Engineering as the engine of growth.

Perspectives for Engineering research and training in Europe

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Preliminary remarks

Historians of technology and economic historians have shown that the acceleration of technical progress and economic growth in XIX century in Western societies has been greatly influenced by two developments:

- the emergence of academic disciplines in Engineering (codification and diffusion of knowledge)

- the creation of professional engineering bodies (definition of professional standards and training requirements).

(Joel Mokyr, Nathan Rosenberg)

Recent economic studies show that economic growth is positively influenced by the share of people with tertiary education with a degree in Engineering (and negatively by the share with a degree in Law…).

Talents may be allocated to:

- creation of economic value, or:
- distribution of available economic value among the members of society

(Andrei Shleifer and co-authors)

Engineering as the engine of growth

Engineering schools have three institutional missions:

- Research
- Education
- Third mission

These missions are inextricably linked together. They are complementary to each other.

At the same time, there are possible tensions and trade-offs, that should be carefully identified and managed:

- between research and education
- between research and third mission
- between third mission and education

Data sources/1

ETER (European Tertiary Education Register)

- Official census of European Higher Education Institutions (HEIs)
- Project supported by DG Education and Culture
- Validated by National Statistical Authorities
- Available as microdata (individual institution)

- Data on students and degrees (undergraduate and postgraduate), staff (academic and non academic), revenues and expenditure + institutional descriptors
- Breakdown by nationality (national, foreign), gender and discipline (Field of Education)

- Data available 2011-2014. Year 2015 currently in data collection.

Data sources/2

Global Research Benchmarking System

- Scopus publications
- Period 2007-2010
- Threshold 50 papers in the 4-year period
- 251 Subject Categories, grouped in 15 broad areas

- Data on publications and citations
    - Absolute value (number)
    - Share in top journals (top 10% or 25% SNIP journals) (%)

Key indicators of research activity

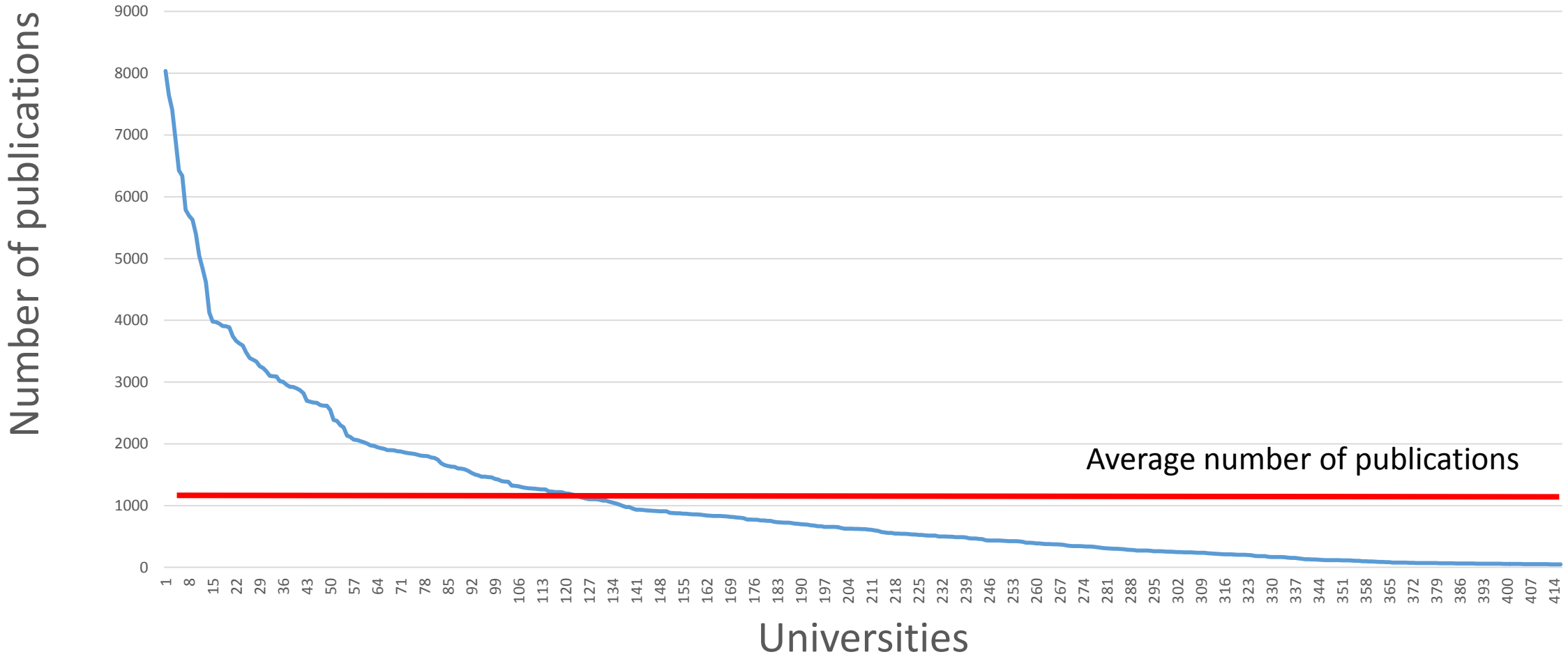
N= 416 European universities with publication volume > 50 papers (2007-2010)

Number of publications= 442.266
Average number of publications per university= 1063

