Productivity Indicators in Higher Education

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Abstract

Productivity in service production in general and especially in university teaching and research is an interesting research question with specific difficulties. In Germany since 2006 the new 'Excellence Initiative Programme' for universities has inhibited further discussions in the context of university management and the productivity of higher education (HE) institutions as well as for the task of evaluating university performance. Therefore an in depth analysis of productivity in universities is of interest for HE managers as well as for HE politicians deciding about public university budgets. Additionally the methods and lessons learned from this specific discussion about higher education as 'service industry' could well be transferred to other service companies and service production contexts. This article describes two different ways to measure university productivity (input-output analysis and data envelopment analysis). Altogether the research results point to the fact that there are in general two ways towards university productivity: (a) Extending budgets ('clustering/scaling', which is limited) and (b) excellence in research/university management ('steering/integration'). Therefore it can be assumed that economies of scale exist in universities but are limited to restricted ranges of institutional size. For other service companies the question of output measurement in KPIs couls be tackled also with indicators offering a huge field of practical applications from top management remuneration to corporate steering and benchmarking.

Keywords

Higher education productivity, university performance indicators, service performance indicators, HE excellence

1 Introduction

Service *production in higher education* is a long standing research objective. Especially an *international perspective* as well as the *self-perspective of research* are interesting in this research field, see [17, 31, 50, 54]. In present days higher education politics may have an special importance as the German Excellence Initiative (GEI) with federal and state level funding is *concentrating resources* in nine universities in Germany. For the most prominent funding programme strand within GEI (No 3 ‚Zukunftskonzept') the institutions FU Berlin, RWTH Aachen, TH Karlsruhe, TU Munich, Universities of Göttingen, Freiburg, Heidelberg, Konstanz and Munich were selected as 'elite universities' [9, 10]. But there are hints that general *economies of scale may not exist in higher education* production and therefore some of this additional public funding may not be invested efficiently [38, 40]. Therefore public money concentrated in large universities may *not* be invested efficiently as these institutions may not be the most productive ones. This would *contradict* the general trend and requirements in the concepts of *new public management* in public institutions aiming at an efficient use of public funds (as defined by law in the German 'Haushaltsgrundsätzegesetz', § 6, (1) and (2), [57]) by an increasing steering, controlling and measurement of *outputs* and information transparency within public institutions, see e.g. [8, 39]. Especially for universities there is a broad discussion about the necessary steps and models in order to achieve efficient (public) universities, see e.g. [7, 11, 39, 51, 59, 64]. The therefore discussed scientific problem is the *productivity* in universities (especially research). The scientific method applied is the comparison of two different productivity calculation methods: (i) an *input-output-analysis* and (ii) a *data envelopment analysis* (DEA). These analysis methods should establish the validity of the used performance indicators for HE service performance.

2 Research Performance Indicators in Rankings for German Universities

The following table lists the set of universities as DMUs in the following input-output analysis as well as the subsequent DEA calculation. Budget figures (A, see [22])[1] are presented besides the DFG ranking 2006 (B, see [23]), the SJTU world universities ranking 2005 (C, see [58]) and the German Excellence Initiative results (E, see [9, 10]).[2] The intermediate scores D (adding B and C) and F (adding scores out of B, C and E) are meta score rankings, see [38].

