CESifo WORKING PAPERS

7055
2018

May 2018

How to Measure Research Efficiency in Higher Education? Research Grants vs. Publication Output

Sabine Gralka, Klaus Wohlrabe, Lutz Bornmann

CESifo

Impressum:

CESifo Working Papers
ISSN 2364-1428 (electronic version)
Publisher and distributor: Munich Society for the Promotion of Economic Research - CESifo GmbH
The international platform of Ludwigs-Maximilians University's Center for Economic Studies and the ifo Institute
Poschingerstr. 5, 81679 Munich, Germany
Telephone +49 (0)89 2180-2740, Telefax +49 (0)89 2180-17845, email office@cesifo.de
Editors: Clemens Fuest, Oliver Falck, Jasmin Gröschl
www.cesifo-group.org/wp

An electronic version of the paper may be downloaded
· from the SSRN website: www.SSRN.com
· from the RePEc website: www.RePEc.org
· from the CESifo website: www.CESifo-group.org/wp

CESifo *Working Paper No. 7055*
Category 5: Economics of Education

How to Measure Research Efficiency in Higher Education? Research Grants vs. Publication Output

Abstract

An ongoing debate in the literature on efficiency of higher education institutions concerns the indicator for research output in the empirical analysis. While several studies chose to use the number of publications, others rely on the overall amount of research grants. The present study investigates whether both lead to similar or different assessments of universities. Besides the amount of research grants and the absolute number of publications, the number of publications belonging to the 10% and 1% most frequently cited papers in the corresponding subject category and publication year are evaluated. We show that there is a high correlation of efficiency values between the estimations using these indicators; however, the concordance is partly lower. The results do not only provide a helpful guideline for researchers, but are also valuable for policy makers deciding which incentives to create through funding.

JEL-Codes: A230, H520, I210, I230, D610.

Keywords: efficiency, data envelopment analysis, stochastic frontier analysis, higher education, universities, Germany.

*Sabine Gralka**
TU Dresden
Münchner Platz 2-3
Germany – 01069 Dresden
sabine.gralka@tu-dresden.de

Klaus Wohlrabe
Ifo Institute – Leibniz Institute for Economic Research at the University of Munich, Poschingerstr. 5
Germany – 81679 Munich
wohlrabe@ifo.de

Lutz Bornmann
Division for Science and Innovation Studies
Administrative Headquarters of the Max Planck Society
Hofgartenstr. 8
Germany – 80539 Munich
bornmann@gv.mpg.de

*corresponding author

May 2018

Introduction

An ongoing debate in the literature on efficiency of higher education [HE] institutions concerns the indicator for research output in the empirical analysis. The necessity to capture not only the quantity, but also the quality of the output makes the measurement of the value of research a controversial topic (Abbott and Doucouliagos, 2003). Usually driven by the data availability to researchers, some studies are based on the number of publications, while others rely on the overall amount of research grants. A line of reasoning for both indicators can easily be derived. While publications have the advantage of being available in multi-disciplinary databases (e.g. Web of Science provided by Clarivate Analytics), the measure is retrospective. To consider quality issues in performance measurements, some form of citation weighting of publication numbers is used in various studies, resulting in more complex indicators (Rhaiem, 2017). The use of research grants in efficiency studies also has its proponents and opponents. Johnes (1997) and Worthington (2001) argue that research grants reflect the market value of conducted research and can therefore be considered as a quality adjusted proxy for output. Johnes and Johnes (1993), however, question the use of external funding as output measure, arguing that the funds are not only spent on research assistance but also on other facilities which are an input for production.

While one cannot conclusively argue whether research grants or number of publications is better suited to represent research output in efficiency examinations, the present study aims to empirically show whether both lead to similar or different overall assessments of universities. We utilize a comprehensive dataset and contrast both indicators. Looking at German universities, we estimate efficiency in different settings (using research grants and publication measures). The comparison of the outcomes reveals whether (or not) the results are comparable (convergently valid) and can therefore be interchangeably used in the assessment of institutions. To investigate the reliability of our findings we estimate institutional efficiency with different methodological approaches utilizing the classic Data Envelopment Analysis [DEA] as well as a recent specification of the Stochastic Frontier Analysis [SFA]. Following the argumentation raised by Agasisti and Haelermans (2016) and assuming that public universities respond to incentives given through funding formulas by focusing on those activities or outputs that are rewarded, the research question is equally relevant for policy makers.

