University System Production Function Simulation

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Production Function, University Simulation, DEA, GAMS

ABSTRACT
Production functions are a cornerstone of business administration research and operations research especially. Though very seldom specific production functions are discussed and calculated – interestingly as it is common sense that each institution and sector has specific production function characteristics. One such sector is the higher education and research sector itself – where many authors argue in literature that there are so many different throughput and output factors for universities that a production function simulation has to fail. This article analyzes the option to calculate ex-post productivity data from a large European dataset (EUMIDA) with DEA and further on build an production and optimiziation approach for a university system-level simulation with obvious correlations (e.g. using the throughput factors public/pricate, country, university hospital) in a GAMS modelling.

PROBLEM DESCRIPTION
Productivity analysis is a very interesting field of study, especially in public market settings as higher education (Cohn et al., 1989; Beasley, 1995; Dundar & Lewis, 1995; Glass et al. 1998; Ng & Li, 2000; Korhonen et al., 2001; Kocher et al., 2006; Kao & Hung, 2008; Sarrico, 2010).

EUMIDA ID	University Name	Found. Year	Univ. Hospital	Staff (Input)	Doctorate Degrees Awarded (Output)	Total Students (Output)	Total Int. Students (Output)	Efficiency (Case A without Int. Students)	Efficiency (Case B without Total Stud.)	Efficiency (Case C - all Output Indic.)	Efficiency (Case D - Restricted Weights 25%)
RO052	RO NSPA Bucharest	1991	No	282	50	14819	110	100.0%	56.0%	100.0%	18.4%
UK135	UK U. Cardiff	1883	Yes	1105	350	26587	4143	100.0%	100.0%	100.0%	88.4%
UK137	UK U. Glamorgan	1913	No	487	40	22710	3777	91.8%	95.1%	100.0%	100.0%
UK126	UK U. Westminster	1838	No	604	25	23224	5446	75.7%	100.0%	100.0%	70.3%
GR016	GR U. Patras	1964	Yes	1324	127	22089	1123	93.2%	36.2%	95.0%	58.4%
GR013	GR U. of Economics Athens	1920	No	371	30	17557	744	87.4%	48.6%	89.7%	71.3%
SK011	SK Elizabeth Coll. Bratislava	2003	Yes	333	36	13304	619	78.7%	40.0%	80.4%	58.3%
GR010	GR U. Macedonia	1948	No	367	24	14086	500	75.6%	26.6%	76.8%	42.7%
UK128	UK U. Wolverhampton	1932	No	653	25	21305	3044	64.3%	55.0%	69.1%	58.6%
GR020	GR Kapodistrian U. Athens	1837	Yes	3070	401	93004	3931	65.3%	41.2%	67.3%	44.7%
NL006	NL U. Groningen	1614	Yes	1498	306	25322	1321	66.1%	64.5%	66.1%	31.0%
RO034	RO U. Sibiu	1844	No	1166	104	26415	157	65.7%	62.8%	65.7%	8.4%
DE052	DE U. Marburg	1527	No	2704	473	19142	1956	55.2%	55.2%	55.2%	21.9%
UK132	UK U. York	1963	No	1576	250	13184	2725	50.1%	50.1%	50.1%	36.1%
AT001	AT U. Vienna	1365	No	4924	594	67457	11962	36.5%	49.2%	49.5%	53.4%
DE105	DE U. Kiel	1665	No	2544	398	22128	1722	49.4%	49.4%	49.4%	22.4%
RO046	RO U. of Econ. Bucharest	1852	No	1006	200	17703	177	48.9%	23.9%	48.9%	4.3%
AT004	AT U. Salzburg	1622	No	1466	134	12471	2408	43.4%	48.3%	48.3%	47.8%
RO010	RO U. Babes-Bolyai	1959	No	2606	275	54285	513	48.5%	33.3%	48.3%	8.3%
AT003	AT U. Innsbruck	1669	No	2296	228	21123	6428	33.3%	47.9%	47.9%	42.1%
RO003	RO U. Pitesti	1962	No	791	60	19652	69	46.9%	28.2%	46.9%	5.7%
CH001	CH U. Basel	1460	Yes	2473	365	11312	2254	46.6%	46.6%	46.6%	20.2%
IT061	IT U. Med. Reggio Calabria	1983	No	674	84	10551	41	46.6%	39.3%	46.6%	3.00%
SE008	SE TU KTH Stockholm	1827	No	2125	235	15719	5136	34.9%	46.2%	46.2%	36.4%
ES038	ES U. Autonoma Madrid	1968	Yes	2491	342	31878	1566	46.1%	43.3%	46.1%	22.3%
DE049	DE U. Gießen	1607	No	3179	462	22508	1325	45.9%	45.9%	45.9%	15.2%
DE058	DE TU Braunschweig	1745	No	2693	385	12683	1359	45.1%	45.1%	45.1%	15.1%
IE004	IE Trinity College Dublin	1592	Yes	1892	269	14642	1507	44.9%	44.9%	44.9%	23.6%
PL192	PL C.S.Wyszynski U. Warsaw	1999	No	924	95	16252	235	44.0%	32.5%	44.0%	11.5%
PT011	PT U. Minho	1973	No	1163	147	15155	614	44.0%	39.9%	44.0%	20.4%

