Comparing the Disciplinary Profiles of National and Regional Research Systems by Extensive and Intensive Measures

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Abstract
In this paper, by modeling national and regional research systems as complex systems, we compare the dynamics of their disciplinary profiles using extensive (size dependent) indicators as well as intensive (size independent) average productivity indicators of scientific production. Our preliminary findings show that the differences between the disciplinary profiles among countries in the world is of the same order of magnitude of the differences among European countries, that in turn, is of the same order of magnitude of the dynamics among regions within a country. While additional research (that is in progress) is needed to confirm these findings, we describe the main advantages (features) of our approach and outline its usefulness to support evidence-based policy making.

Conference Topics
Methods and techniques; Citation and co-citation analysis; Indicators; Science policy and research assessment; Country-level studies

Introduction, scope and structure of this paper
The dynamics of national or regional research systems is one of the most important topics in quantitative science and technology research. Interestingly, a lot of studies have analyzed the disciplinary specialization of countries (see e.g. Glanzel, 2000; Glanzel & Schlemmer, 2007; Glanzel et al., 2006, 2008; Hu & Rousseau, 2009; Tian et al., 2008; Wong, 2013; Wong et al., 2012; Yang et al., 2012; Horlings & Van den Besselaar, 2013; Radosevic & Yoruk, 2014) or have investigated the disciplinary specialization of regions within a particular country, or have conducted case studies on individual regions and/or on a few number of selected disciplines (see e.g. Zhu et al., 2009; Glanzel, Tang & Shapira, 2011).
Much less studied are the disciplinary profiles of European countries at the regional level. To the best of our knowledge there are not empirical analyses at European level, investigating the evolution of the disciplinary composition (i.e. the 27 Scopus Subject categories) of regions. Moreover, none of the existing studies have analyzed in a comparative way, the range of variability (briefly: the dynamics) of national and regional research systems which is the aim of our paper. We investigate here this dynamics in terms of both extensive measures of scientific production (i.e. total number of scientific publications, citations and so on) and in terms of intensive average scientific productivity (i.e. number of publications per author).
In particular, the investigation of the dynamics of intensive measures of scientific production has an important policy relevance. According to the macroeconomic theory, we have growth convergence when smaller (poorer) countries, in terms of output per capita (e.g. GDP per capita), grow faster than larger (richer) countries. In the context of research systems, we can say that there is a convergence if smaller scientific systems, in terms of scientific output per capita, grow faster than larger one. This is an important question, related to the policy

decision of supporting catching up countries depending on whether there is convergence or not. This question is extremely important also at the regional level, for which there is an increasing interest in the smart specialization of regions, defined in terms of technological specialization, linked to the degree of innovativeness of the regions, to develop effective policies of cohesion (McCann & Ortega-Argilés, 2013; Camagni & Capello, 2013). Despite the fact that scientific specialization is commonly considered as a relevant factor for the technological specialization of regions, there is not available evidence on the scientific specialization of regions and their dynamics. Even more scant is the empirical evidence aiming at analyzing the dynamics of the scientific profiles of regions together with those at the national level, to derive informative policies to support research at national and regional level, able to take into account the complementarity/substitution relationship between national and regional research systems. We try to fill this gap, providing an investigation of the dynamics of the disciplinary profiles at the national and regional level using extensive and intensive measures.[1]

Bongioanni, Daraio, Moed and Ruocco (2014) provided a first exploration at the world country level. In the current paper, the analyses are extended systematically in the following three manners.

a) The paper analyzes a series of both extensive (size dependent) and intensive (size independent) bibliometric indicators of research productivity, impact and collaboration. Table 2 gives a list of all indicators included in the study. Data was extracted from the Scopus database and relate to the scientific production of world countries and 27 Scopus subject categories from 1996 to 2012.
b) The analyses do not only relate to *national* research systems, but also to *regions* within European countries. In terms of the Nomenclature of Territorial Units for Statistics, NUTS-2 units were analyzed.
c) We describe the main features and advantages of our approach to investigate the scientific convergence of national and regional research systems.

The model

A spin glass is a disordered assembly of spins (e.g. dipole magnets) that are not aligned in a regular pattern. The term "glass" comes from an analogy between the "magnetic" disorder in a spin glass and the positional disorder of a conventional, chemical glass, e.g., a window glass. In window glass or any amorphous solid the atomic bond structure is highly irregular; in contrast, a crystal has a uniform pattern of atomic bonds. In ferromagnetic solid, magnetic spins all align in the same direction; this would be analogous to a crystal. The individual interactions in a spin glass are a mixture of roughly equal numbers of ferromagnetic bonds (where neighbors prefer to have the same orientation) and antiferromagnetic bonds (where neighbors tend to orientate in the opposite directions). These patterns of aligned and misaligned magnets create what are known as frustrated interactions - distortions in the geometry of atomic bonds compared to what would be seen in a regular, fully aligned solid. They may also create situations where more than one arrangement of spins is stable.