The paper is divided into six main sections. The second and the third section briefly discuss the existing literature and the methods of efficiency measurement. The fourth section deals with the specification of higher education inputs and outputs and describes the used data and its sources. The fifth section presents the results and the paper ends with some concluding remarks.

Literature

A comprehensive overview of the literature regarding efficiency in HE can be found in Rhaiem (2017) and De Witte and López-Torres (2017). Both overviews verify that the research output of universities can be represented in a number of ways, with most studies either choosing publications

or research grants. The utilization of both indicators in a single study is uncommon. To the best of our knowledge only few studies combine them, among them are Warning (2007) for the German HE sector, Johnes and Johnes (1993) for university departments of economics in the UK and Worthington and Lee (2008) as well as Worthington and Higgs (2011) for Australian universities. With the exception of the latter all three utilize a DEA framework. They employ both indicators for the measurement of output, partially acknowledging that the inclusion of both as an output is critical, due to their mutual conditionality (Johnes and Johnes, 1993). A classification of studies with regard to the applied research indicators [RI] can be found in Table 1, an overview of all studies regarding the German HE sector in Table 2.

Table 1: Categorization of selected studies evaluating universities with respect to their applied RI

RI:	Research Grants	Publications	Both
DEA	Johnes (2006); Agasisti and Johnes (2009); Thanassoulis et al. (2011)	Wolszczak-Derlacz and Parteka (2011); Nazarko and Šaparauskas (2014)	Johnes and Johnes (1993); Worthington and Lee (2008)
SFA	Izadi et al. (2002); Stevens (2005); Agasisti and Johnes (2010)	De Groot, McMahon and Volkwein (1991); Bayraktar et al. (2013)	-

Table 2: Categorization of studies evaluating German universities with respect to their applied RI

RI:	Research Grants	Publications	Both
DEA	Fandel (2007); Başkaya and Klumpp (2014); Gawellek and Sunder (2016)	Lehmann et al. (2018); Wohlrabe et al. (2018)	Warning (2007)
SFA	Kempkes and Pohl (2008); Johnes and Schwarzenberger (2011); Olivares and Wetzel (2011); (Agasisti and Gralka 2017); Gralka (2018)	-	-
DEA and SFA	Kempkes and Pohl (2010); Eck, Gralka and Heller (2015)	-	-

Methods

To investigate the reliability of our indicator comparisons, we estimate efficiency utilizing DEA as well as a recent specification of the SFA. While the former, as a non-parametric method, permits the comparison of multiple in- and outputs and does not require assumptions regarding the underlying production or cost function, the latter as a parametric approach allows to control for noise and provides information on the statistical properties of the estimators. A detailed overview of both methods with regard to the HE Sector can be found exemplary in Johnes et al. (2005). For the DEA, the specification by Banker, Charnes and Cooper (1984) is used, assuming a variable returns to scale, output-oriented model. For the SFA, the approach from Kumbhakar, Lien and Hardaker (2014) is used allowing to control for heterogeneity between institutions. Heterogeneity refers to permanent differences between institutions, which are not alterable by the institutions and should therefore be ruled out from the efficiency term. This control is essential for an accurate

estimation (Gralka, 2018).[1] The SFA specifications are based on a normalized translog costfunction and are estimated using maximum likelihood, assuming a half-normal distribution of the efficiency term, following Kempkes and Pohl (2010).

Data

The panel dataset for the present study covers the years 2004 to 2013 and consists of 72 German public universities, providing a comprehensive view of the German HE landscape. The dataset includes information concerning the amount of research grants as well as three bibliometric output measures. The graduate numbers cover the academic years 2004/2005 through 2013/14, and the financial variables cover the business years 2004 until 2013. German institutions specialized in certain fields, such as fine arts, universities of applied sciences, and distance universities are excluded from the set. All data used in this study are adjusted by the medical sector. The inclusion of their (inflated) costs could lead to a severe bias of the efficiency results as they do not only refer to research, but also to the general health provision. Furthermore, not all German universities provide hospitals.