Table 1: EUMIDA Dataset Example

EUMIDA DATASET AND DEA
For a comprehensive ex-post productivity study the EUMIDA dataset for all European universities was used (Bonaccorsi et al, 2010; EUMIDA Project, 2012; table 1). The method applied in this first step was the data envelopment analysis (Charnes et al, 1978) – latest applied for unviersities for example in Australia (Worthington & Higgs, 2011). Though other methods for productivity analysis and comparison exist (e.g. Zangoueinezhad & Moshabaki, 2011), the DEA method is seen as very suited for the university sector due to the multi-product and multi-objective output. The following figures provide several different analysis results by this DEA application – which shall be used in the suggested research contribution in order to synthesize a GAMS prognosis model for an ex-ante productivity simulation for universities based on the exemplified factors size (staff), institution (public or private), university hospital (yes or no) as well as the input factor budget and the output factors doctoral degrees awarded, number of students and number of international students.

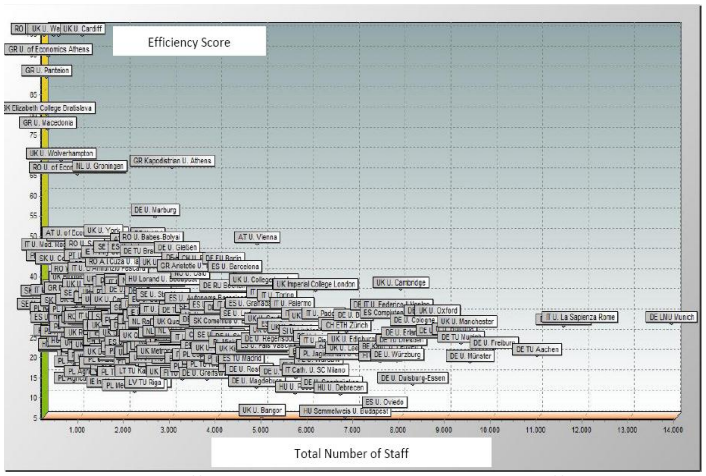


Figure 1: Efficiency Distribution Regarding Size (Staff)