In the physics of complex systems, a mathematical framework is developed to analyze spin glass systems. This paper uses certain elements of this framework. National or regional research systems are conceived as analoga of spins and their complex interactions give rise to disordered, spin glass like, systems. Their orientation is described in terms of the distribution of a research system's publication output or related bibliometric measures over the various research disciplines. A research system's disciplinary orientation is described as a vector the

[1] This is the first step of our analysis. Further research will be subsequently devoted to the exploration and investigation of the link between scientific and technological profiles of regional and national research systems.

elements of which contain the percentage of publications in the various disciplines. The rationale for using the spin glass model lies in the ability to analyze the dynamical interactions among research units in a wider system analogously to the analysis of spin orientations in spin glasses.

The following Table 1 summarizes the analogy between the main physical notions of a spin glass model and the corresponding notions in the research system model (see also the Appendix of Bongioanni, Daraio & Ruocco, 2014).

Table 1. Spin glass model: main physical notions and their corresponding notions for research system.

Notion in the physical system	Notion in the Research system
Spin	Country/region
Spin components	Scientific disciplines
J couplings	Country-to-country or region-to-region interactions
Energy (it has to be mini-mized to find stable solutions)	Generalized cost function (to be minimized)
Overlap	Similarity measure

Within the framework of this model, Bongioanni, Daraio & Ruocco (2014) proposed to compare the disciplinary patterns of research systems, by computing the 'overlaps' quantities, that are similarity measures between disciplinary patterns, borrowed from the physics of complex systems. The main variables analysed here are the Pa(i) i.e. the shares of articles published in a subject category i for a given country (or region) a over the sum of publications made during 1996-2012. Similar variables are based on the number of citations received, or the number of internationally co-authored papers. Table 2 gives an overview of all indicators used in this study. The measure of the overlap between the pattern of disciplinary profiles of two countries a and b, $P_a(i)$ and $P_b(i)$ respectively, that is the measure of similarity between systems, is defined as:

$$q_{ab} = \frac{1}{D}\sum_{i=1}^{D} \sigma_a(i)\sigma_b(i),$$

where

$$\sigma_a(i) = \frac{P_a(i) - <P_a>}{\sqrt{<{P_a}^2> - <P_a>^2}},$$

in which <A> stands for average of A, $\sigma_a(i)$ and $\sigma_b(i)$ represent the normalised shares of the indicator considered, for country (or region) a and b, respectively; and D is the number of subjects or disciplines analysed, which in this study amounts to 27 and are derived from Scopus. We note that if we use as variables $\pi_a(i) = P_a(i) - < P_a >$ instead of $P_a(i)$, q_{ab} coincides with the Salton's cosine (calculated with the variables π).

The overlap measure or similarity of profiles between two countries a and b, q_{ab}, ranges from −1, meaning precisely the opposite profile, to 1, meaning precisely the same profile, with 0 representing independence and intermediate values indicating in-between levels of similarity or dissimilarity. Moreover, the overlap can be calculated with respect to another country, with respect to an average or standard value or with respect to a given distribution.

Interpreting the distribution of the overlaps to shed lights on the dynamics of the overall system.

An interesting property of the computed overlap measures between two countries (or regions)' profiles relates to their distribution. The distribution of the overlap reveals whether there is a *converge*nce in the overall system towards a unique disciplinary profile or whether there is a divergence of the system towards different disciplinary configurations. In particular, according to Bongioanni, Daraio and Ruocco (2014) the interpretation of the distribution of the overlap values is as follows: one pick on one shows a convergence towards the *same* disciplinary profile for all countries, while two picks point to two *different* configurations of disciplinary profiles.