The data on expenditures, research grants and graduates were provided by the Federal Statistical Office of Germany. All monetary variables are deflated to the year 2013. Research grants are defined as funds which are raised in addition to the regular university budget with the aim to promote research and the development of young scientists. They are provided by public as well as private bodies.[2] The bibliometric data are from an in-house database developed and maintained by the Max Planck Digital Library (MPDL, Munich) and derived from the Science Citation Index Expanded (SCI-E), Social Sciences Citation Index (SSCI), Arts and Humanities Citation Index (AHCI) prepared by Clarivate Analytics. Publications are defined as articles and reviews. To our knowledge it is the first time that publication measures, taking quality into account, are incorporated in the efficiency evaluation of German universities.

We consider teaching and research as the primary activities of universities. These two outputs are evaluated with respect to the main input, i.e., the institution's expenses. The first output variable "teaching" is represented by the total number of graduates from bachelor's and master's courses (or equivalent) differentiated across science and non-science subject categories.[3] Research output is measured either by research grants [RG] or the number of publications [P]. To account for quality issues in output measurements we additionally use the number of publications which belong to the 10% [$P_{top\ 10\%}$] or 1% [$P_{top\ 1\%}$] most frequently cited papers in their subject category and publication year besides P. The dependent variable is the sum of annual personnel and other current expenditures, less research grants. To capture differences in the structure of staff across

[1] The additionally estimated classic SFA specification by Battese and Coelli (1992) produces even higher correlations between the estimations than the recent specification using both indicators (not shown in this paper).

[2] For more information see German Federal Statistical Office (2015).

[3] Science contains mathematics, natural sciences, veterinary medicine, agricultural, forest and nutritional sciences, and engineering. Non-science subjects are courses related to art, economics, law, sports, and culture.

universities the wage levels are included. Wages, approximated by the total personnel expenditures divided by the number of full-time occupied equivalents, are included as an input in the DEA and as an input price in the SFA (Stevens, 2005).

Descriptive statistics are reported in Table 3. The values are similar to Johnes and Schwarzenberger (2011) who look at Germany, as well as Bolli et al. (2016), who consider selected European countries. The graduate numbers amount to approximately 900 on average in sciences and 1,500 in non-science areas. An average institution possesses research grants of around 50 million euros and brings out around 1,050 publications. The current expenditures sum up to 130 million euros annually and the average wage rate amounts to around 77,000 euros per year. A rather prominent characteristic of the descriptive statistics, which is in line with the literature, is that for each variable, the standard deviation is close to the mean. This indicates a considerable degree of heterogeneity among institutions.

Table 3: Descriptive statistics

Variable	Mean	Std. Dev.	Min	Max
Graduates Science [a]	935.46	786.58	0.00	6089.00
Graduate Non-Science [a]	1467.54	1040.31	0.00	5838.00
Research Grants [b]	50.06	44.85	1.01	265.73
Publications Count [a]	1048.72	944.76	2.00	4986.00
Publications Top 10 % [a]	142.66	150.51	0.00	917.45
Publications Top 1 % [a]	17.23	20.95	0.00	153.37
Expenditures [b]	132.71	78.63	12.87	375.33
Wages [c]	76.81	15.28	32.34	154.37

Source: Federal Statistical Office of Germany; own calculations.
[a] Absolut values, [b] In € million, 2013 prices, [c] In 1000 €, 2013 prices.

Results and Discussion

The results from the DEA estimations show that all four RI lead to mean efficiency values of around 0.78 (Table 4), with a low standard deviation.[4] The similarity is confirmed by a high correlation of the efficiency values, illustrated in Figure 1. The plot of the institutional efficiency values for the three publication measures relative to the RG estimation exhibits an almost diagonal line. This conclusion is confirmed by a high mean Spearman rank and Pearson correlation coefficient as well as a high concordance measure (Lin 2000), displayed in Table 4.[5] Figure 2 shows that the results for all three coefficients are robust over the whole time span and increase over time. Therefore, the utilized RI seems to lead to similar overall efficiency assessments within the DEA framework.