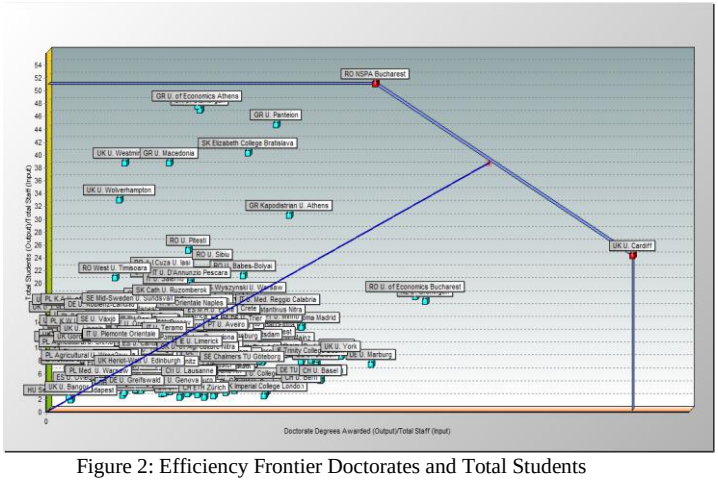


Figure 2: Efficiency Frontier Doctorates and Total Students

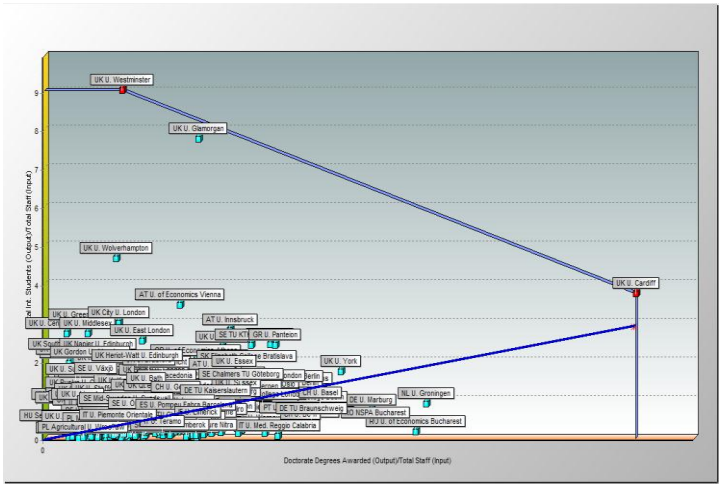


Figure 3: Efficiency Frontier Doctorates and Int. Students

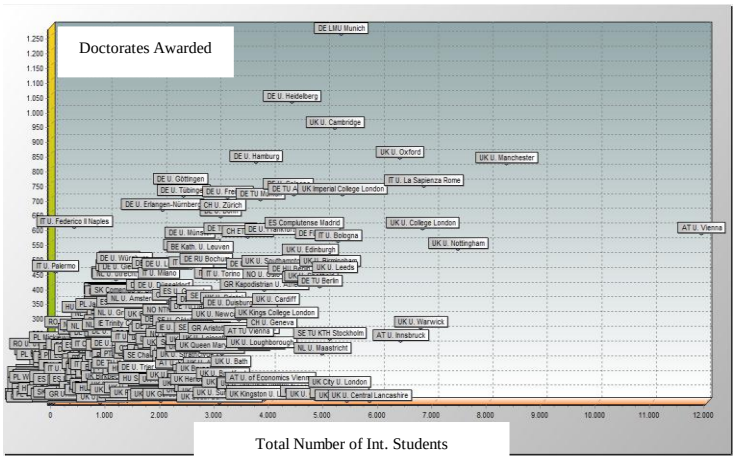


Figure 4: Correlation between Ouput Factors Doctorates and Int. Students

GAMS OPTIMIZATION UNIVERSITY SYSTEM

In a second simulation and modeling step an optimiziation problem for whole university systems (national or even European level) is addressed: Usually the correlation between different university objectives such as research, teaching and third mission (e.g. knowledge transfer, regional interaction) are not defined very clearly. For example different indicators for those objective areas are also included in performance-based funding schemes, pressuring universities to reach out for all those objectives at the same time. This is seen very critically as usually also politics demand more "specialization" and profile building from university insitutions. Therefore knowledge about a system-wide production and optimization function would help this discussion by making clear if there are economies of scale and scope as expected which would support the specializiation approach or not.

Therefore a first draft for a university system production optimiziation problem is outlined in GAMS in order to work with the afore mentioned data derived from DEA productivity settings. This should contribute to the international policy discussions regarding the "optimal" investment strategies in higher education, especially in the light of "world class university" concept favouring budget accumulation in some large-scale university operations. For this model draft data from the described EUMIDA and DEA dataset are taken for the included six Swiss universities (Universities of Basel, Bern, Geneva, Lausanne, Zürich and ETH Zürich). The first draft model on a HE systems level assumes fixed staff capacities for the existing six universities as outlined in the following table 2 (column 5).