We point out that this is one of the main advantages of our approach compared to currently bibliometric approaches used for comparing disciplinary profiles. Although a systematic comparison of our approach with other existing methods is in progress, we think that our approach offers an easy way, based on the investigation of the distribution of the overlap, to check whether there is convergence or not without having to adopt one of the alternative methods developed in the theory of growth to measure convergence. The most applied method to assess convergence in this context, adopted also in the context of scientific convergence (see e.g. Horlings & van den Besselaar, 2013), is based on *regressions*. Within this framework (see e.g. Barro & Sala-i-Martin, 1992), it is said that there is *beta-convergence* (where beta is the coefficient of the initial level of per capita output in the growth regression) when poor economies tend to grow faster than rich economies (and hence the beta coefficient is lower than zero, implying that the higher initial level of output per capita negatively affects the growth rate). Another related concept is that of *sigma-convergence*, which happens when the dispersion of the output per capita decreases over time. The sigma-convergence is often measured by analyzing the variation of the standard deviation (or the coefficient of variation or the concentration) of the output per capita over time. However, this regression based approach has been questioned in the growth literature (see e.g. Durlauf, 2000) and other studies of convergence have applied different methods, including a test on the distribution of the output and how it evolves over time, reaching often very different results (see e.g. Durlauf, Kourtellos, & Tan, 2005). Our approach, offers an interesting alternative to estimate the convergence, by analyzing the distribution of the overlaps and their dispersion.

Another interesting property of our approach is related to the exploitation of the *ultrametric* structure of the overlap values to obtain "automatically" clusters of the national or regional research systems analysed, without having to carry out a specific clustering exercise.[2]

Note that the indicators reported in bold in Table 2 are average productivity indicators, that is intensive (size independent) indicators of the scientific production, while the others are extensive (size dependent) indicators of scientific production.

In this paper the following overlaps were computed:

- Of each main country in the world against all other countries, using a set of 41 countries, including all member states of the European Union and major countries from the rest of the world.
- Of each 27 European country against all other European countries, to provide an aggregate benchmark for the regional analysis.
- Of each NUTS-2 region against all other regions, using a set of 266 NUTS-2 regions in member states of the European Union.

[2] Research on this point is in progress.

Table 2. Indicators applied in the study

Indicator	Description
PUB	Number of articles (integer count).
PUBf	Number of articles (fractional counts based on authors affiliations).
C	Total citations (4 years window, i.e., for articles in 2006; citations are from 2006-2009).
CPP	Total citations per paper (4 years window, i.e., for articles in 2006; citations from 2006-2009).
HCPUB	Number of articles in top 10 per cent of most highly cited articles in a discipline.
PUBINT	Number of internationally co-authored papers.
PUBNAT	Number of nationally (but not internationally) co-authored papers.
PUBINST	Number of papers co-authored by members of different institutions within a country.
PUBSA	Number of non-collaborative (single address) papers.
NA	Number of publishing authors in a particular year, by discipline.
APUB	Number of articles (integer count) divided by NA
APUBf	Number of articles (fractional counts based on authors affiliations) divided by NA
AC	Total citations (4 years window, i.e., for articles in 2006; citations are from 2006-2009) divided by NA
ACPP	Total citations per paper (4 years window, i.e., for articles in 2006; citations from 2006-2009) divided by NA
AHCPUB	Number of articles in top 10 per cent of most highly cited articles in a discipline divided by NA
APUBINT	Number of internationally co-authored papers divided by NA
APUBNAT	Number of nationally (but not internationally) co-authored papers divided by NA
APUBINST	Number of papers co-authored by members of different institutions within a country divided by NA
APUBSA	Number of non-collaborative (single address) papers divided by NA

Legend to Table 2: Data was extracted from the Scopus database and relate to the scientific production of world countries and NUTS2 European regions for 27 Scopus subject categories from 1996 to 2012.

Results are presented in two sections. The first part explains the base notion of a disciplinary profile, compares pair-wise profiles of countries and NUTS2 regions, and analyzes the structure within the set of profiles. It focuses on one single indicator: the number of articles (PUBf) published in 2012. The second part analyzes also average productivity indicators (APUBf) and dynamical aspects.

Disciplinary profiles of countries and regions

Figure 1 shows large differences in the distribution of research articles among subject fields between USA and China. The first country has a strong focus on medical sciences and biomedical research, including biochemistry, genetics and molecular biology, neurosciences, and on social sciences and humanities. The latter shows a large publication activity in physical sciences and engineering: chemistry, materials science, physics, and engineering and computer science.