	University (DMU)	A. Budget	B. DFG Ranking			C. SJTU World Universities Ranking				D. R-Meta	E. Excellence Initiative Ranking				F. Meta
No	Name	2001-03, Mio €	DFG Fund	EU Fund	S	World Rank	Region Rank	National Rank	S	B.+C.	Area 1 GS	Area 2 CL	Area 3 FU	S	B.+C.+E
1	Univ Munich	3082,6	1	2	99	51	10	1	100	199,0	1	3	1	100	299,0
2	Tech Univ Munich	1917,6	9	3	90	52	11	2	99,5	189,5	1	2	1	80	269,5
3	Univ Heidelberg	2136,5	3	5	94	71	21	3	94,5	188,5	3	2	1	100	288,5
4	RWTH Aachen	2313,3	2	4	96	203-300	80-123	17-23	65	161,0	1	3	1	100	261,0
5	Univ Karlsruhe	708,9	6	7	89	203-300	80-123	17-23	65	154,0	1	1	1	60	214,0
6	Univ Bonn	2222,1	13	12	77	101-152	36-56	6-11	87	164,0	2	1		40	204,0
7	Univ Goettingen	1996,4	12	9	81	84	26	4	92	173,0	1	1	1	60	233,0
8	Univ Freiburg	1861,7	11	10	81	90	29	5	90,5	171,5	1	1	1	60	231,5
9	Univ Frankfurt	1646,9	20	8	74	101-152	36-56	6-11	87	161,0		2		40	201,0
10	Univ Wuerzburg	1396,7	4	27	71	101-152	36-56	6-11	87	158,0	1			10	168,0
11	Univ Tuebingen	1880,7	8	6	88	101-152	36-56	6-11	87	175,0		1		20	195,0
12	Univ Bochum	964,7	16	13	73	203-300	80-123	17-23	65	138,0	1			10	148,0
13	Univ Erl-Nuernberg	1727,7	7	26	69	203-300	80-123	17-23	65	134,0	1	1		30	164,0
14	Univ Hamburg	1952,9	17	19	66	101-152	36-56	6-11	87	153,0		1		20	173,0
15	Univ Stuttgart	904,7	14	1	87	203-300	80-123	17-23	65	152,0	1	1		30	182,0
16	Tech Univ Dresden	1607,6	21	14	67	301-400	124-168	24-33	43	110,0	1	1		30	140,0
17	Tech Univ Berlin	943,5	22	15	65	203-300	80-123	17-23	65	130,0	1	1		30	160,0
18	Univ Muenster	2159,9	15	25	62	101-152	36-56	6-11	87	149,0		1		20	169,0
19	Univ Mainz	1779,3	19	11	72	153-202	57-79	12-16	76,5	148,5	1			10	158,5
20	Univ Koeln	1871,2	18	20	64	153-202	57-79	12-16	76,5	140,5		1		20	160,5
21	Univ Kiel	1464,9	36	37	29	153-202	57-79	12-16	76,5	105,5	1	2		50	155,5
22	Univ Marburg	1197,1	27	31	44	153-202	57-79	12-16	76,5	120,5				0	120,5
23	Univ Giessen	1408,0	26	24	52	401-500	169-205	34-40	20,5	72,5	1	1		30	102,5
24	Univ Leipzig	1435,8	40	33	29	153-202	57-79	12-16	76,5	105,5	1			10	115,5
25	TU Darmstadt	633,7	25	17	60	301-400	124-168	24-33	43	103,0	1	1		30	133,0
26	HU Berlin	2985,3	5	18	79				0	79,0	3	1		50	129,0
27	Univ Bremen	575,7	23	23	56	401-500	169-205	34-40	20,5	76,5	2	1		40	116,5
28	FU Berlin	1724,7	10	16	76				0	76,0	3	2	1	100	176,0
29	Univ Konstanz	297,8	34	35	33	301-400	124-168	24-33	43	76,0	1	1	1	60	136,0
30	Univ Halle - Wit	1225,3	35	40	27	203-300	80-123	17-23	65	92,0				0	92,0
31	Univ Duesseldorf	1533,6	29	32	41	301-400	124-168	24-33	43	84,0				0	84,0
32	Univ Ulm	1111,4	33	28	41	301-400	124-168	24-33	43	84,0	1			10	94,0
33	Univ Bielefeld	471,1	38	30	34	301-400	124-168	24-33	43	77,0	1	1		30	107,0
34	TU Braunschweig	566,7	31	38	33	301-400	124-168	24-33	43	76,0				0	76,0
35	Univ Regensburg	987,7	37	39	26	301-400	124-168	24-33	43	69,0				0	69,0
36	U Duisburg Essen	1828,3	28	29	45	401-500	169-205	34-40	20,5	65,5				0	65,5
37	Univ Saarlandes	1273,4	39	22	41	401-500	169-205	34-40	20,5	61,5	1	1		30	91,5
38	Hannover Med Sch	1471,1	51	51	0	401-500	169-205	34-40	20,5	20,5	1	1		30	50,5
39	Univ Hannover	765,3	24	21	57				0	57,0		1		20	77,0
40	Univ Jena	1265,0	30	36	36	401-500	169-205	34-40	20,5	56,5	1			10	66,5
41	Univ Bayreuth	291,8	51	51	0	301-400	124-168	24-33	43	43,0	1			10	53,0
42	Univ Greifswald	648,2	51	51	0	301-400	124-168	24-33	43	43,0				0	43,0
43	Univ Dortmund	566,9	32	34	36				0	36,0				0	36,0
44	Univ Rostock	942,0	51	51	0	401-500	169-205	34-40	20,5	20,5				0	20,5
45	Univ Mannheim	220,7	51	51	0				0	0,0	1			10	10,0

Table 1. Input-output data and ranking criteria for German universities.