Number of citations= 1.273.450
Average number of citations per university= 3061

Average number of citations per paper= 2,88

Size distribution of universities in Engineering
Number of publications



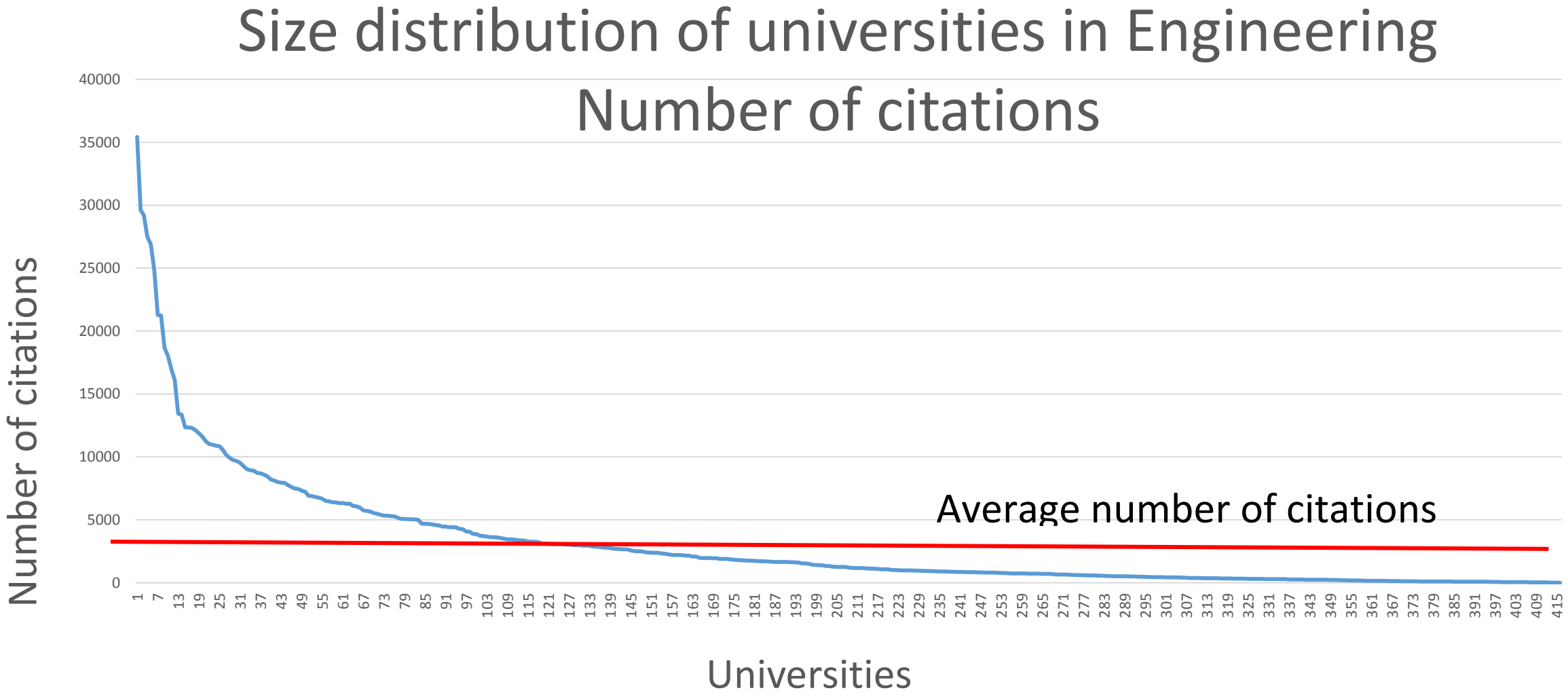
	Number of universities active in Engineering	Total publications in Engineering	Largest university in Engineering	Publications of the largest university
Austria	10	8124	Vienna University of Technology	3093
Belgium	5	11559	KU Leuven	5628
Bulgaria	2	656	Sofia University St. Kliment Ohridski	486
Switzerland	8	16187	Federal Institute of Technology Zurich	6920
Cyprus	1	496	University of Cyprus	496
Czech Republic	11	6548	Charles University in Prague	1900
Germany	62	68750	Karlsruhe Institute of Technology	6425
Denmark	5	8769	Technical University of Denmark	5398
Estonia	2	916	Tallinn University of Technology	488
Spain	38	34275	Technical University of Catalonia	3744
Finland	10	8102	Aalto University	3100
France	44	36579	Pierre and Marie Curie University	3981
Greece	12	10869	National Technical University of Athens	3333
Hungary	5	1088	Eötvös Loránd University	440
Ireland	8	5601	Trinity College Dublin	1396

	Number of universities active in Engineering	Total publications in Engineering	Largest university in Engineering	Publications of the largest university
Italy	46	49206	Politecnico di Milano	4617
Lithuania	3	1824	Kaunas University of Technology	863
Latvia	1	566	University of Latvia	566
Netherlands	12	22709	Delft University of Technology	8038
Norway	5	5157	The Norwegian University of Science and Technology	3887
Poland	26	16751	Warsaw University of Technology	2616
Portugal	8	13283	Technical University of Lisbon	3946
Romania	13	7158	University 'Politehnica' of Bucharest	1642
Sweden	12	18972	Royal Institute of Technology	5694
Slovenia	2	3146	University of Ljubljana	2372
Slovak	5	1910	Slovak University of Technology in Bratislava	1129
United Kingdom	60	83065	The University of Cambridge	7645

Top 20 by number of publications

University	Country	Number of publications 2007-2010
Delft University of Technology	Netherlands	8038
The University of Cambridge	UK	7645
Imperial College of Science, Technology and Medicine	UK	7407
Federal Institute of Technology Zurich	Switzerland	6920
Karlsruhe Institute of Technology	Germany	6425
Federal Institute of Technology Lausanne	Switzerland	6339
The University of Manchester	UK	5789
Royal Institute of Technology	Sweden	5694
KU Leuven	Belgium	5628
Technical University of Denmark	Denmark	5398
Eindhoven University of Technology	Netherlands	5045
The University of Oxford	UK	4839
Politecnico di Milano	Italy	4617
Politecnico di Torino	Italy	4128
Pierre and Marie Curie University	France	3981
The University of Sheffield	UK	3974
Technical University of Lisbon	Portugal	3946
The University of Southampton	UK	3909
Aachen University	Denmark	3905
The Norwegian University of Science and Technology	Norway	3887

	Number of universities active in Engineering	Total publications in Engineering	Share of universities	Share of publications
United Kingdom	60	83065	14,4	18,8
Germany	62	68750	14,9	15,5
Italy	46	49206	11,1	11,1
France	44	36579	10,6	8,3
Spain	38	34275	9,1	7,7
Netherlands	12	22709	2,9	5,1
Sweden	12	18972	2,9	4,3
Poland	26	16751	6,3	3,8
Switzerland	8	16187	1,9	3,7
Portugal	8	13283	1,9	3,0
Belgium	5	11559	1,2	2,6
Greece	12	10869	2,9	2,5
Denmark	5	8769	1,2	2,0
Austria	10	8124	2,4	1,8
Finland	10	8102	2,4	1,8
Romania	13	7158	3,1	1,6
Czech Republic	11	6548	2,6	1,5
Ireland	8	5601	1,9	1,3
Norway	5	5157	1,2	1,2
Slovenia	2	3146	0,5	0,7
Slovak	5	1910	1,2	0,4
Lithuania	3	1824	0,7	0,4
Hungary	5	1088	1,2	0,2
Estonia	2	916	0,5	0,2
Bulgaria	2	656	0,5	0,1
Latvia	1	566	0,2	0,1
Cyprus	1	496	0,2	0,1