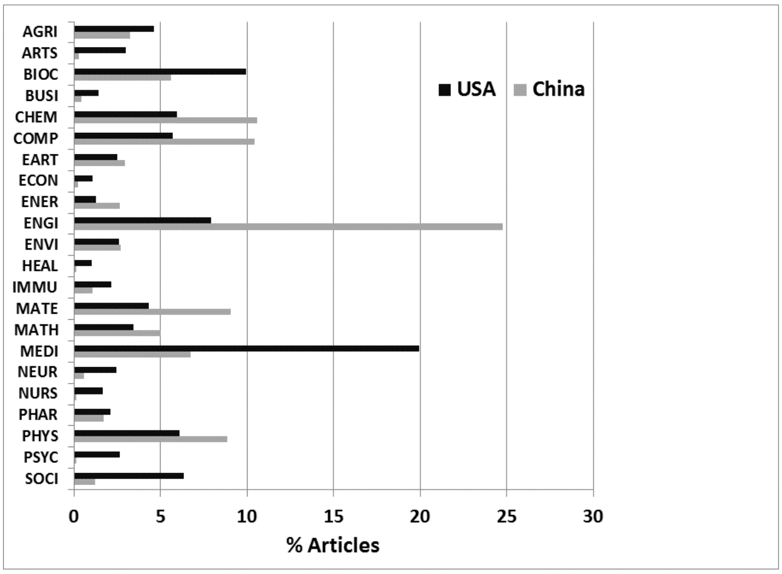

Figure 1. Disciplinary profiles of two countries large countries: China vs. USA. Data relate to the year 2012, and are extracted from Scopus.3 In this figure, four small disciplines have been left out: Dentistry, Decision Sciences, General, and Veterinary Sciences. Chemical Engineering is merged with Chemistry.

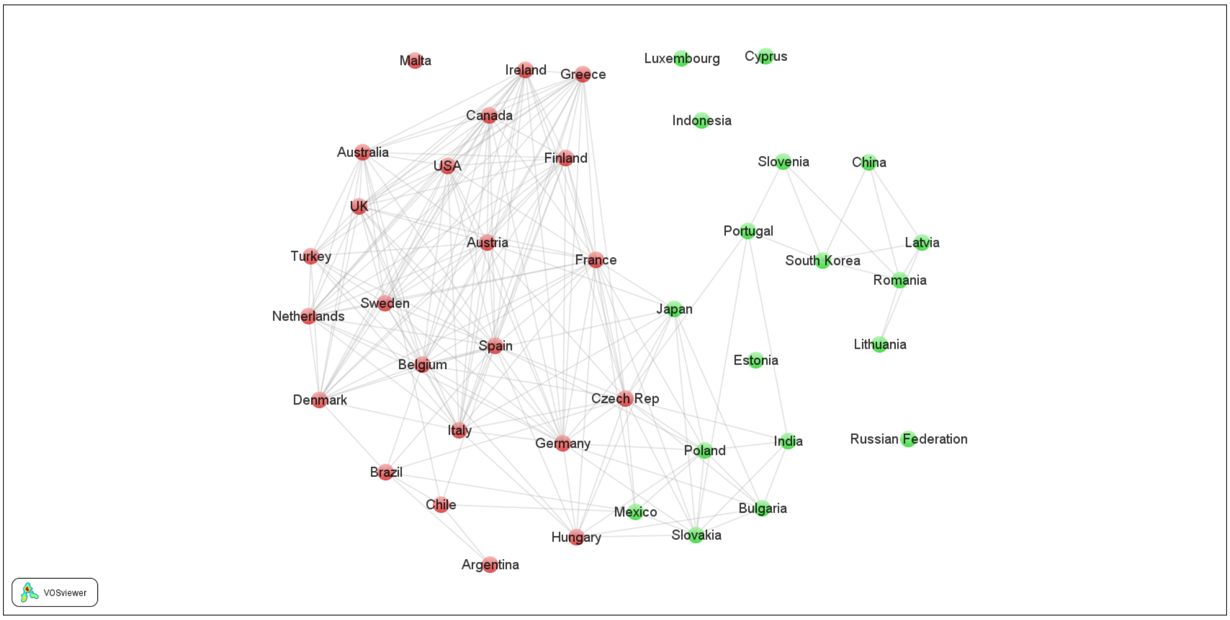

Figure 2. VoS-Viewer Map of the de degree of overlap of disciplinary profiles among 41 countries. For more details about VoS viewer, the reader is referred to www.vosviewer.com

Figure 2 shows a map of a set of 41 countries, including all member states of the European Community, and major countries from the rest of the world. Interestingly, the cluster module in the VoS Viewer identified two clusters of countries. These clusters correspond to the

3 The labels of the disciplines are the following: AGRI: Agricultural and Biological Sciences; ARTS: Arts and Humanities; BIOC: Biochemistry, Genet, Mol Biol; BUSI: Business, Managmnt, Accounting; CHEM: Chemistry; COMP: Computer Science; DECI: Decision Sciences; DENT: Dentistry; EART: Earth and Planetary Sciences; ECON: Economics, Econometrics and Finance; ENER: Energy; ENGI: Engineering; ENVI: Environmental Science; GENE: General; HEAL: Health Professions; IMMU: Immunology and Microbiology; MATE: Materials Science; MATH: Mathematics; MEDI: Medicine; NEUR Neuroscience; NURS: Nursing; PHAR: Pharmacology, Toxicology and Pharmaceutics; PHYS: Physics and Astronomy; PSYC: Psychology; SOCI: Social Sciences; VETE: Veterinary Sci.