EUMIDA ID	University Name	Found. Year	Univ. Hospital	Staff (Input)	Doctorate Degrees Awarded (Output)	Total Students (Output)	Total Int. Students (Output)	Efficiency (Case A without Int. Students)	Efficiency (Case B without Total Stud.)	Efficiency (Case C - all Output Indic.)	Efficiency (Case D - Restricted Weights 25%)
CH012	CH ETH Zürich	1855	No	6875	581	13572	3624	26.7%	26.7%	26.7%	9.9%
CH001	CH U. Basel	1460	Yes	2473	365	11312	2254	46.6%	46.6%	46.6%	20.2%
CH002	CH U. Bern	1528	Yes	3616	496	13014	1258	43.3%	43.3%	43.3%	11.0%
CH004	CH U. Geneva	1559	Yes	3872	272	12212	4063	22.2%	24.4%	24.4%	16.3%
CH005	CH U. Lausanne	1537	Yes	2436	186	11113	1699	24.1%	24.1%	24.1%	17.0%
CH009	CH U. Zürich	1500	Yes	5730	670	24123	3165	36.9%	36.9%	36.9%	15.1%

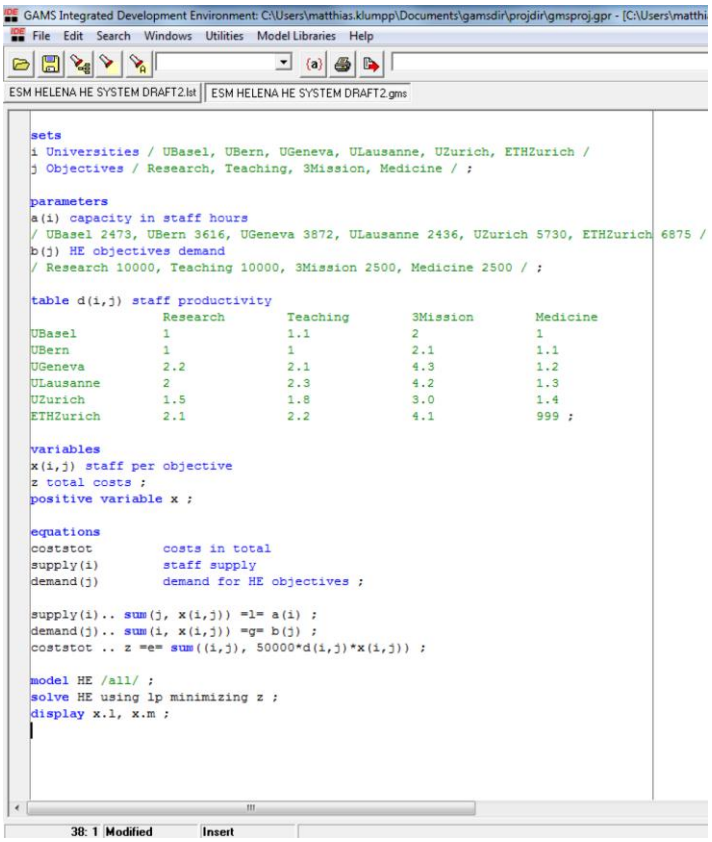
Table 2: EUMIDA and DEA Data for Swiss Universities

A total cost minimizing linear programming solver is used in GAMS to identify an optimal distribution of staff for the six universities (i) towards the four objective areas in higher education (research, teaching, third mission, medicine – j). A total demand for those four objective areas is defined on a HE systems level (given numbers) in order to simulate the state or society as demanding party on a HE market.

Further specific productivity or cost ratios are taken from the previously shown DEA research, mainly addressing the specific relations of efficiency between the six different universities – showing the University of Basel being the most efficient one followed by the University of Bern and Zurich. The most inefficient productivity ratios have been found for the Universities of Geneva and Lausanne and are therefore implemented with higher cost ratios into the model.