Size distribution of universities in Engineering
Number of citations
Number of citations
40000
35000
30000
25000
20000
15000
10000
5000
0
Average number of citations
1
7
13
19
25
31
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73
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85
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121
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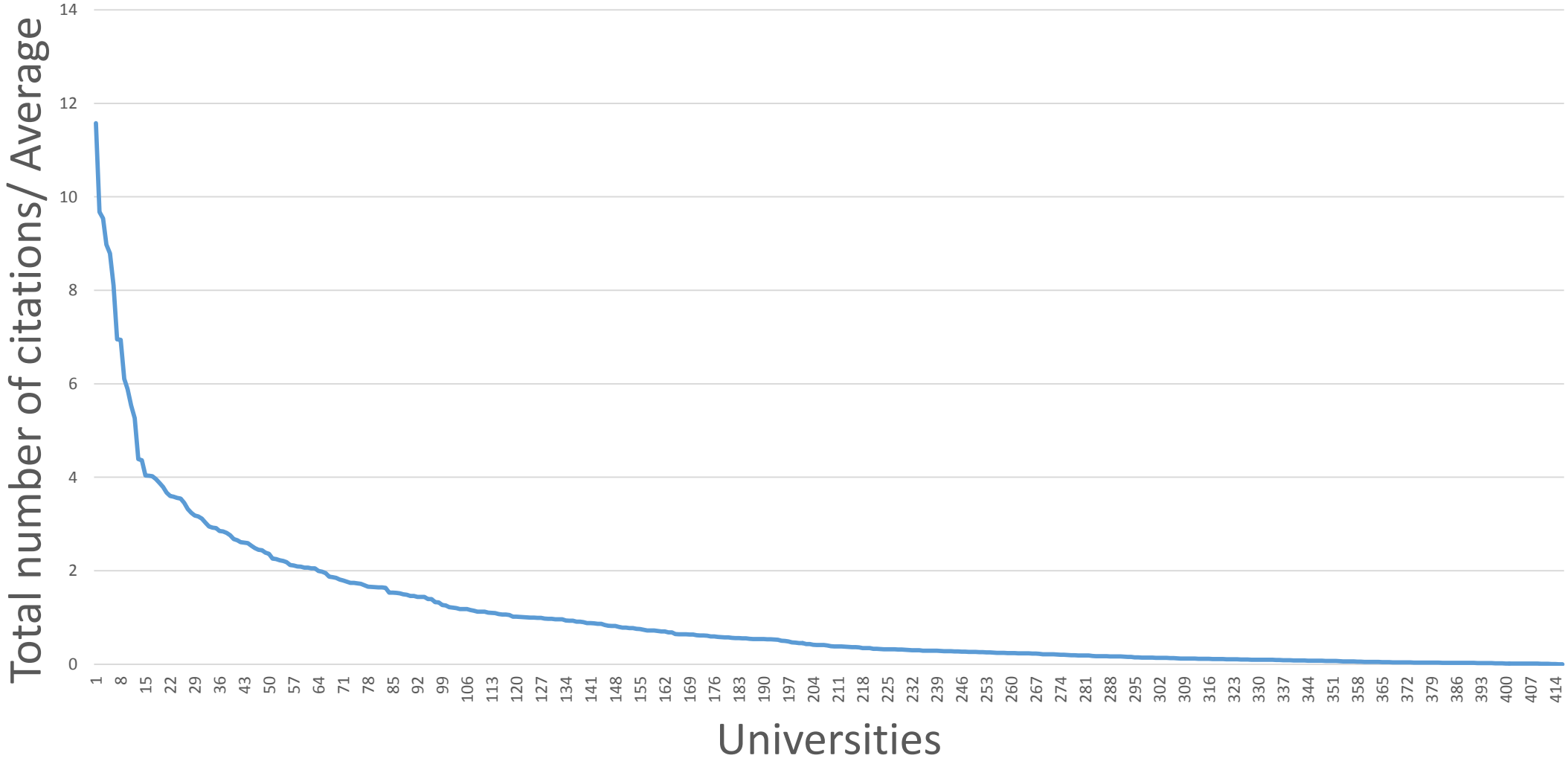
403
409
415
Universities

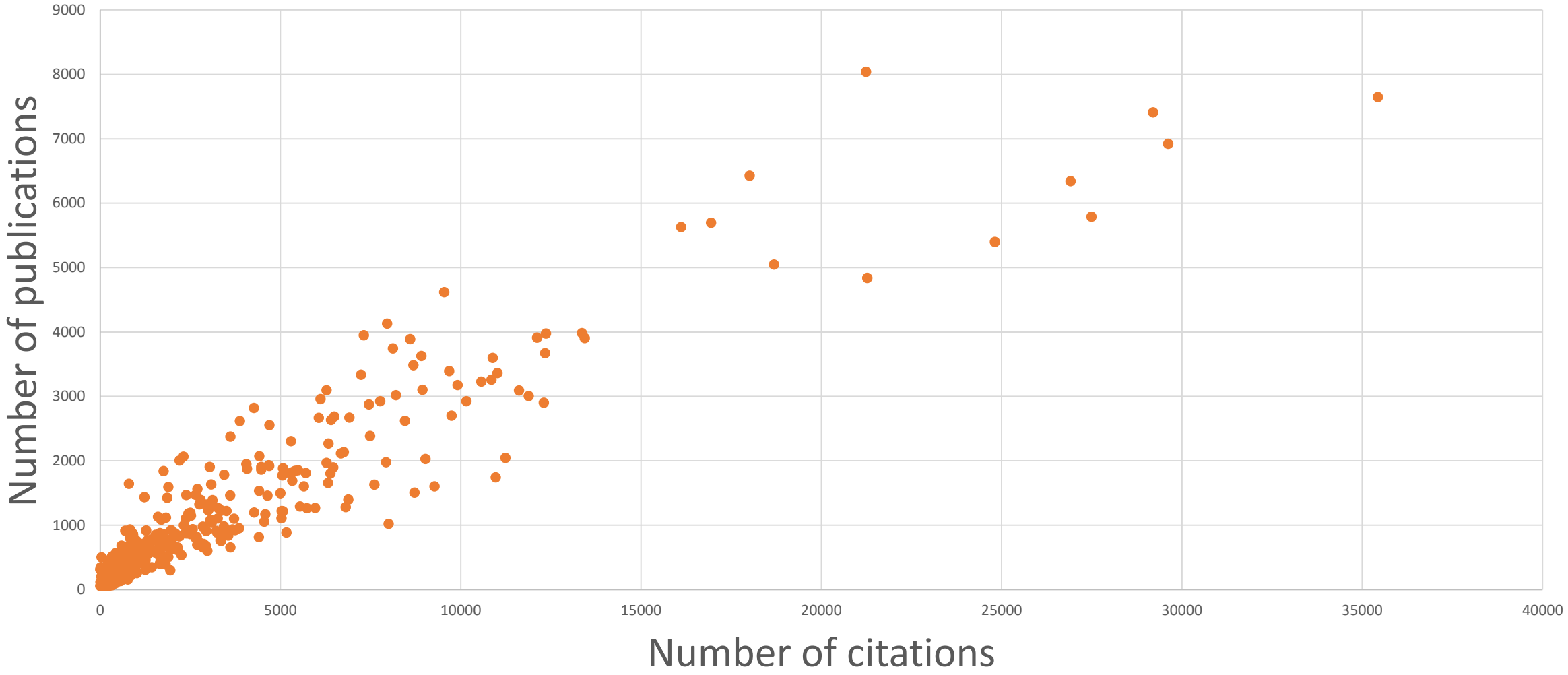
Distribution of normalized total citations



