}^{j=1} x_{ij}\lambda_j \leq x_{ik} \qquad \forall\, i = 1,..., m \qquad (2)$$

$$\sum_{n}^{j=1} y_{rj}\lambda_j \geq y_{rk}\eta_k \quad \forall\, r = 1,...,s \qquad (3)$$

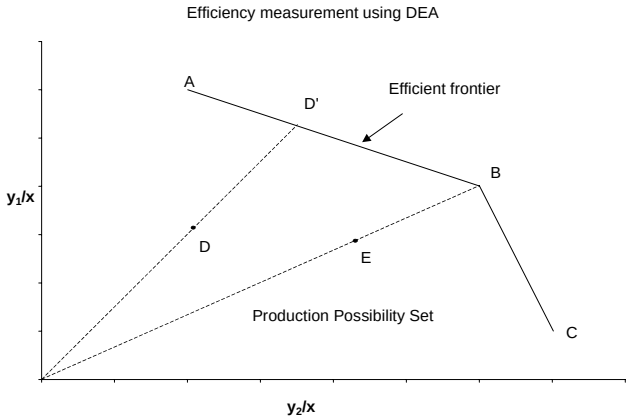
$$\lambda_j \geq 0 \;\forall\, j = 1,...,n \qquad (4)$$

The optimal value of η satisfies $\eta \geq 1$, with $\eta = 1$ indicating efficient service provision (apart from

any slacks that may be present in the constraints (2) and (3)) and the magnitude of $\eta > 1$ indicating the extent of radial inefficiency in service provision relative to best practice in the sample. If library k is rated fully efficient (i.e. $\eta_k = 1$ and $TE_k = 1$) there is no other library (actual or virtual, the latter expressed as a linear combination of actual libraries; see (2) and (3)) which produces more services than library k, given the level of resources. If library k is rated inefficient (i.e. $\eta_k > 1$ and $TE_k < 1$ and) there are, however, other (actual or virtual) libraries which produce more services than library k, given their resources. If library k is rated inefficient, the solution to LP (1)-(4) additionally reveals two further interesting features: firstly, it gives the target output levels which would render an inefficient library efficient. The targets are calculated by proportionally expanding the outputs by the optimal value of η. Secondly, the λ_j, $j = 1,...,k,...,n$ intensity variables whose non-zero values identify efficient libraries provide information on which efficient libraries serve as benchmarks and should thus be further scrutinised to learn from best practice. In addition, the efficiency index is derived under the assumption of constant returns-to-scale which implies that both managerial (waste of resources) and scale inefficiencies are expressed in the (in)efficiency term.

Figure 1 illustrates the simple case where five different libraries A, B, C, D and E use the same amount of one input x to produce two different types of services y_1 and y_2 so that the libraries only differ in the service level they produce per input unit. Thus, we can plot the units in a two dimensional diagram as shown in figure 1. The piecewise linear boundary ABC is the locus of efficient service production and therefore, A, B and C are rated fully efficient. In particular, A and B are used as reference points for the inefficient library D (i.e. A and B form library D's reference set) since D lies within the service production possibility set and is, therefore, rated inefficient. In Figure 1 efficiency is defined as the proportion to which outputs can be extended radially without changing the input level. To derive the efficiency of D we simply calculate how far D can be moved towards the frontier along the dotted line through the origin. The dotted line 0D intersects the efficiency frontier at D' and therefore indicates where we have the highest level of

Figure 1: Efficiency measurement using DEA



service production, maintaining the output mix of D while keeping its respective input level. D' (which, in return, is a linear combination of the actual libraries A and B) is called the virtual peer relative to which D is compared. If the inefficient library E is projected onto the frontier it intersects the efficiency boundary exactly at B. Therefore, B is the actual peer of E.