[4] The detailed results are available upon requests from the authors.
[5] Since correlation does not measure agreement (or reproducibility), we additionally calculated the concordance.

Figure 1: Scatter plot of mean efficiency values per institution

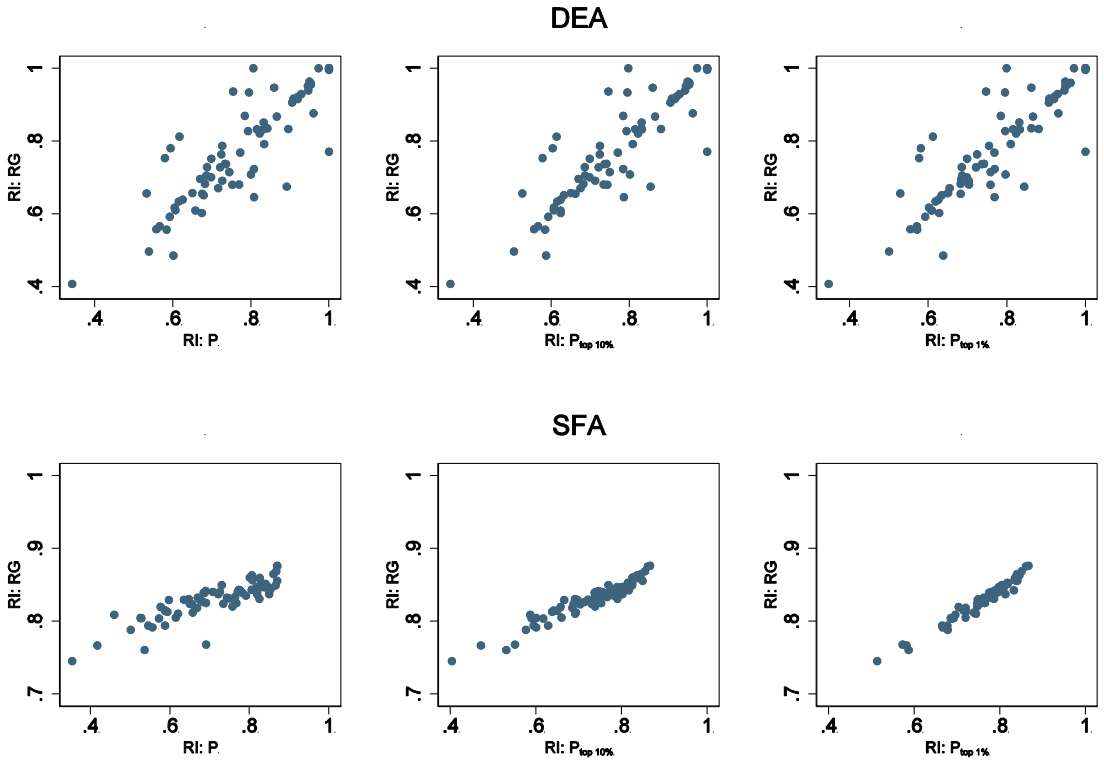

Figure 2: Spearman rank correlations, Pearson correlations and concordance to RG estimation over time