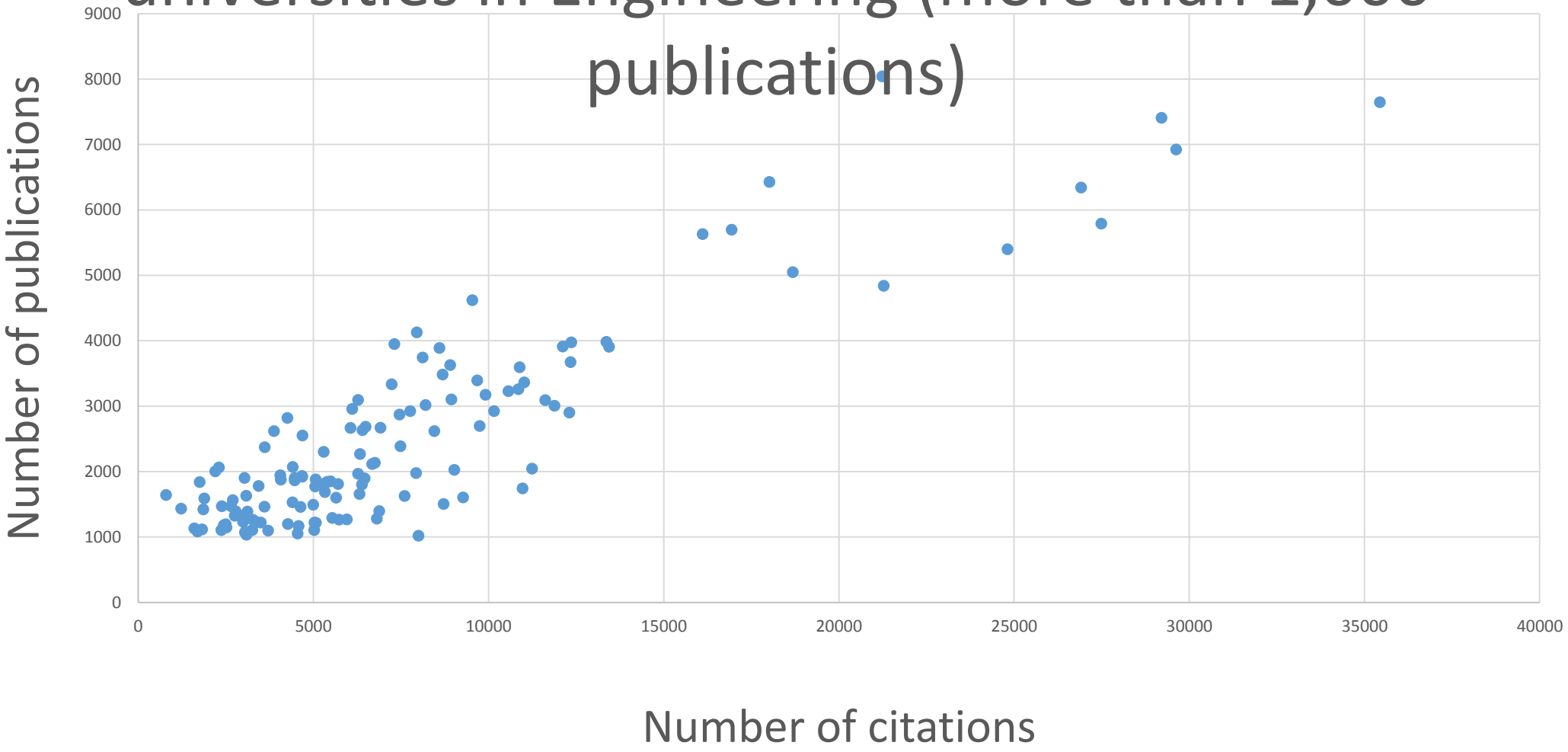
Top 20 by number of citations

University	Country	Number of citations received 2007-2010
The University of Cambridge	UK	35438
Federal Institute of Technology Zurich	Switzerland	29623
Imperial College of Science, Technology and Medicine	UK	29206
The University of Manchester	UK	27492
Federal Institute of Technology Lausanne	Switzerland	26913
Technical University of Denmark	Denmark	24814
The University of Oxford	UK	21279
Delft University of Technology	Netherlands	21241
Eindhoven University of Technology	Netherlands	18687
Karlsruhe Institute of Technology	Germany	18015
Royal Institute of Technology	Sweden	16943
KU Leuven	Belgium	16115
Aachen University	Denmark	13439
Pierre and Marie Curie University	France	13362
The University of Sheffield	UK	12363
University of Bologna	Italy	12340
Lund University	Sweden	12307
The University of Southampton	UK	12122
University of Erlangen-Nürnberg	Germany	11884
The University of Bristol	UK	11619

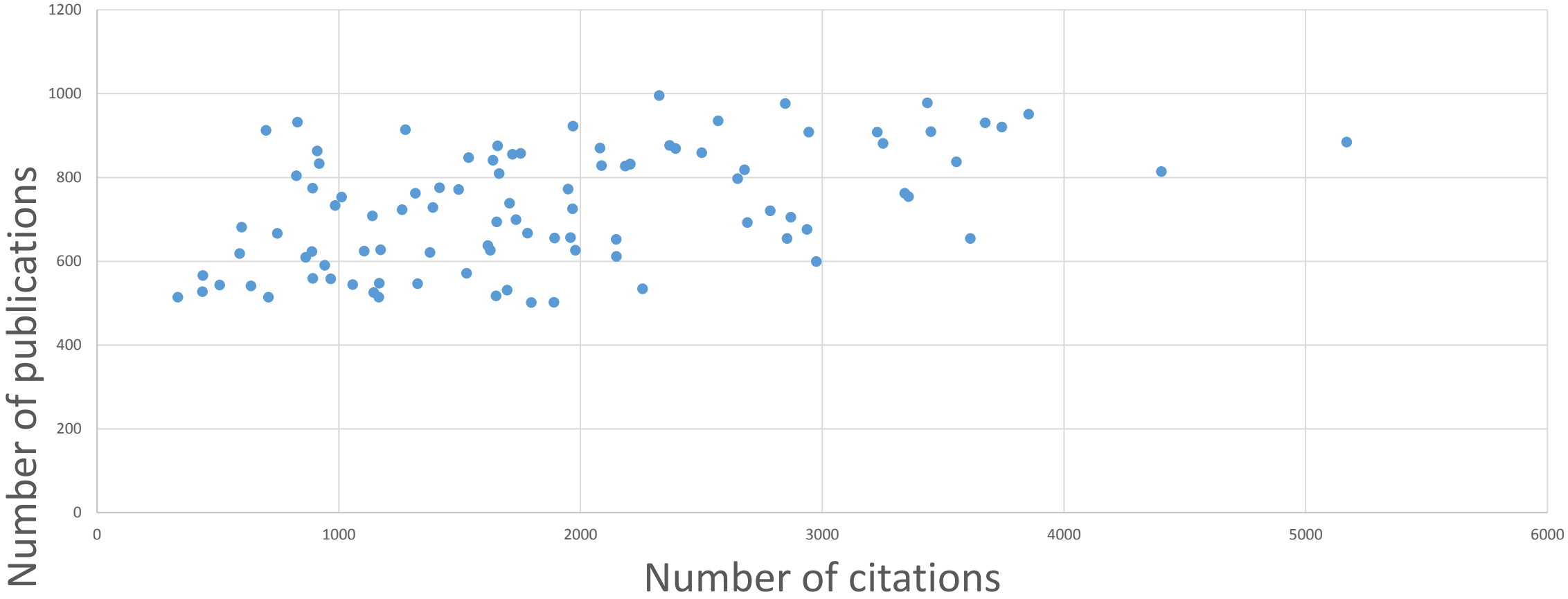
Publications and citations of European universities in Engineering