Nowadays, there are a sufficient number of commercial software products available so that the calculation of DEA efficiency scores is no longer problematic, even for those not familiar with linear programming methods. Accordingly, the number of applications for profit organisations and, in particular, non-profit institutions is increasing considerably; for an extensive overview of DEA applications, see Seiford (2000); for informative applications of DEA to assess library performance see, for example, Chen (1997), Kao et al. (1999), Shim et al. (1998), Shim (2000), Reichmann (2001) and Reichmann (2003). To avoid misunderstandings the following has to be taken into consideration: First, the DEA efficiency score is a relative index which is calculated for the sample of university libraries based on particular input and output factors which are considered to sufficiently depict the service production process. This implies that efficiency scores might change as soon as the number of libraries under evaluation changes, additional input and output measures are included or particular measures are omitted. The selection of meaningful input and output measures is, therefore, of considerable importance. Additionally, the number of institutions under evaluation should be three times as high as the sum of inputs and outputs to avoid degrees-

of-freedom problems. However, as regards the number of input and output factors, a study should select as few as possible but as many as necessary to depict sufficiently the service production process.

In this study we use two inputs and four outputs to measure the relative efficiency of the 118 university libraries. The number of library employees, measured in full-time equivalents, and the number of book materials held are considered to be reliable proxies for current and capital resource use respectively. The number of full-time equivalents was chosen because it was observed that another candidate input measure, namely total current library expenditure, was barely comparable across libraries: some libraries reported current material plus labour expenditure as total expenditure, some libraries showed special features regarding the financing of employees, and others specified current plus capital expenditure as total expenditure without further disaggregating total expenditure. The total number of book materials held, counted in bookbinder volumes, however, is highly correlated with the total area (in square metres) which was also considered to be a good proxy for capital resource use. As there was a high number of libraries with missing values on total area and the correlation with the number of book materials held was sufficiently high (0.85) we finally chose the number of book materials held as the single proxy of capital input.

On the output side, the number of serial subscriptions, total circulations, regular opening hours per week, and book materials added are considered to be good proxies for service provision, thereby covering both the archival and the utilisation function. The measure 'serial subscriptions' comprises the number of serials in the narrow sense as well as newspapers, annual reports and other journal-like series, for which the library has a subscription in the respective year. The figure 'total circulations' corresponds to the total number of circulations plus renewals. The measure 'regular working hours per week' corresponds to the average number of weekly opening hours of the main reading room during semester hours and the figure 'book materials added' comprises the annual additions of book materials via buying, exchange and donation. Undoubtedly, there are other candidate input and output measures but based on the available data these were the factors which best represent the production process. However, there was no possibility of including measures such as in-library use or user satisfaction simply because there were no readily available data.

Table 1: Stratified sample: Affiliation to countries and size groups

	Number of university libraries		
Country	Large	Small	Total
Austria	1	11	12
Germany	3	44	47
Switzerland	0	7	7
United States	35	3	38
Australia	3	2	5
Canada	6	3	9
Total	48	70	118

Sample

The sample consists of randomly selected university libraries from Austria, Germany, Switzerland, the United States, Australia and Canada. It should be mentioned that the libraries included in the sample are supposed to be homogeneous units. Libraries were selected based on a county-specific stratified sample. In particular, the sample of US American and Canadian libraries was taken from ARL libraries only. Table 1 provides an overview on the composition of the sample: The sample consists of 12 Austrian, 47 German, 7 Swiss, 38 US American, 5 Australian and 9 Canadian university libraries. Therefore, 66 university libraries belong to the group of libraries from German-speaking countries whereas 52 belong to the group of libraries from English-speaking countries.

The classification of the sample according to the library size was initially no stratification criteria. However, it is of considerable interest whether or not there is a significant difference in efficiency between small and large university libraries. The size categories are based on the number of library employees, measured in full-time equivalents: University libraries with more than 175 full-time equivalents were assigned to the group of large libraries whereas the others belong to the group of small libraries. Originally, further size criteria such as the number of book materials held or the area (in square metres) were considered. The

analysis revealed similar results, irrespective of which (combination of) size criteria were selected. Therefore, we agreed upon the use of full-time equivalents as a separation criterion only. As regards the 118 university libraries, 48 libraries (41%) belong to the group of large and 70 (59%) to the group of small libraries. Table 2 contains the summary statistics for libraries according to countries and size group.