[1] Input factor: Budget of the individual university in the three-year time span 2001 to 2003 in million Euro.
[2] Ouput factors: Second-hand data from existing *rankings*, ranking positions transferred to scores in this analysis; mainly *research* output indicators.

3 Validation of Performance Indicators in Productivity Calculations

3.1 Input-Ouput-Analysis

The table below shows productivity calculations (G, H, I) for the division of outputs (D, E, F)[3] by the budget input (A) as research (D/A), excellence (E/A) and meta productivity (F/A).

No	University (DMU)	A. Budget	B. DFG Rank*	C. SJTU Rank*	D. Res Rank*	E. Exc Rank*	F. Total Rank	G. Research Productivity**	H. Excellence Productivity**	I. META Productivity**
29	[redacted]	297,8	33,0	43,0	76,0	60,0	136,0	0,255	0,201	0,457
5	[redacted]	708,9	89,0	65,0	154,0	60,0	214,0	0,217	0,085	0,302
33	Univ Bielefeld	471,1	34,0	43,0	77,0	30,0	107,0	0,163	0,064	0,227
25	Tech Univ Darmstadt	633,7	60,0	43,0	103,0	30,0	133,0	0,163	0,047	0,210
27	Univ Bremen	575,7	56,0	20,5	76,5	40,0	116,5	0,133	0,069	0,202
15	Univ Stuttgart	904,7	87,0	65,0	152,0	30,0	182,0	0,168	0,033	0,201
41	Univ Bayreuth	291,8	0,0	43,0	43,0	10,0	53,0	0,147	0,034	0,182
17	Tech Univ Berlin	943,5	65,0	65,0	130,0	30,0	160,0	0,138	0,032	0,170
12	Univ Bochum	964,7	73,0	65,0	138,0	10,0	148,0	0,143	0,010	0,153
2	[redacted]	1917,6	90,0	99,5	189,5	80,0	269,5	0,099	0,042	0,141
3	[redacted]	2136,5	94,0	94,5	188,5	100,0	288,5	0,088	0,047	0,135
34	Tech Univ Braunschweig	566,7	33,0	43,0	76,0	0,0	76,0	0,134	0,000	0,134
8	[redacted]	1861,7	81,0	90,5	171,5	60,0	231,5	0,092	0,032	0,124
9	Univ Frankfurt	1646,9	74,0	87,0	161,0	40,0	201,0	0,098	0,024	0,122
10	Univ Wuerzburg	1396,7	71,0	87,0	158,0	10,0	168,0	0,113	0,007	0,120
7	[redacted]	1996,4	81,0	92,0	173,0	60,0	233,0	0,087	0,030	0,117
4	[redacted]	2313,3	96,0	65,0	161,0	100,0	261,0	0,070	0,043	0,113
21	Univ Kiel	1464,9	29,0	76,5	105,5	50,0	155,5	0,072	0,034	0,106
11	Univ Tuebingen	1880,7	88,0	87,0	175,0	20,0	195,0	0,093	0,011	0,104
28	[redacted]	1724,7	76,0	0,0	76,0	100,0	176,0	0,044	0,058	0,102
22	Univ Marburg	1197,1	44,0	76,5	120,5	0,0	120,5	0,101	0,000	0,101
39	Univ Hannover	765,3	57,0	0,0	57,0	20,0	77,0	0,074	0,026	0,101
1	[redacted]	3082,6	99,0	100,0	199,0	100,0	299,0	0,065	0,032	0,097
13	Univ Erlangen-Nuernberg	1727,7	69,0	65,0	134,0	30,0	164,0	0,078	0,017	0,095
6	Univ Bonn	2222,1	77,0	87,0	164,0	40,0	204,0	0,074	0,018	0,092
19	Univ Mainz	1779,3	72,0	76,5	148,5	10,0	158,5	0,083	0,006	0,089
14	Univ Hamburg	1952,9	66,0	87,0	153,0	20,0	173,0	0,078	0,010	0,089
16	Tech Univ Dresden	1607,6	67,0	43,0	110,0	30,0	140,0	0,068	0,019	0,087
20	Univ Koeln	1871,2	64,0	76,5	140,5	20,0	160,5	0,075	0,011	0,086
32	Univ Ulm	1111,4	41,0	43,0	84,0	10,0	94,0	0,076	0,009	0,085
24	Univ Leipzig	1435,8	29,0	76,5	105,5	10,0	115,5	0,073	0,007	0,080
18	Univ Muenster	2159,9	62,0	87,0	149,0	20,0	169,0	0,069	0,009	0,078
30	Univ Halle - Wittenberg	1225,3	27,0	65,0	92,0	0,0	92,0	0,075	0,000	0,075
23	Univ Giessen	1408,0	52,0	20,5	72,5	30,0	102,5	0,051	0,021	0,073
37	Univ Saarlandes	1273,4	41,0	20,5	61,5	30,0	91,5	0,048	0,024	0,072
35	Univ Regensburg	987,7	26,0	43,0	69,0	0,0	69,0	0,070	0,000	0,070
42	Univ Greifswald	648,2	0,0	43,0	43,0	0,0	43,0	0,066	0,000	0,066
43	Univ Dortmund	566,9	36,0	0,0	36,0	0,0	36,0	0,064	0,000	0,064
31	Univ Duesseldorf	1533,6	41,0	43,0	84,0	0,0	84,0	0,055	0,000	0,055
40	Univ Jena	1265,0	36,0	20,5	56,5	10,0	66,5	0,045	0,008	0,053
45	Univ Mannheim	220,7	0,0	0,0	0,0	10,0	10,0	0,000	0,045	0,045
26	HU Berlin	2985,3	79,0	0,0	79,0	50,0	129,0	0,026	0,017	0,043
36	Univ Duisburg Essen	1828,3	45,0	20,5	65,5	0,0	65,5	0,036	0,000	0,036
38	Hannover Med Sch	1471,1	0,0	20,5	20,5	30,0	50,5	0,014	0,020	0,034
44	Univ Rostock	942,0	0,0	20,5	20,5	0,0	20,5	0,022	0,000	0,022