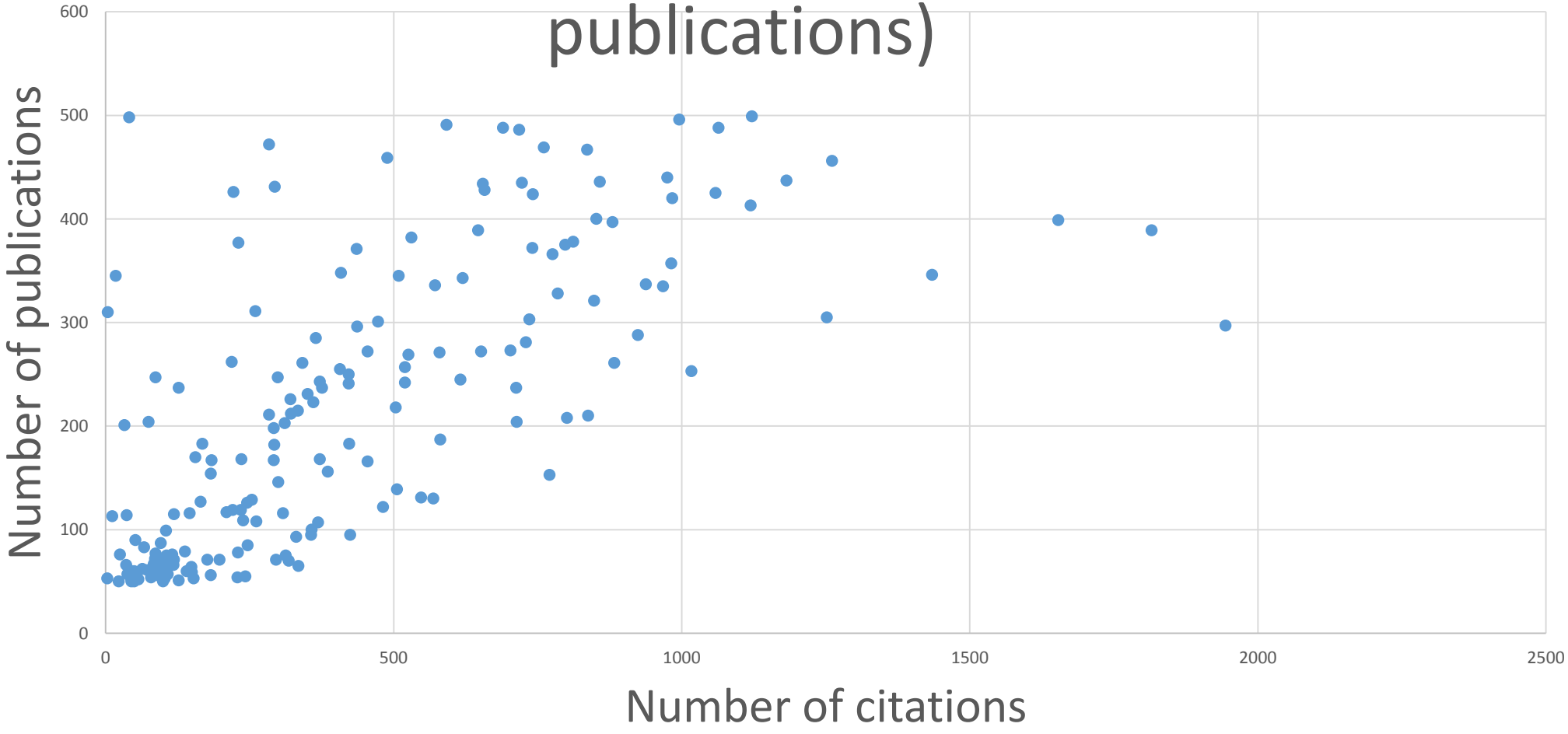
Publications and citations of large universities in Engineering (more than 1,000 publications)



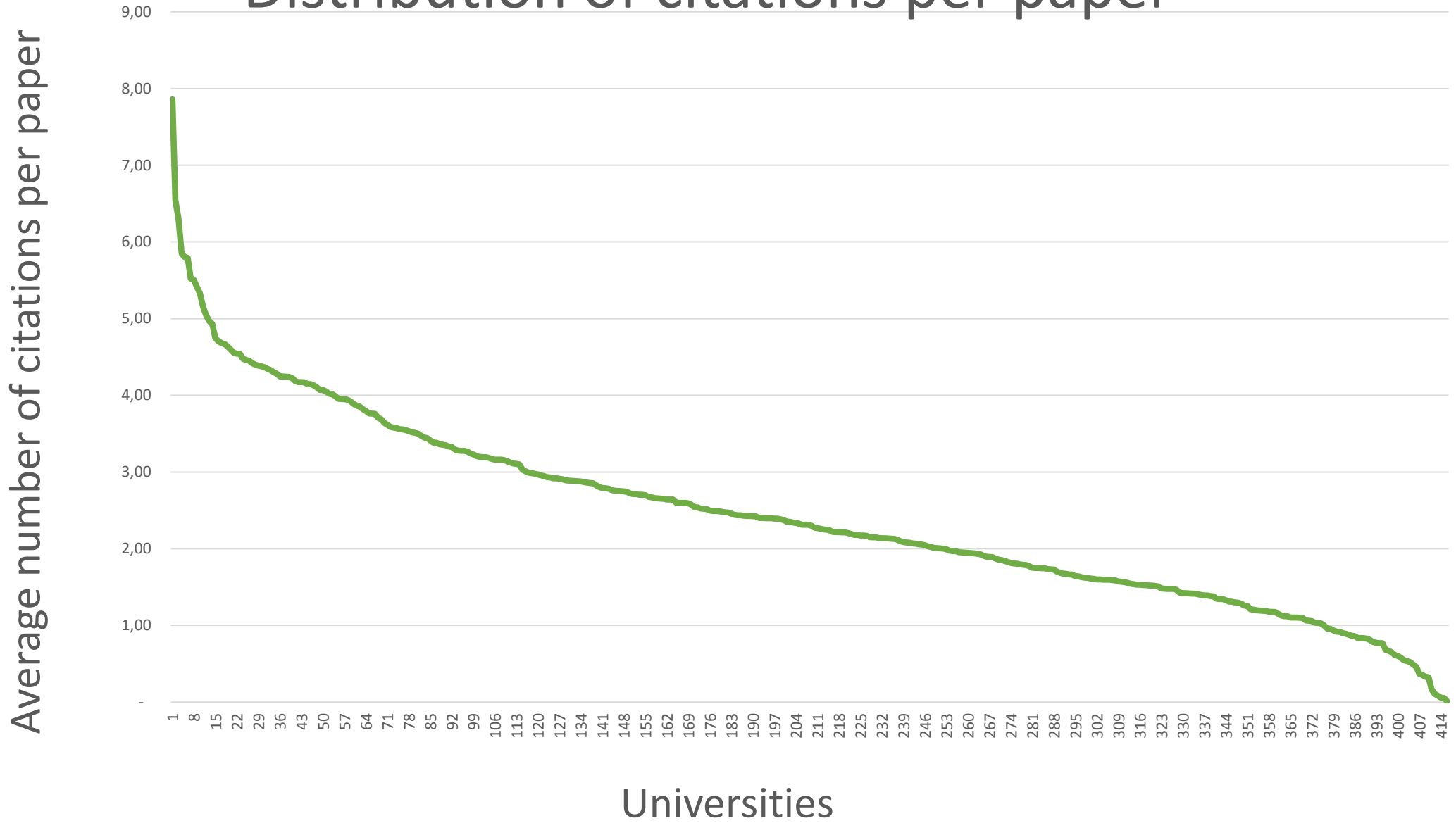
Publications and citations of medium-sized universities in Engineering (500-1000 publications)