In a first step, data to perform the cross-sectional assessment of library performance were obtained from the 1998 national library statistics and the 1998 annual library reports. This means that the data source for the US American and Canadian libraries was the 1998/1999 ARL database which is available through the Internet. Similarly, the data for the Australian libraries were taken from the 1998 CAUL database. The survey on data for the libraries from German-speaking countries was much more difficult as there are no electronically available library statistics. The data sources for the German and Swiss libraries were the 1998 printed German and Swiss library statistics (DBS and Statistische Übersichten für Schweizerische Bibliotheken respectively). As regards the Austrian library data, we had to use each library's 1998 printed library report since there are as yet no official and publicly accessible library statistics covering all Austrian university libraries.

In a second step, the sample libraries were contacted via email and asked to check whether the previously collected data were correct. In case of missing data, they were kindly requested to complete the required information whenever possible. Overall, more than 40 out of 118 sample libraries responded. As regards those libraries which did not answer to the email, the data taken from the respective statistics was used for the assessment without further completion.

Results

Table 3 contains the summary statistics for efficiency measures calculated relative to the sample of the 118 university libraries. However, the presentation of results is restricted to those libraries which have obtained efficiency scores above the average efficiency score of 67%. The calculations were carried out using Frontier Analyst from BANXIA Software.

Overall, 10 libraries (8.5%) were rated fully (100%) efficient, comprising libraries from both English- and German-speaking countries. However, it is conspicuous that all fully efficient libraries from German-speaking countries belong to the group of small university libraries. Another 32%, i.e. a further 38 libraries, show above-average efficiency scores. Among those 48 libraries which are rated above-average efficient are 6 (out of 12) libraries from Austria, 18 (out of 47) libraries from Germany, 1 (out of 7) library from Switzerland, 18 (out of 38) libraries from the United States, 4 (out of 5!) libraries from Australia and 1 (out of 9) library from Canada. In Austria, Germany, the United States and Australia there is at least one fully efficient library whereas the highest-ranked Canadian library occupies the 41st rank with an efficiency score of 72% and the highest-ranked Swiss library the 46th rank with an efficiency score of 69%. The efficiency results reveal that – in terms of efficiency – the performance of the Austrian libraries is comparable to the performance of libraries from the other countries. This is confirmed by the above-average efficiency score of the Austrian libraries of about 69% (see the mean efficiency score of 67% for the whole sample in Table 3).

As mentioned in the methodology section, the DEA results not only provide information on which libraries outperform other libraries included in the sample (and are therefore rated as fully efficient), but also which efficient libraries serve as benchmarks for inefficient libraries (see column 4 in Table 3; for the definition of a reference set see section 'Methodology'). In most cases, the reference set of inefficient libraries comprises more than one efficient library, indicating that there exists a virtual peer (comparable to unit D' in Figure 1) which provides a higher level of services, given the inputs used.

Table 3 lists the reference sets for those inefficient libraries which have above-average efficiency scores (i.e. higher than 67%). This is useful information because libraries rated as inefficient might be interested in how efficient libraries organise their service production process in order to learn form best practice. Consequently, it makes sense, for example, for the UL British Columbia to analyse the service production processes of the members of its reference set since it includes those benchmarks (namely Lüneburg, Davis and Swin-