* Values of "0" are replaced with a small non-zero number ("0,0001") for the following data envelopment analysis.
** In ranking score per million Euro (budget).

Table 2. Input-output productivity results for German universities.

[3] Output criteria are ranking positions transferred to scores; most output criteria represent research as e.g. attraction of industry, DFG and EU competitive funding for research projects (B), research prizes and faculty size in the SJTU world ranking (C) or awards in the CEI which is also focused on research (esp. first and second strand).

3.2 Data Envelopment Analysis

A data envelopment analysis (DEA) is a widely used tool to calculate the efficiency by individual input-output comparisons of decision making units (DMU). A knowledge of specific production functions as input-output transformation laws is not necessary ('black box') as they are in general not known for universities. Moreover there is no fixed weighting distribution as input necessary but the DEA algorithm is calculating these weighting factors individually and internally for each DMU in order to allow different and individual tracks to efficiency. DEA is seen as an 'objective' method; for general method amendmends see [13, 14, 15, 16, 18, 19, 20, 24, 25, 31, 36, 37, 44, 49, 52, 53, 55, 56, 61, 63]. As a DEA calculation does not require external weighting factors it is often used in areas with assumed and necessary but unidentified weighting factors as well as 'non-monetary indicators', see [45, 48]. This holds true especially for universities as there is *no common sense* in university input as well as output measurement or evaluation, see [39, 54]. Therefore areas with *social output* dimensions ('non-monetary') are typically a striving environment for DEA calculations as e.g. health care and education; see for the *health care* sector [12, 21, 27, 29, 35, 41, 62] and for the *university* sector [1, 2, 3, 4, 26, 28, 31, 32, 34, 40, 43, 46, 47, 60]. Different modelling decisions regarding the DEA model are necessary – the most important ones are discussed in detail, for general criteria compare [33]:

(A) DEA can be basically used as input-oriented or output-oriented model (not-oriented models can be neglected). Both models provide interesting research questions and outcomes in an university analysis: In an *input-oriented* model the assumption has to hold true that universities are faced with *fixed* outputs and try to *minimize* their input resources – this is obviously the 'budgeting' perspective of higher education politicians and politics (ministry of education or ministry of finance). As *output-oriented* model it has to be assumed that input parameters are inflexible and can not be influenced – this is naturally the perspective of institutional management within the universities who has only a very small definition clout to change resource inflow. Proximate university management will try to *maximise output* indicators by steering mechanims in order to increase university productivity. This can be compared to the management concept of a *resource-based view* emphasising the intangible nature especially of e.g. human capital as important production factor in HE. It can be assumed that this output-oriented model largely reflects the *interior perspective* of universities and their management respectively.