Publications and citations of small-sized universities in Engineering (less than 500 publications)



Distribution of citations per paper



Remarks

Distributions of research output indicators are skewed.

Distribution of citations and of citations per paper more skewed

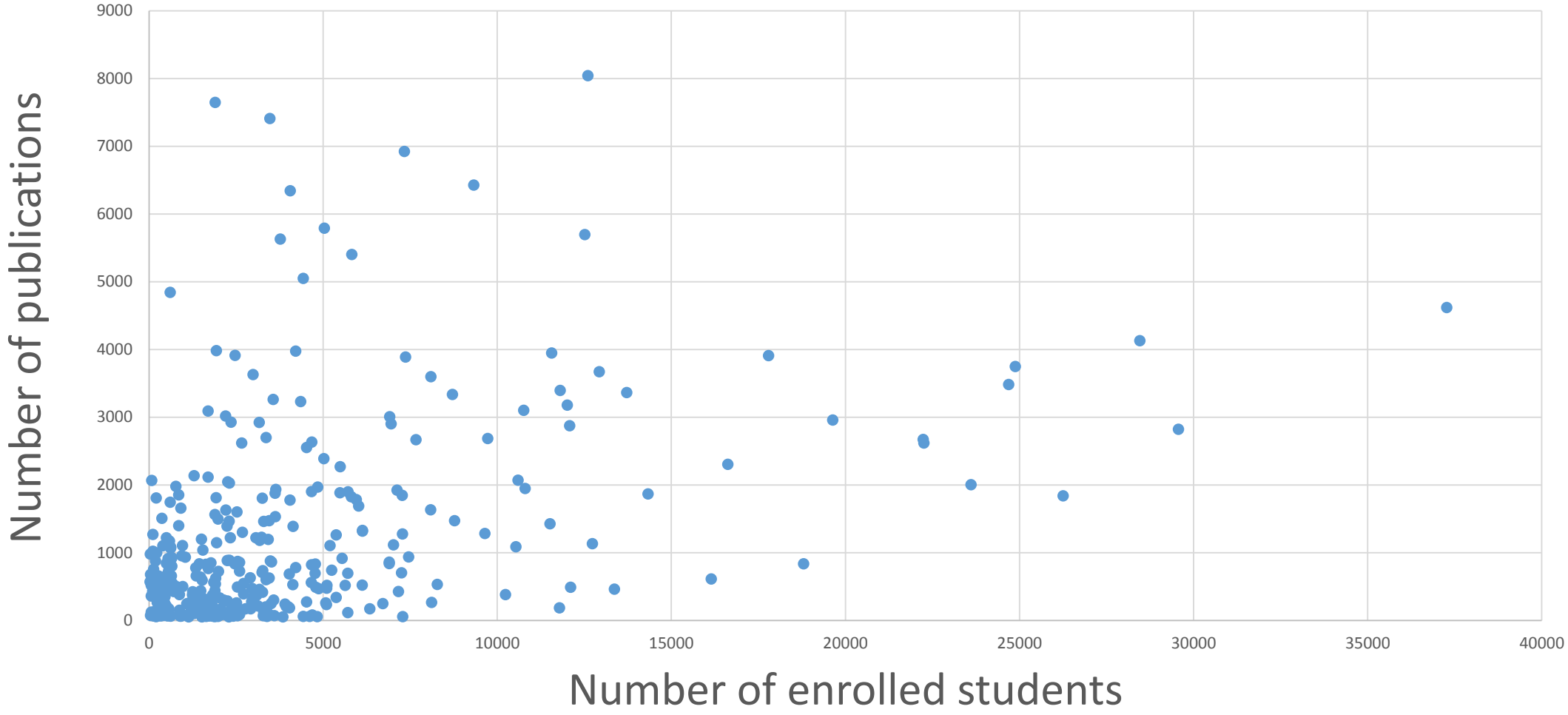
- Lotka law applies not only at the level of individual researchers, but also at the level of institutions
- If researcher ranked 1 has x citations, researcher ranked 2 has $(x/2^{\alpha})$ citations, researcher ranked 3 has $(x/3^{\alpha})$ citations etc
- empirical estimates of parameter α close to unity