Table 2: Stratified sample: Single university libraries

University library	Size		University library	Size	
	small	large		small	large
UL Graz	X		Municipal Library and UL Bern	X	
UL Graz, Tech	X		State Library and UL Freiburg	X	
UL Innsbruck	X		State Library and UL Lausanne	X	
UL Klagenfurt	X		UL Lausanne, Tech	X	
UL Leoben	X		Public Library and UL Neuenburg	X	
UL Linz	X		Central Library Zürich	X	
UL Salzburg	X		UL Zürich, Tech	X	
UL Vienna		X	UL Alabama		X
UL Vienna, Tech	X		UL Albany	X	
UL Vienna, WU	X		UL Arizona		X
UL Vienna, BOKU	X		UL Arizona State		X
UL Vienna, VETMED	X		UL Brown		X
UL Augsburg	X		UL Chicago		X
UL Bayreuth	X		UL Cincinnati		X
UL Bielefeld	X		UL Connecticut		X
Federal Library und UL Bremen	X		UL California, Davis		X
UL Chemnitz, Tech	X		UL Duke		X
UL Cottbus, Tech	X		UL Florida State		X
UL Dortmund		X	UL Georgetown		X
State Library and UL Dresden	X		UL Georgia, Tech	X	
State Library and UL Düsseldorf	X		UL Houston		X
UL Duisburg	X		UL Illinois, Chicago		X
UL Eichstätt	X		UL Illinois, Urbana-Champaign		X
UL and Research Library Erfurt	X		UL Iowa State		X
UL Essen	X		UL California, Irvine		X
UL Flensburg	X		UL Kent State		X
UL Frankfurt / Oder	X		UL Kentucky		X
UL Freiberg, Tech	X		UL Michigan		X
UL Greifswald	X		UL Northwestern		X
State Library and UL Halle / S		X	UL Notre Dame		X
UL Hamburg, Tech	X		UL Ohio		X
UL Hamburg, BW	X		UL Oklahoma State		X
UL and Technical Library Hannover	X		UL Penn State		X
UL Hildesheim	X		UL Pittsburgh		X
UL Ilmenau, Tech	X		UL Princeton		X
State Library and UL Jena	X		UL Purdue		X
UL Kaiserslautern	X		UL California, Riverside	X	
UL Kassel	X		UL California, San Diego		X
UL Koblenz	X		UL California, Santa Barbara		X
UL Konstanz	X		UL Stanford		X
UL Landau	X		UL Temple		X
UL Leipzig	X		UL Texas, Tech		X
UL Lübeck	X		UL Tulane		X
UL Lüneburg	X		UL Virginia		X
UL Magdeburg	X		UL Yale		X
UL Mannheim	X		UL Melbourne		X
UL München-Neubiberg, BW	X		UL New South Wales		X
UL Oldenburg	X		UL Northern Territory	X	
UL Osnabrück	X		UL Queensland		X
UL Paderborn	X		UL Swinburne, Tech	X	
UL Passau	X		UL British Columbia		X
UL Potsdam	X		UL Guelph	X	
UL Regensburg		X	UL Laval		X
UL Rostock	X		UL McMaster	X	
UL Siegen	X		UL Manitoba		X
UL Trier	X		UL Queen's		X
UL Ulm	X		UL Saskatchewan	X	
UL Weimar	X		UL Western Ontario		X
UL Wuppertal	X		UL York		X

Table 3: Ranking, technical efficiency and reference sets for inefficient libraries