Though the model (figure 5) can be solved one crucial factor for further improvement ("reality check") is the cost or *efficiency relation between the four objective areas* – for this no specific correlations or data were obtainable from the DEA calculation. Therefore the model optimizes according to those artificial data used here (showing e.g. the most efficient Universities of Basel and Bern to concentrate totally on the third mission objective, figure 6). The total cost in this case is computed, being 2.14 billion € in total staff cost for all six universities. This is *no feasible HE system allocation* and has to be *enhanced* by maximum restrictions for each

objective area realistic cost level data. Therefore this contribution showed as *main research result* that a *HE systems level modelling is feasible* based on existing institutional productivity data as e.g. from DEA calculations.



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sets
i Universities / UBasel, UBern, UGeneva, ULausanne, UZurich, ETHZurich /
j Objectives / Research, Teaching, 3Mission, Medicine / ;

parameters
a(i) capacity in staff hours
/ UBasel 2473, UBern 3616, UGeneva 3872, ULausanne 2436, UZurich 5730, ETHZurich 6875 /
b(j) HE objectives demand
/ Research 10000, Teaching 10000, 3Mission 2500, Medicine 2500 / ;

table d(i,j) staff productivity
                Research        Teaching        3Mission        Medicine
UBasel          1               1.1             2               1
UBern           1               1               2.1             1.1
UGeneva         2.2             2.1             4.3             1.2
ULausanne       2               2.3             4.2             1.3
UZurich         1.5             1.8             3.0             1.4
ETHZurich       2.1             2.2             4.1             999 ;

variables
x(i,j) staff per objective
z total costs ;
positive variable x ;

equations
coststot        costs in total
supply(i)       staff supply
demand(j)       demand for HE objectives ;

supply(i).. sum(j, x(i,j)) =l= a(i) ;
demand(j).. sum(i, x(i,j)) =g= b(j) ;
coststot .. z =e= sum((i,j), 50000*d(i,j)*x(i,j)) ;

model HE /all/ ;
solve HE using lp minimizing z ;
display x.l, x.m ;

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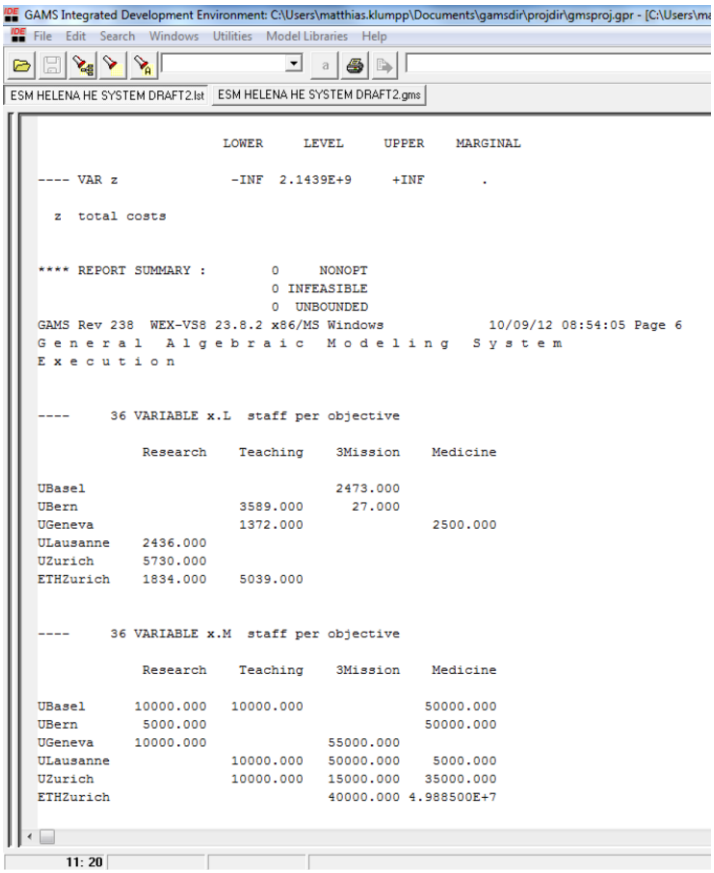
Figure 5: Draft HE System Model



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                    LOWER     LEVEL     UPPER    MARGINAL