Emergence of a core of large and highly productive universities in Engineering

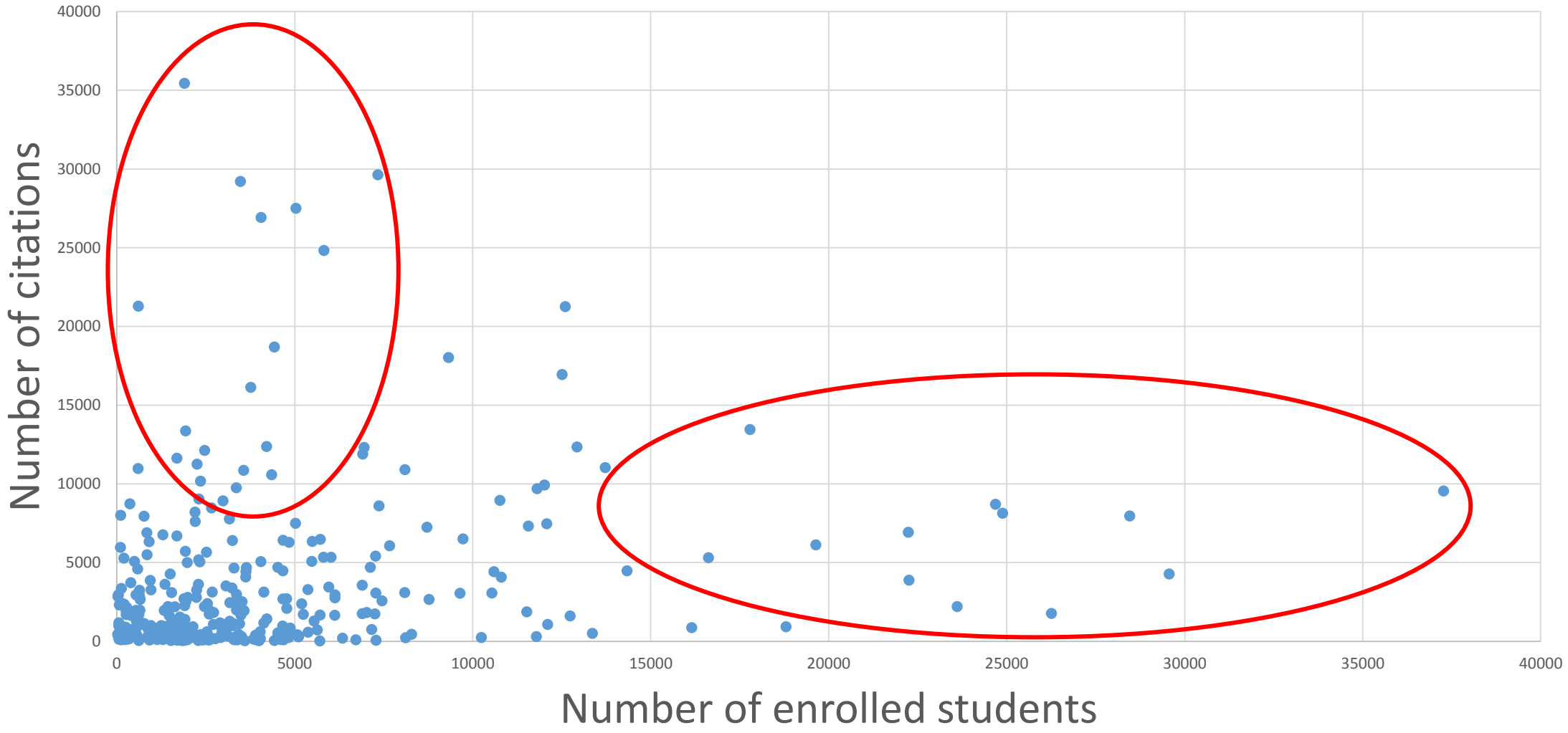
- small number of universities with outstanding number of citations
- also large in terms of volume of publications

University	Country	Number of students enrolled ISCED 5-7 Year 2011
Politecnico di Milano	Italy	37275
Technical University of Madrid	Spain	29566
Politecnico di Torino	Italy	28460
AGH University of Science and Technology in Cracow	Poland	26258
Technical University of Catalonia	Spain	24886
Sapienza University of Rome	Italy	24691
Wrocław University of Technology	Poland	23611
Warsaw University of Technology	Poland	22257
Technical University of Valencia	Spain	22239
University of Naples Federico II	Italy	19642
Silesian University of Technology in Gliwic	Poland	18802
Aachen University	Germany	17794
Technische Universität Berlin	Germany	16625
Gdańsk University of Technology	Poland	16153
University of Sevilla	Spain	14335
Technische Universität München	Germany	13724
Poznań University of Technology	Poland	13366
University of Bologna	Italy	12933
Slovak University of Technology in Bratislava	Slovak	12739
Delft University of Technology	Netherlands	12607