Library	Rank	Technical efficiency in %	Efficient benchmarks (reference sets)
UL Vienna, VETMED	1	100	---
UL and Research Library Erfurt	1	100	---
UL Frankfurt / Oder	1	100	---
UL Hildesheim	1	100	---
UL Landau	1	100	---
UL Lüneburg	1	100	---
UL California, Davis	1	100	---
UL Illinois, Urbana-Champaign	1	100	---
UL Ohio	1	100	---
UL Swinburne, Tech	1	100	---
UL Georgia, Tech	11	95	UL Hildesheim, UL Landau, UL Illinois, Urbana-Champaign
UL Paderborn	12	93	UL Lüneburg
UL Flensburg	12	93	UL Vienna, VETMED, UL Lüneburg
UL Northern Territory	12	93	UL Vienna, VETMED, UL California, Davis, UL Swinburne, Tech
UL Queensland	15	92	UL Lüneburg, UL California, Davis, UL Swinburne, Tech
UL Graz	16	89	UL Hildesheim, UL Illinois, Urbana-Champaign
UL Lübeck	17	88	UL Vienna, VETMED, UL Hildesheim, UL Lüneburg
UL Virginia	17	88	UL Lüneburg, UL California, Davis, UL Illinois, Urbana-Champaign
UL Essen	17	88	UL Lüneburg, UL California, Davis, UL Illinois, Urbana-Champaign
UL Hamburg, BW	20	87	UL Hildesheim, UL Landau, UL Illinois, Urbana-Champaign, UL Ohio
UL Cottbus, Tech	21	85	UL Vienna, VETMED, UL and Research Library Erfurt, UL Lüneburg, UL Swinburne, Tech
UL New South Wales	22	83	UL Lüneburg, UL California, Davis, UL Swinburne, Tech
UL Oklahoma State	23	82	UL Frankfurt / Oder, UL Landau, UL Lüneburg, UL Ohio
UL Chicago	24	81	UL Hildesheim, UL Landau, UL Illinois, Urbana-Champaign
UL California, Santa Barbara	24	81	UL Frankfurt / Oder, UL Landau, UL Ohio
UL Passau	26	80	UL Hildesheim, UL Landau, UL Illinois, Urbana-Champaign
UL Arizona State	26	80	UL Frankfurt / Oder, UL Lüneburg, UL Ohio, UL Swinburne, Tech
UL Linz	26	80	UL Hildesheim, UL Landau, UL Illinois, Urbana-Champaign, UL Ohio
UL Magdeburg	29	79	UL Frankfurt / Oder, UL Lüneburg, UL Ohio, UL Swinburne, Tech
UL Vienna, BOKU	30	78	UL Vienna, VETMED, UL Hildesheim, UL Illinois, Urbana-Champaign, UL Ohio
UL Texas, Tech	31	77	UL Frankfurt / Oder, UL Ohio, UL Swinburne, Tech
UL Georgetown	32	76	UL Vienna, VETMED, UL California, Davis, UL Swinburne, Tech
UL Iowa State	32	76	UL Vienna, VETMED, UL Lüneburg, UL California, Davis, UL Ohio, UL Swinburne, Tech
UL Michigan	32	76	UL Vienna VETMED, UL California, Davis, UL Illinois, Urbana-Champaign
UL Northwestern	35	75	UL Vienna, VETMED, UL California, Davis, UL Illinois, Urbana-Champaign
UL Ilmenau, Tech	35	75	UL and Research Library Erfurt, UL Frankfurt / Oder, UL Lüneburg
UL Klagenfurt	37	74	UL Hildesheim, UL Landau, UL Illinois, Urbana-Champaign, UL Ohio
UL Wuppertal	38	73	UL Lüneburg, UL California, Davis, UL Illinois, Urbana-Champaign
UL Notre Dame	38	73	UL Vienna, VETMED, UL Hildesheim, UL Landau, UL Ohio
UL Duke	38	73	UL Landau, UL Illinois, Urbana-Champaign, UL Ohio
UL British Columbia	41	72	UL Lüneburg, UL California, Davis, UL Swinburne, Tech
UL Koblenz	42	71	UL Vienna, VETMED, UL Frankfurt / Oder, UL Hildesheim, UL Landau, UL Lüneburg
Federal Library and UL Bremen	42	71	UL Hildesheim, UL Illinois, Urbana-Champaign
UL Osnabrück	42	71	UL Hildesheim, UL Landau, UL Lüneburg, UL Ohio
UL Vienna, WU	45	70	UL Vienna, VETMED, UL Hildesheim, UL Landau, UL Ohio
State Library and UL Freiburg	46	69	UL Hildesheim, UL Illinois, Urbana-Champaign
UL Houston	47	68	UL Vienna, VETMED, UL Frankfurt / Oder, UL Ohio, UL Swinburne, Tech
UL Albany	47	68	UL Vienna, VETMED, UL California, Davis, UL Illinois, Urbana-Champaign, UL Ohio
Mean (whole sample)		67	
Range (whole sample)		59	