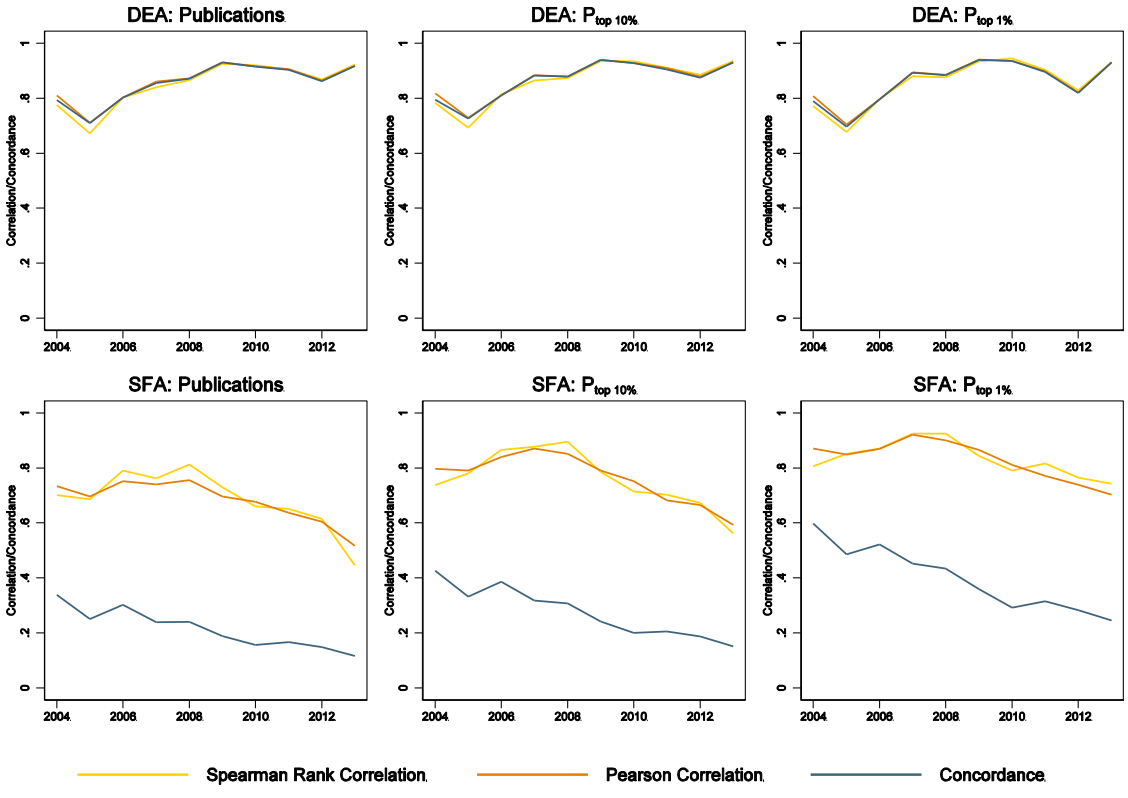

Table 4: Average efficiency scores, Spearman rank correlations, Pearson correlations and concordance between 2004 and 2013

	DEA				SFA			
RI:	**RG**	**P**	**$P_{top\ 10\%}$**	**$P_{top\ 1\%}$**	**RG**	**P**	**$P_{top\ 10\%}$**	**$P_{top\ 1\%}$**
Efficiency Scores	0.782	0.785	0.781	0.779	0.829	0.712	0.729	0.760
Std. Deviation	0.163	0.158	0.160	0.163	0.041	0.123	0.099	0.073
Spearman	-	0.849	0.863	0.854	-	0.685	0.759	0.833
Pearson	-	0.859	0.871	0.861	-	0.681	0.763	0.830
Concordance	-	0.856	0.867	0.858	-	0.214	0.275	0.398

This conclusion is partly confirmed by the SFA estimation results. Table 4 shows that the RG indicator leads to a slightly higher mean efficiency value (0.83) than the inclusion of the publication measures (0.72). The low standard deviation implies that the variance of efficiency values is small again, with most values being close to the mean. The Spearman and Pearson correlation coefficients, depicted in Table 4, confirm a high correlation between the three publication measures relative to the RG estimation. Figure 2 shows that the results are robust over the whole time span, but that the correlation coefficient decreases slightly over time. While the concordance measure exhibits a similar trend, it is lower, driven by the lower mean efficiency value of the publication estimation. Table 4 additionally displays that the correlation between RG and bibliometric measures increases with the focus on highly cited papers. This result can be seen as a sign that universities which are good in acquiring third party funds are the ones which are equally good in publishing high-quality research.