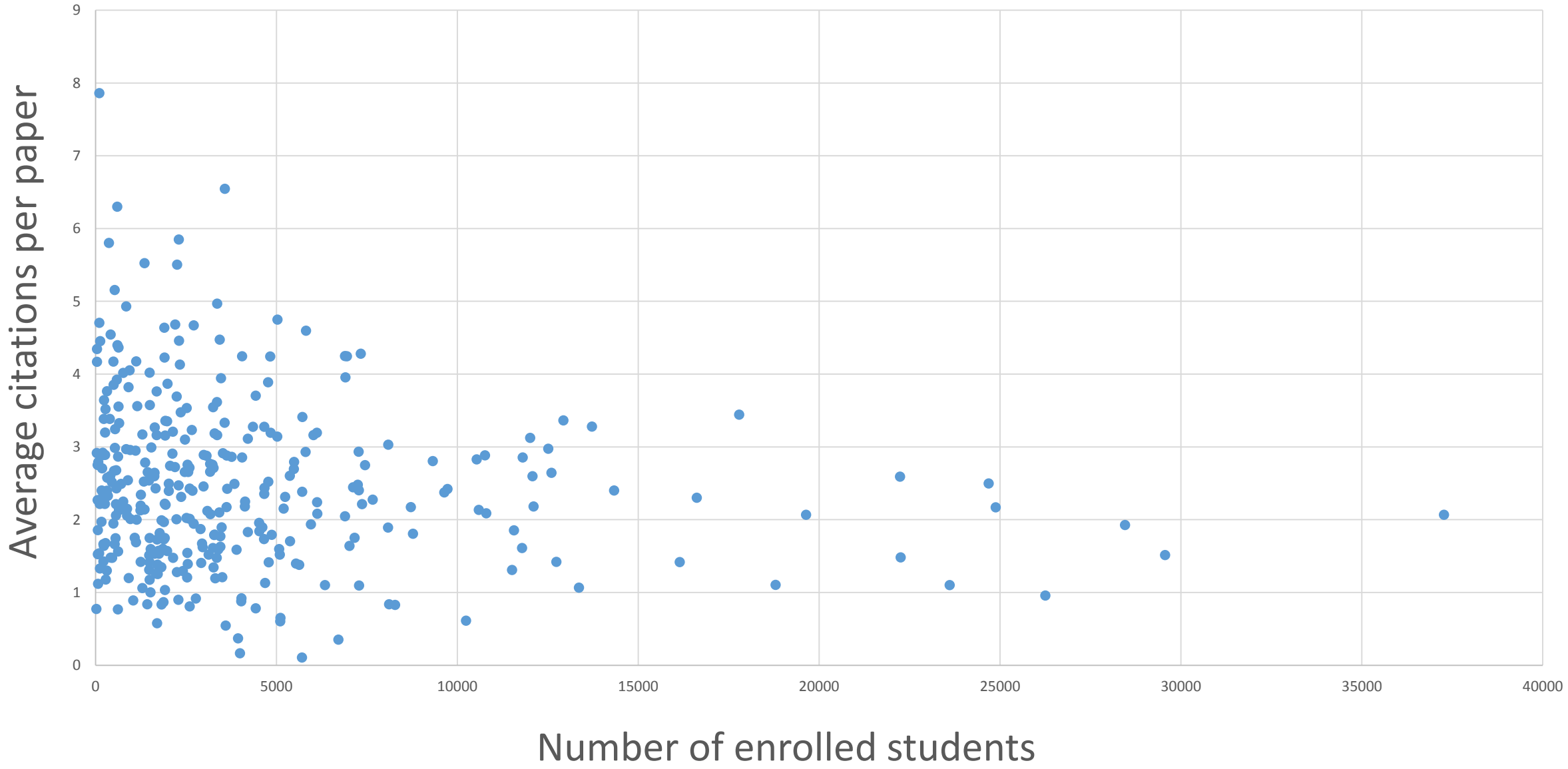
Student size and publications



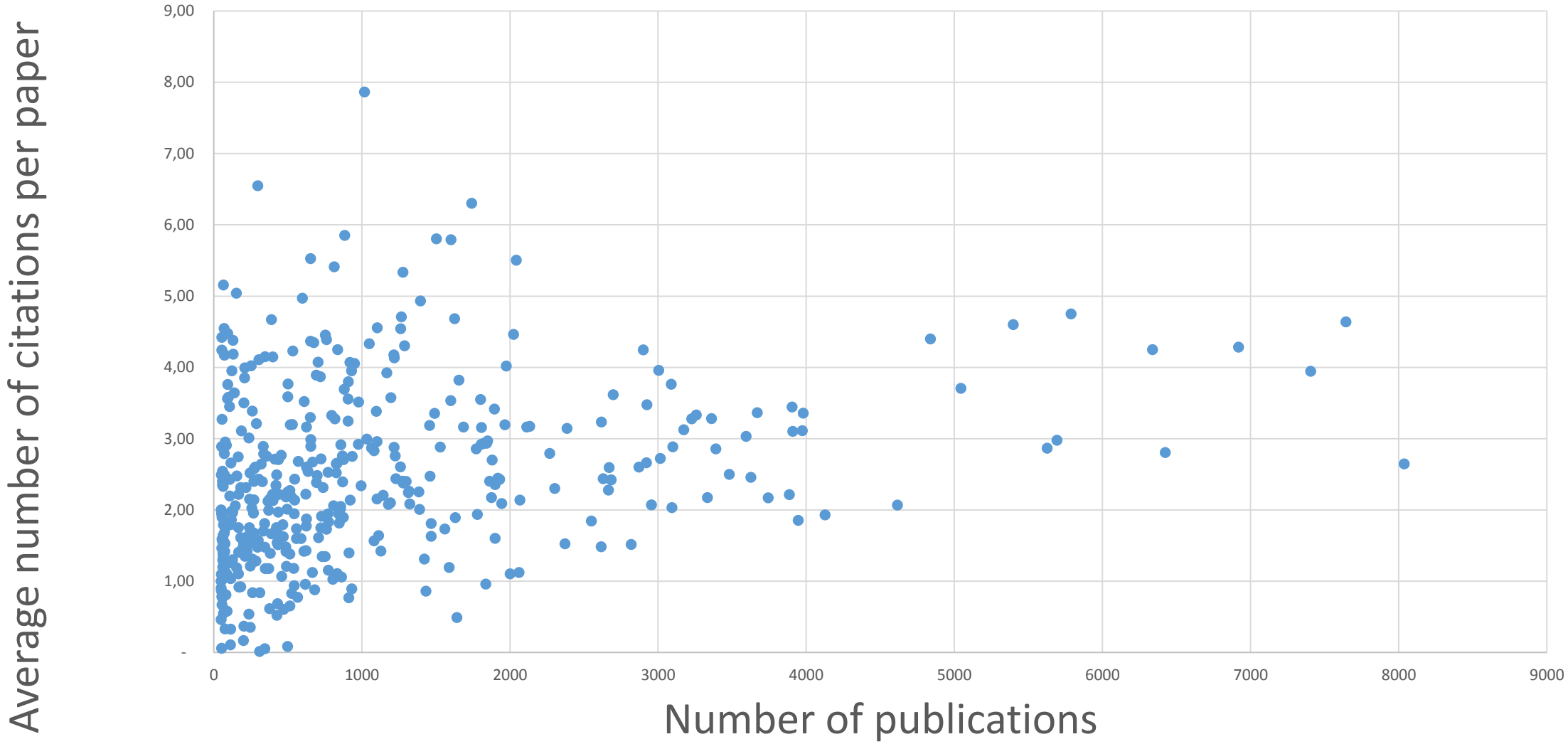
Student size and citations



Student size and citations per paper



Impact of size on average citations per paper



Remarks

Student education and research activities are complementary activities.

However, they jointly make use of a limited time-budget of researchers and professors. Beyond a certain threshold it is likely that some tensions may be found.

Addressing successfully these tensions require strong organizational capabilities, clear career incentives, adequate division of labour among people at various stages of the academic life and/or orientation, and good administrative support.

Putting together qualified education and knowledge creation

One way to measure the complementarity between research and education is to build up a multiplicative indicator

- Number of students * Number of publications
  * Number of citations

- Number of degrees * Number of publications
  * Number of citations

After normalization, these indicators might be used at country level and university level.

Top 20 universities by (number of degrees)*(number of citations) index

University	Country	Index of Qualified Human Capital
Politecnico di Milano	Italy	1000
Delft University of Technology	Netherlands	752
The University of Manchester	UK	608
Federal Institute of Technology Zurich	Switzerland	551
Politecnico di Torino	Italy	467
Technical University of Denmark	Denmark	457
Royal Institute of Technology	Sweden	452
Imperial College of Science, Technology and Medicine	UK	437
Sapienza University of Rome	Italy	418
Chalmers University of Technology	Sweden	393
Technical University of Catalonia	Spain	331
Aachen University	Germany	330
University of Bologna	Italy	328
The University of Cambridge	UK	290
Federal Institute of Technology Lausanne	Switzerland	283
Technische Universität München	Germany	280
University of Padova	Italy	271
Eindhoven University of Technology	Netherlands	241
Karlsruhe Institute of Technology	Germany	231
KU Leuven	Belgium	214

Future work and improvements

Quality of education

- comparable data at European level do not exist
- meta-analysis of employability data on employment, careers and earnings of graduates in several European countries
- future standardization of questionnaires

Third mission

- comparable data at European level do not exist
- patent data available (but disambiguation work daunting)
- data on spinoff production available for many countries

Doctoral education

- ETER data already available

What can be done with existing data?

Benchmarking

- Construction of sets of comparable universities (by age, size, subject mix or other dimensions)
- Analysis of indicators and learning exercises

Productivity analysis

- Relative measures of productivity (e.g. publications per unit of academic staff)
- Regression framework + instrumental variables

Efficiency analysis

- Universities as multi-input multi-output organizations
- Nonparametric techniques (Daraio and Simar: *robust conditional efficiency analysis)*

Impact

- Analysis of spillover effects at regional and local level

Final remarks

Culture of measurement from Engineering tradition to the field of higher education.

Great care about the differences between inanimate reality and social reality: measurement in the social domain is inevitably intervention, and then calls for a deep reflection on ends and values.

Need for a European dimension.

European universities are not well equipped to take the leadership of the global competition for talented staff.

Engineering schools are more subject to intense international competition on talented staff and are moving in the right direction.