Figure 2: UL Lüneburg compared to UL Paderborn

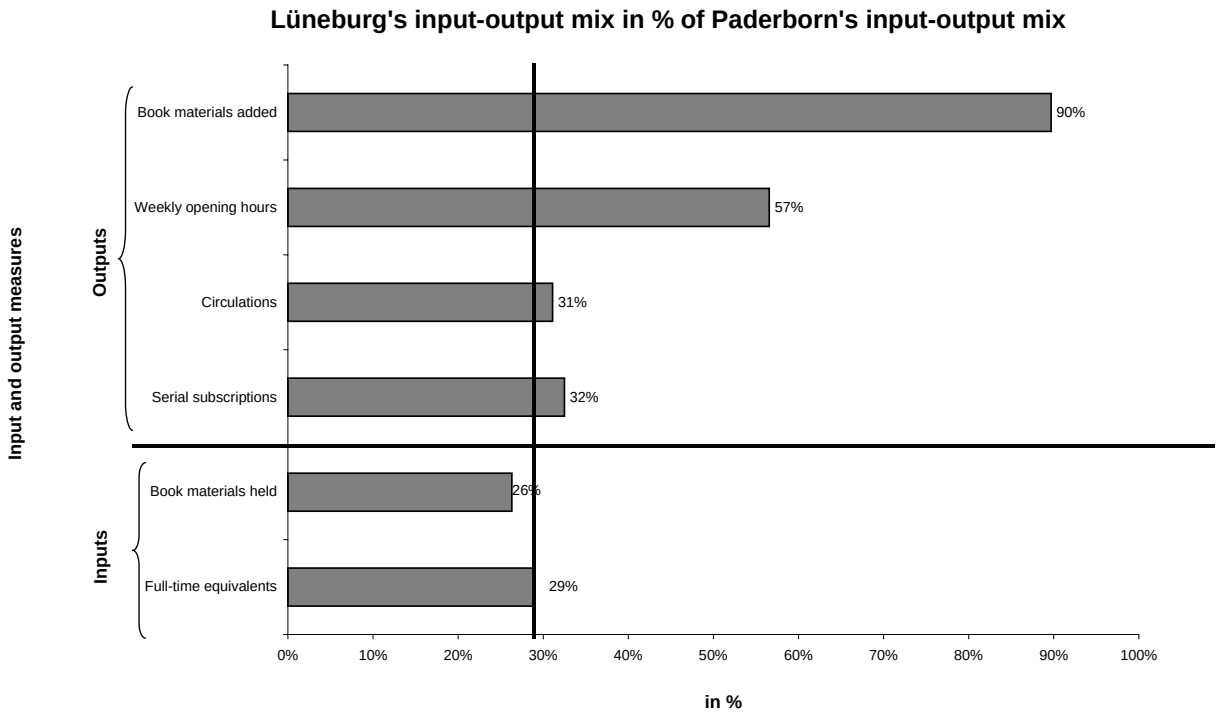
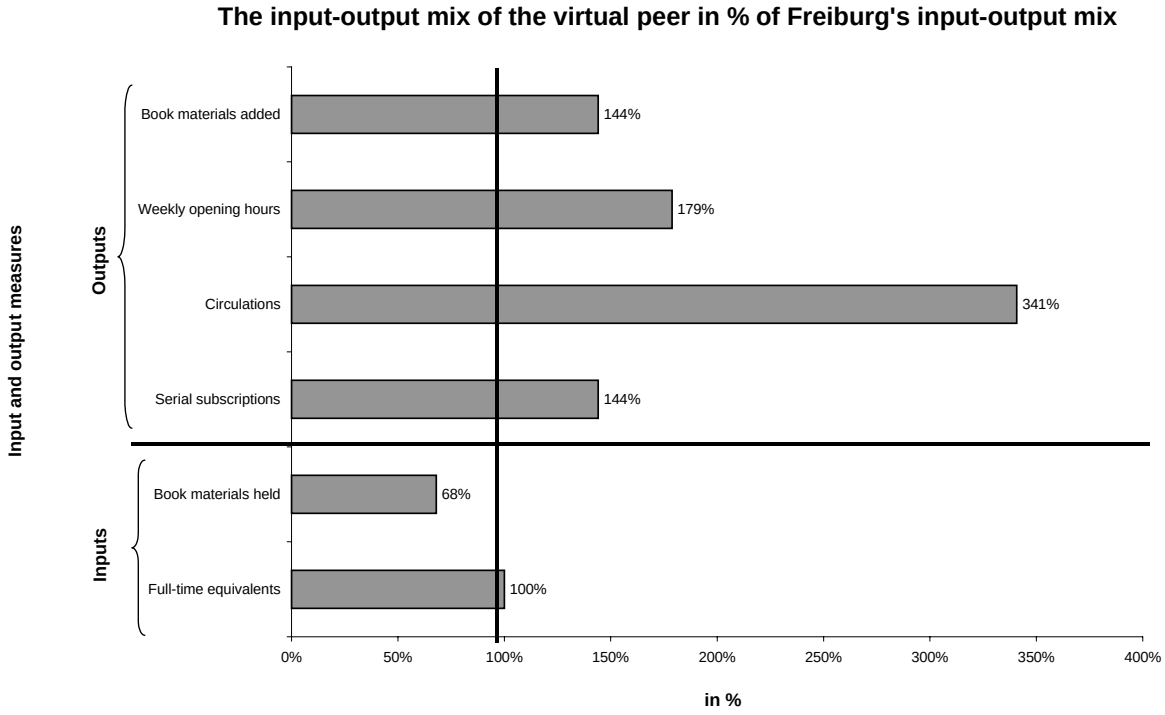