Furthermore interesting is the look at the outliers, which are prominent in the DEA estimation, depicted in Figure 1. Seven universities possess a deviation between the efficiency values of the respective indicators greater than 0.1 (and are therefore located “above” the line). In other words, the TH Aachen, TU Freiberg, TU Chemnitz, TU Clausthal, U Bremen, U Konstanz and U Stuttgart exhibit a higher efficiency value if research grants are used for the estimation, instead of publications. In contrast four universities show a deviation which is lower than -0.1 (and are therefore “below” the line). The universities U Düsseldorf, U Heidelberg, U Tübingen and U Ulm seem to benefit from the estimation using publications as a research indicator. While the DEA does not allow to conclusively explain the drivers behind the efficiency values, a look at the descriptive statistic of these outliers is insightful. Table 5 shows the ratio of the average amount of publications to the average amount of research grants, for each of the mentioned institutions relative to the mean of the sample. As one would expect, the seven universities exhibit a value below average (due to their relative high amount of research grants) and the four institutions exhibit a value above average (due to their relative high amount of publications). These differences seem to at least partially explain the position of the outliers. When applying the DEA to measure

efficiency of higher education institutions one should therefore keep the heterogeneity aspect of the institutions in mind.[6]

Table 5: University specific ratios of the RI (ratios of the mean)

	Ratio P / RG	**Ratio $P_{top\ 10\%}$ / RG**	**Ratio $P_{top\ 1\%}$ / RG**
TH Aachen	10.307	1.361	0.178
U Stuttgart	7.682	0.980	0.109
U Konstanz	12.946	1.898	0.159
TU Chemnitz	7.469	0.640	0.062
TU Freiberg	6.644	0.418	0.036
U Bremen	9.423	1.130	0.111
TU Clausthal	9.065	0.769	0.069
Mean	**22.170**	**2.875**	**0.344**
U Heidelberg	43.990	6.873	0.930
U Tübingen	44.820	6.458	0.832
U Düsseldorf	59.429	8.570	1.236
U Ulm	51.709	6.866	0.869

Source: Federal Statistical Office of Germany; own calculations.

Conclusions

The present study investigates whether the often used indicators for research output "publications" and "research grants" lead to similar or different assessments of universities. Besides the amount of research grants and the absolute number of publications, the number of publications belonging to the 10% and 1% most frequently cited papers in the corresponding subject category and publication year are evaluated. To investigate the reliability of our indicator comparisons, we estimate efficiency utilizing DEA as well as a recent specification of the SFA, controlling for heterogeneity between institutions.

Our analysis points out that the efficiency values based on research grants and publication measures are highly correlated. Slightly varying results can be seen with the SFA, with a slight decrease in correlation over time and a lower concordance. We conclude that the RIs can be used interchangeably in the assessment of universities (at least with the DEA). In the interpretation of the results, however, it should be considered that the present study only evaluates the German HE sector. While it is likely that this holds true for other countries, we advise to examine this with corresponding datasets.

[6] Since there are no outliers with a deviation bigger than 0.1 (or lower than -0.1) in the SFA estimation, we put our focus on the DEA results only. These in comparison "missing outliers" can be explained by the allowance of heterogeneity between institutions in the utilized SFA specification, confirming the advantage of it. In contrast, the additional tested classic SFA specification by Battese and Coelli (1992) exhibits outliers.

The results of this study are not only interesting for researchers, but also for policy makers deciding which incentives should be selected to increase research output (or efficiency). Following the argumentation raised by Agasisti and Haelermans (2016) public universities respond to incentives given through funding formulas by focusing on those activities or outputs that are rewarded. Thus, if our findings had shown that both indicators (number of publications and grants) lead to strongly varying efficiency values, it would have implied that the relative efficiency is strongly influenced by the policy perspective adopted. Since our results nevertheless show that the resulting efficiency values are alike, one can assume that research grants and publications go hand in hand and the incentive for one probably has a positive effect on the other.

References

Abbott, Malcolm, and Chris Doucouliagos. 2003. "The Efficiency of Australian Universities: A Data Envelopment Analysis." *Economics of Education Review* 22 (1): 89–97.