(B) A modus for assumed *returns to scale* has to be identified depicting the actual production context: Based on practical management experience and heuristic assumptions generally a model with *constant* returns to scale is used as CCR-Model [15, 56]. The specific situation of universities with unknown production technologies and functions requires this modus and therefore it will be used here. The prerequisite of a university's ability to *scale its size* according to external requirements can be assumed to hold true and in this way a comparison to other research findings is possible. An alternative could be the so-called BCC-Model with *variable* returns to scale, see [5, 6]. This is not needed in the provided case.

(C) The number n_{Ob} of required DMU (here: number of universities) data sets for n_{in} inputs und n_{out} outputs has to be checked against the general fuzzy requirement: $n_{Ob} \geq \max \{ n_{in} \bullet n_{out}, 3 \bullet (n_{in}+n_{out}) \}$; see [19, 33]. With $n_{Ob} = 45$ DMUs in this DEA calculation there is no significant restriction to model combinations as there are only three possible factors present altogether inputs or outputs. This would denote that $n_{in} \bullet n_{out} = 2$ and $n_{in} + n_{out} = 3$ hold true for all cases and therefore $n_{Ob} \geq \max \{2,9\}$, implying $n_{Ob} \geq 9$ for all possible cases.

The presented results were calculated and printed with the software ‚Frontier Analyst®', version 4.0.10, of Banxia Holdings Ltd. and are adressing the following factor combination: input A (Budget); output D (Research Ranking) and output E (Excellence Initiative Ranking). Within this input-oriented combination the DEA analysis refers to the DMU no. 29 (University of Konstanz) as the *sole* efficient institution, being referred to 45 times for efficiency improvements of other DMUs (which stands for a very high 'benchmarking power' of this university).

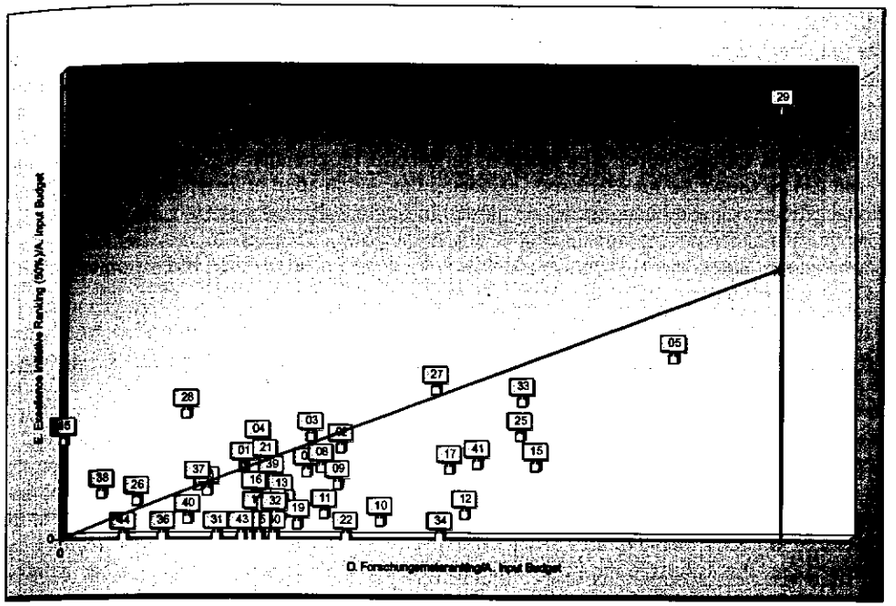

Figure 1. DEA efficiency frontier for input A (Budget) and outputs D (Research Meta Ranking) and E (Excellence Initiative Ranking).