Figure 3: State library and UL Freiburg compared to virtual peer



burne, Tech) with which, at last, the performance of the UL British Columbia is compared.

Table 3 contains one inefficient library (comparable to unit E in Figure 1) with only one actual peer (comparable to unit B in Figure 1), namely the UL Paderborn. Paderborn's inefficiency stems from the fact that Lüneburg uses around 30% of Paderborn's inputs but produces more than 30% of Paderborn's services (for details see Figure 2).

The highest-ranked Swiss library, UL Freiburg (comparable to unit D in Figure 1), is referenced by the university libraries Hildesheim and Urbana-Champaign (comparable to the units A and B in Figure 1), thereby indicating that the performance

Figure 4: Ranking fully efficient libraries

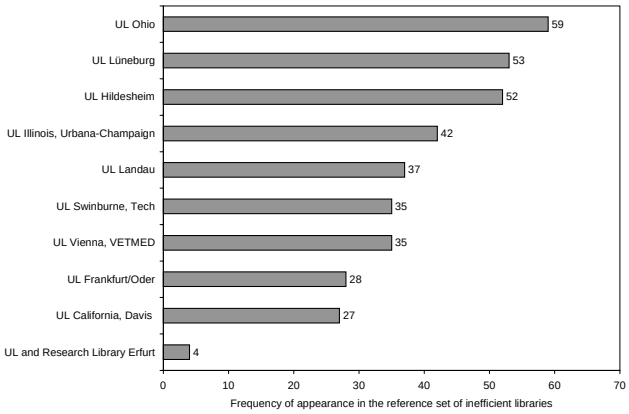
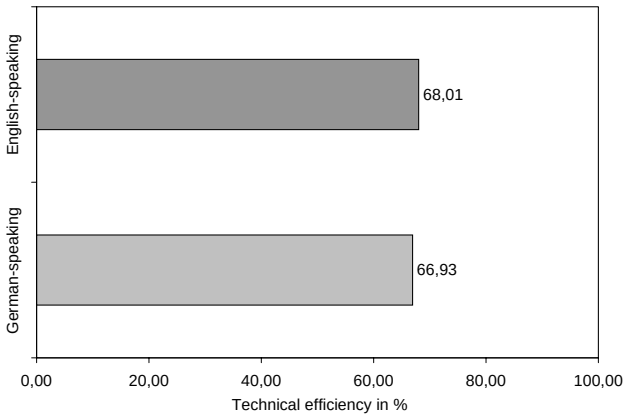


Figure 5: UL from English-speaking versus UL from German-speaking countries



of Freiburg is compared to a virtual peer (comparable to unit D' in Figure 1) which is located on the empirical efficiency frontier bounded by the two efficient libraries Hildesheim and Urbana-Champaign. Figure 3 reveals that the virtual peer, constructed as convex combination of Hildesheim and Urbana-Champaign (for details on the analytical construction of virtual peers see (2) and (3) in the formulas in the Methodology section), uses less capital input and the same number of full-time equivalents in producing higher levels of services.