Agasisti, Tommaso, and Sabine Gralka. 2017. "The Transient and Persistent Efficiency of Italian and German Universities: A Stochastic Frontier Analysis." *CEPIE Working Paper* 14/17.

Agasisti, Tommaso, and Carla Haelermans. 2016. "Comparing Efficiency of Public Universities among European Countries: Different Incentives Lead to Different Performances." *Higher Education Quarterly* 70 (1): 81–104.

Agasisti, Tommaso, and Geraint Johnes. 2009. "Beyond Frontiers: Comparing the Efficiency of Higher Education Decision-Making Units across More than One Country." *Education Economics* 17 (1): 59–79.

Agasisti, Tommaso, and Geraint Johnes. 2010. "Heterogeneity and the Evaluation of Efficiency: The Case of Italian Universities." *Applied Economics* 42 (11): 1365–1375.

Banker, Rajiv D., Abraham Charnes, and William Wager Cooper. 1984. "Some Models for Estimating Technical and Scale Inefficiencies in Data Envelopment Analysis." *Management Science* 30 (9): 1078–1092.

Başkaya, Sait, and Matthias Klumpp. 2014. "International Data Envelopment Analysis in Higher Education: How Do Institutional Factors Influence University Efficiency?" *Journal of Business and Economics* 5 (11): 2085–2090.

Battese, George E., and Tim J. Coelli. 1992. *Frontier Production Functions, Technical Efficiency and Panel Data: With Application to Paddy Farmers in India*. Springer.

Bayraktar, Erkan, Ekrem Tatoglu, and Selim Zaim. 2013. "Measuring the Relative Efficiency of Quality Management Practices in Turkish Public and Private Universities." *Journal of the Operational Research Society* 64 (12): 1810–1830.

Bolli, Thomas, Maria Olivares, Andrea Bonaccorsi, Cinzia Daraio, Adela Garcia Aracil, and Benedetto Lepori. 2016. "The Differential Effects of Competitive Funding on the Production Frontier and the Efficiency of Universities." *Economics of Education Review* 52: 91–104.

De Groot, Hans, Walter W. McMahon, and J. Fredericks Volkwein. 1991. "The Cost Structure of American Research Universities." *The Review of Economics and Statistics*, 424–431.

De Witte, Kristof, and Laura López-Torres. 2017. "Efficiency in Education: A Review of Literature and a Way Forward." *Journal of the Operational Research Society* 68 (4): 339–363.

Eck, Alexander, Sabine Gralka, and Julia Heller. 2015. "Zur Effizienz Der Hochschulen in Den Ost-Und Westdeutschen Flächenländern." *Ifo Dresden Berichtet* 22 (2): 33–41.

Fandel, Günter. 2007. "On the Performance of Universities in North Rhine-Westphalia, Germany: Government's Redistribution of Funds Judged Using DEA Efficiency Measures." *European Journal of Operational Research* 176 (1): 521–533.

Gawellek, Bastian, and Marco Sunder. 2016. *The German Excellence Initiative and Efficiency Change among Universities, 2001-2011*. Working Paper, Universität Leipzig, Wirtschaftswissenschaftliche Fakultät.

German Federal Statistical Office. 2015. "Monetäre Hochschulstatistische Kennzahlen, Fachserie 11 Reihe 4.3.2." *Wiesbaden*, January, 1–8.

Gralka, Sabine. 2018. "Persistent Inefficiency in the Higher Education Sector: Evidence from Germany." *Education Economics*, in press.

Izadi, Hooshang, Geraint Johnes, Reza Oskrochi, and Robert Crouchley. 2002. "Stochastic Frontier Estimation of a CES Cost Function: The Case of Higher Education in Britain." *Economics of Education Review* 21 (1): 63–71.

Johnes, Geraint. 1997. "Costs and Industrial Structure in Contemporary British Higher Education." *The Economic Journal* 107 (442): 727–737.

Johnes, Geraint, and Jill Johnes. 1993. “Measuring the Research Performance of UK Economics Departments: An Application of Data Envelopment Analysis.” *Oxford Economic Papers*, 332–347.