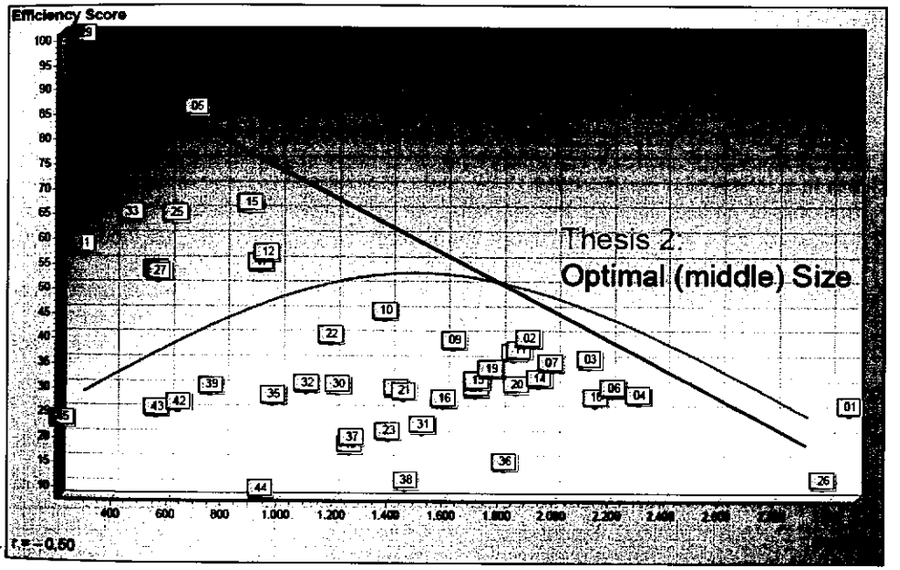

Figure 2. DEA efficiency plot for input A (Budget, three years sum 2001-2003).

Combined with the institutional history as a very young institution founded less than 50 years ago this productivity result is astonishing and can be related to a very special history ('reform university') as well as professional concept development and tender management in the process of the GEI Programme during 2006 and 2007. The next second efficient DMU in this calculation is the University of Karlsruhe (no. 5) with 85,1% efficiency – and subsequently all

other universities are positioned below 70% efficiency compared to no. 29. Figure 1 shows the specific efficiency frontier with the exceptional position of no. 29 (University of Konstanz). For the explained *political* interpretation (input-oriented model) this would translate into the thesis, that public funding 'invested' in the most efficient universities of Konstanz and Karlsruhe relatively yield the *highest* 'returns' in terms of research output, research ranking positions and the 'excellence position' in the GEI Programme. An additional interesting result can be shown in this calculation regarding the combination of efficiency score ('institutional efficiency') and budget size:[4] As plotted in figure 2 there is a *slightly inverted correlation* in this indicator set announcing a slightly higher efficiency for smaller institutions (measured in budget size). Therefore *diseconomies of scale* can be observed for universities – at least for larger institutions (thesis 1 in figure 2).

This DEA model has a precondition in *constant* returns to scale. This concept is widely acknowledged but should also be reviewed regarding the specific situation of university production – especially as the standard assumption of a scalable institutional size could be *seriously doubted* in the light of the DEA results presented here. It could be assumed on the contrary that for universities there may exist an *optimal 'middle' institutional size* (thesis 2 in figure 2). Larger universities may well be confronted with *disproportionate higher* input requirements in order to increase their output further and therefore experience *decreasing* productivity ratios. Therefore a BCC model for a further DEA analysis should be tested for universities in order to allow for variable returns to scale, see [5]. In a later research study then a *comparison* between the DEA results in the CCR model and the BCC model may establish further insights into the specific production situation and efficiency in universities.

4 Conclusions

The described productivity and performance indicators and analysis (input-output analysis and data envelopment analysis) may well lead to the below-listed general research theses:[5]

- University productivity is only weakly linked to (budget) size of universities. It can be assumed that an optimal size of universities can be defined in a middle range institutional size. University productivity is also not strongly correlated to ranking positions.
- For some industries and situations rankings could also be also reliable performance indicators (e.g. in service areas as tourism).
- Rankings as rational input i.e. for top management incentives (not based on absolute turnover, stock price development or profit but performance compared to other industry competitors – „best in class" concept) could improve on the "princial-agent problem".
- Rankings and competitions could probably be powerpul instruments for internatial resource allocation in companies (e.g. product development).
- As in HE for service industries there may exist a crucial role of industry standards / accepted rankings as reference indicators.

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[4] Be aware that the y-axis does not plot output but efficiency. Absolute output still may be considerably higher in larger institutions but not in relative terms when measured as ratio between output and input. Efficiency is calculated within the DEA as individual production combination (throughput) comparing output and input.

[5] Political implications may include *inverse* funding (larger funds for smaller institutions, no extra grant money for larger institutions), integration of *efficiency* criteria in indicator based budgets for public funded universities as well as the use of separate *efficiency* criteria in official rankings.

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