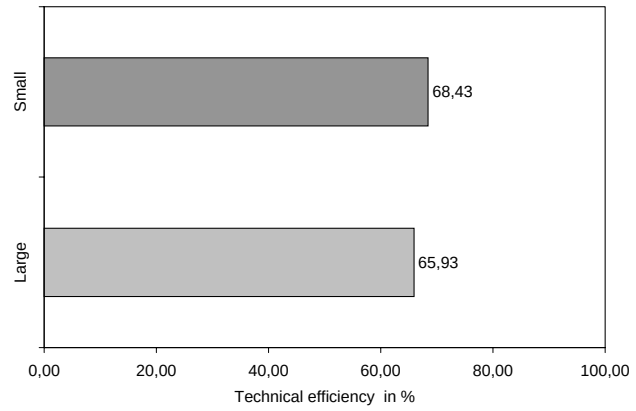
Among the group of fully efficient libraries, we might further differentiate according to the frequency of their appearance in the reference set of the inefficient libraries. At most, an efficient library may appear 108 (118–10) times in the reference set of inefficient libraries. The frequency of appearance in an inefficient library's reference set provides information on how many inefficient libraries are affected by the presence of the efficient library and therefore enables us to further rank fully efficient libraries. The corresponding results are included in Figure 4. This figure illustrates that the UL Ohio, for example, appears 59 times in the reference set of inefficient libraries as opposed to the UL Erfurt which appears only 4 times as a reference library. This reveals that there are considerable differences regarding the impact of efficient libraries on inefficient libraries.

Group-specific comparisons

Apart from the performance assessment of single libraries, the purpose of this study is to investigate whether there are significant differences in efficiency scores between different library groups: i.e. libraries from English-speaking countries versus libraries from German-speaking countries and small libraries versus large libraries. The null hypothesis is that there is no difference in library performance between the different library groups. First, we calculate the mean efficiency score for each library group. Then, we compare the mean efficiency scores using a diagram. To investigate whether or not there are significant differences (the significance level is 5%) we first test for the existence of a normal distribution. If the normal distribution is confirmed, we apply the Levene Test to check for variance homogeneity. If both normal distribution and variance homogeneity are confirmed, we apply the parametric two-sample t-Test to compare the two groups. Otherwise, we use the non-parametric Mann-Whitney test. All statistical tests are carried out using SPSS for Windows, version 7.5.

Figure 5 reveals that there are only marginal differences in average efficiency scores between libraries from English- and German-speaking countries: University libraries from English-speaking countries are slightly more efficient than those from German-speaking countries. The above-mentioned test procedure confirms the null hypothesis: There is no significant difference between the two library groups. However, we assume that the results favour libraries from German-speaking countries since we did not include candidate measures regarding library infrastructure which is considered to be far better in libraries from English-speaking countries.

Figure 6: Large versus small university libraries



To perform the size-specific comparison we grouped the libraries with up to 175 full-time equivalents into the small library group and the others into the large library group. This size-specific classification is similar to the classification of English- and German-speaking countries since 94% of libraries from German-speaking countries belong to the small library group whilst 84% of libraries from English-speaking countries belong to the large library group. As indicated by Figure 6, there is only a small difference in mean efficiency between small and large university libraries: The group of small university libraries is on average slightly more efficient than the group of large university libraries. This is surprising since the group of large university libraries mostly comprises libraries from English-speaking countries which performed better compared to the group of libraries from German-speaking countries. We did not analyse this fact further since the statistical tests revealed that the difference in technical efficiency between the groups of small and large university libraries is not statistically significant.

Conclusion

Summing up, we found clear differences when analysing individual university library efficiency scores but no clear differences in the group-specific indexes, where we found no indication that there are significant differences in performance between university libraries from English- and German-speaking countries or between large and small university libraries.

Finally, we would like to mention again that the results obtained in this study are based on the assumption that the 118 university libraries are homogeneous institutions. If this assumption is rejected, DEA efficiency scores have to be recalculated separately for each sub-sample. Using this procedure, however, we can only compare group-specific efficiency scores, i.e. the efficiency scores within each homogenous group but not the efficiency scores of different groups. Consideration of the homogeneity is the subject of future research.

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