Johnes, Geraint, Jill Johnes, Emmanuel Thanassoulis, Pam Lenton, and Ali Emrouznejad. 2005. *An Exploratory Analysis of the Cost Structure of Higher Education in England*. UK Department for Education and Skills.

Johnes, Geraint, and Astrid Schwarzenberger. 2011. “Differences in Cost Structure and the Evaluation of Efficiency: The Case of German Universities.” *Education Economics* 19 (5): 487–499.

Johnes, Jill. 2006. “Data Envelopment Analysis and Its Application to the Measurement of Efficiency in Higher Education.” *Economics of Education Review* 25 (3): 273–288.

Kempkes, Gerhard, and Carsten Pohl. 2008. “Do Institutions Matter for University Cost Efficiency? Evidence from Germany.” *CESifo Economic Studies* 54 (2): 177–203.

Kempkes, Gerhard, and Carsten Pohl. 2010. “The Efficiency of German Universities–some Evidence from Nonparametric and Parametric Methods.” *Applied Economics* 42 (16): 2063–2079.

Kumbhakar, Subal C., Gudbrand Lien, and J. Brian Hardaker. 2014. “Technical Efficiency in Competing Panel Data Models: A Study of Norwegian Grain Farming.” *Journal of Productivity Analysis* 41 (2): 321–337.

Lehmann, Erik E., Michele Meoli, Stefano Paleari, and Sarah AE Stockinger. 2018. “Approaching Effects of the Economic Crisis on University Efficiency: A Comparative Study of Germany and Italy.” *Eurasian Business Review* 8 (1): 37–54.

Lin, L.I.-K. 2000. “A Note on the Concordance Correlation Coefficient.” *Biometrics 56,* 324–325.

Nazarko, Joanicjusz, and Jonas Šaparauskas. 2014. “Application of DEA Method in Efficiency Evaluation of Public Higher Education Institutions.” *Technological and Economic Development of Economy* 20 (1): 25–44.

Olivares, Maria, and Heike Wetzel. 2011. “Competing in the Higher Education Market: Empirical Evidence for Economies of Scale and Scope in German Higher Education Institutions.” *CESifo Economic Studies* 60 (4): 653–680.

Rhaiem, Mehdi. 2017. “Measurement and Determinants of Academic Research Efficiency: A Systematic Review of the Evidence.” *Scientometrics* 110 (2): 581–615.

Stevens, Philip Andrew. 2005. “A Stochastic Frontier Analysis of English and Welsh Universities.” *Education Economics* 13 (4): 355–374.

Thanassoulis, Emmanuel, Mika Kortelainen, Geraint Johnes, and Jill Johnes. 2011. “Costs and Efficiency of Higher Education Institutions in England: A DEA Analysis.” *Journal of the Operational Research Society* 62 (7): 1282–1297.

Warning, Susanne. 2007. *The Economic Analysis of Universities: Strategic Groups and Positioning*. Cheltenham UK: Elgar.

Wohlrabe, Klaus, Lutz Bornmann, Sabine Gralka, and Felix de Moya Anegon. 2018. “Wie Effizient Forschen Universitäten in Deutschland, Deren Zukunftskonzepte Im Rahmen Der Exzellenzinitiative Ausgezeichnet Wurden?” *Ifo Working Paper* 253.

Wolszczak-Derlacz, Joanna, and Aleksandra Parteka. 2011. “Efficiency of European Public Higher Education Institutions: A Two-Stage Multicountry Approach.” *Scientometrics* 89 (3): 887.

Worthington, Andrew C. 2001. “An Empirical Survey of Frontier Efficiency Measurement Techniques in Education.” *Education Economics* 9 (3): 245–268.

Worthington, Andrew C., and Helen Higgs. 2011. “Economies of Scale and Scope in Australian Higher Education.” *Higher Education* 61 (4): 387–414.

Worthington, Andrew C., and Boon L. Lee. 2008. “Efficiency, Technology and Productivity Change in Australian Universities, 1998–2003.” *Economics of Education Review* 27 (3): 285–298.