---- VAR z           -INF  2.1439E+9     +INF       .

  z  total costs


**** REPORT SUMMARY :        0     NONOPT
                             0 INFEASIBLE
                             0  UNBOUNDED
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G e n e r a l  A l g e b r a i c  M o d e l i n g  S y s t e m
E x e c u t i o n


----     36 VARIABLE x.L  staff per objective

            Research    Teaching    3Mission    Medicine

UBasel                                2473.000
UBern                    3589.000      27.000
UGeneva                  1372.000                2500.000
ULausanne     2436.000
UZurich       5730.000
ETHZurich     1834.000    5039.000


----     36 VARIABLE x.M  staff per objective

            Research    Teaching    3Mission    Medicine

UBasel       10000.000   10000.000                50000.000
UBern         5000.000                            50000.000
UGeneva      10000.000                55000.000
ULausanne                10000.000   50000.000     5000.000
UZurich                  10000.000   15000.000    35000.000
ETHZurich                            40000.000 4.988500E+7

11: 20
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Figure 6: Solution Report Draft HE System Model

ACKNOWLEDGEMENT

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REFERENCES

Beasley, J. E. 1995. Determining teaching and research efficiencies. In: Journal of the Operational Research Society, 46, 441-452.

Bonaccorsi, A., Brandt, T., De Filippo, D., Lepori, B., Molinari, F., Niederl, A., Schmoch, U., Schubert, T., Slipersaeter, S. 2010. Feasibility Study for Creating a European University Data Collection. Brussels: EU Commission Documents.

Charnes, A., Cooper, W., Rhodes, E. 1978. Measuring the efficiency of decision making units. In: European Journal of Operational Research, 2, 429-444.

Cohn, E., Rhine, S. L. W., Santos, M. C. 1989. Institutions of higher education as multi-product firms: Economies of scale and scope. In: Review of Economics and Statistics, 71, 284-290.

Dundar, H., Lewis, D. R. 1995. Departmental productivity in American universities: Economies of scale and scope. In: Economics of Education Review, 14, 199-244.

EUMIDA Project 2012. EUMIDA European University Data Collection. Download at http://thedatahub.org/dataset/eumida on 05.08.2012, Pisa.

Glass, J. C., Mckillop, D. G., O'Rourke, G. 1998. A cost indirect evaluation of productivity change in UK universities. In: Journal of Productivity Analysis, 10, 153-175.

Kao, C., Hung, H.-T. 2008. Efficiency analysis of university departments: An empirical study. In: Omega, 36 (4), 653-664.

Kocher, G.M., Luptacik, M. & Sutter, M. 2006. Measuring Productivity of Research in Economics: A Cross-country Study Using DEA. In: Socio-Economic Planning Sciences, 40, 314-332.

Korhonen, P., Tainio, R. & Wallenius, J. 2001. Value efficiency analysis of academic research. In: European Journal of Operational Research, 130, 121-132.

Ng, Y.C., Li, S.K. 2000. Measuring the Research Performance of Chinese Higher Education Institutions: An Application of Data Envelopment Analysis. In: Education Economics, (8), 139-156.

Sarrico, C.S. 2010. On Performance in Higher Education – Towards Performance Government. In: Tertiary Education and Management, 16 (2), 145-158.

Worthington, A. C., Higgs, H. 2011. Economies of scale and scope in Australian higher education. In: Higher Education, 61, 387-414.

Zangoueinezhad, A., Moshabaki, A. 2011. Measuring university performance using a knowledge-based balanced scorecard. In: Iran International Journal of Productivity and Performance Management, 60 (8), 824-843.

BIOGRAPHY

MATTHIAS KLUMPP studied economics and business administration after a vocational degree in logistics (Speditionskaufmann) at University Leipzig and the IECS Strasbourg from 1995 to 1998. Parallel to his professional consultant career in strategy management, logistics and education he obtained a PhD at University Leipzig in 2007 and started at FOM University of Applied Sciences. He founded the Institute for Logistics and Service Management (ild) at FOM in 2009 (www.fom-ild.de) and since 2011 leads the HELENA research group at the University of Duisburg-Essen regarding university productivity.