different profiles illustrated in Figure 1. The countries indicated with red circles, located at the left hand side of the plot, tend to have a biomedical disciplinary profile, similar to USA and the Netherlands. At the right hand side a group of countries indicated by green circles tends to have a physical-sciences profile, like China, and Russia. Many Central and Eastern-European countries belong to this group: apart from South Korea, also India, Indonesia, Mexico, Portugal, and the small countries Luxembourg and Cyprus.

Several studies in the past have found differences in disciplinary profiles between countries. But to the best of our knowledge, no study has systematically analyzed geographical regions within countries. Figures 3 and 4 show results for the so called NUTS-2 regions. In total, 266 NUTS2 regions were identified. Table 3 presents the quantiles of the distribution of the number of published articles (year 2012) among regions. The distribution is highly skewed. The top 25 per cent of regions has published more than 4,146 articles in 2012. 5 per cent has published more than 11,612 articles. The bottom 25 per cent has published less than 496, and the bottom 10 per cent less than 89. Figure 3 shows disciplinary profiles of two pairs of NUTS2 regions: Inner London and the German city Stuttgart. The figure reveals the same main profiles as Figure 1 did at the level of countries: a biomedical profile in Inner London, and a physical sciences profile in Stuttgart.

Table 3. Quantiles of the distribution of number of publications among NUTS2 regions

Level	*Score*
Number of NUTS2 regions	266
Average articles/region	3,326
Level	*Quantile*
100% Max	46,451
90%	8,247
75% Q3	4,146
50% Median	1,815
25% Q1	496
10%	89
0% Min	1

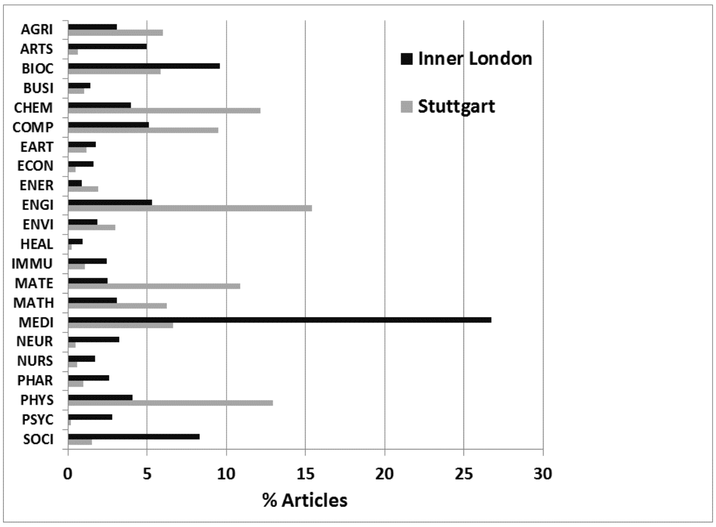

Figure 3. Disciplinary profiles of Inner London (UK) vs. Stuttgart (Germany)

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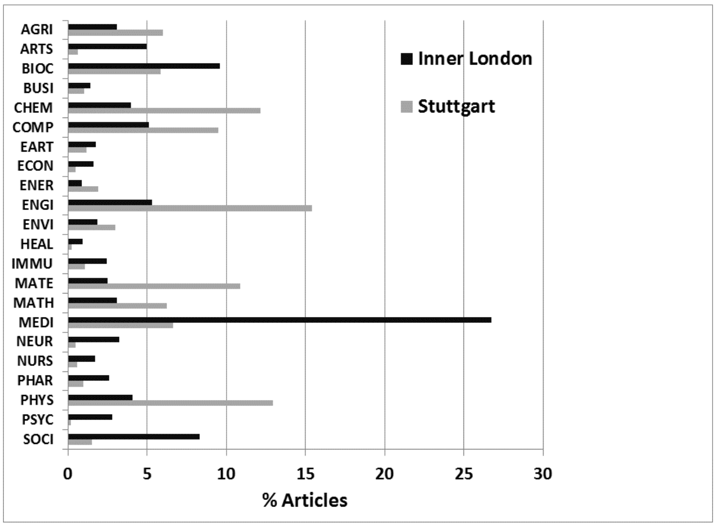

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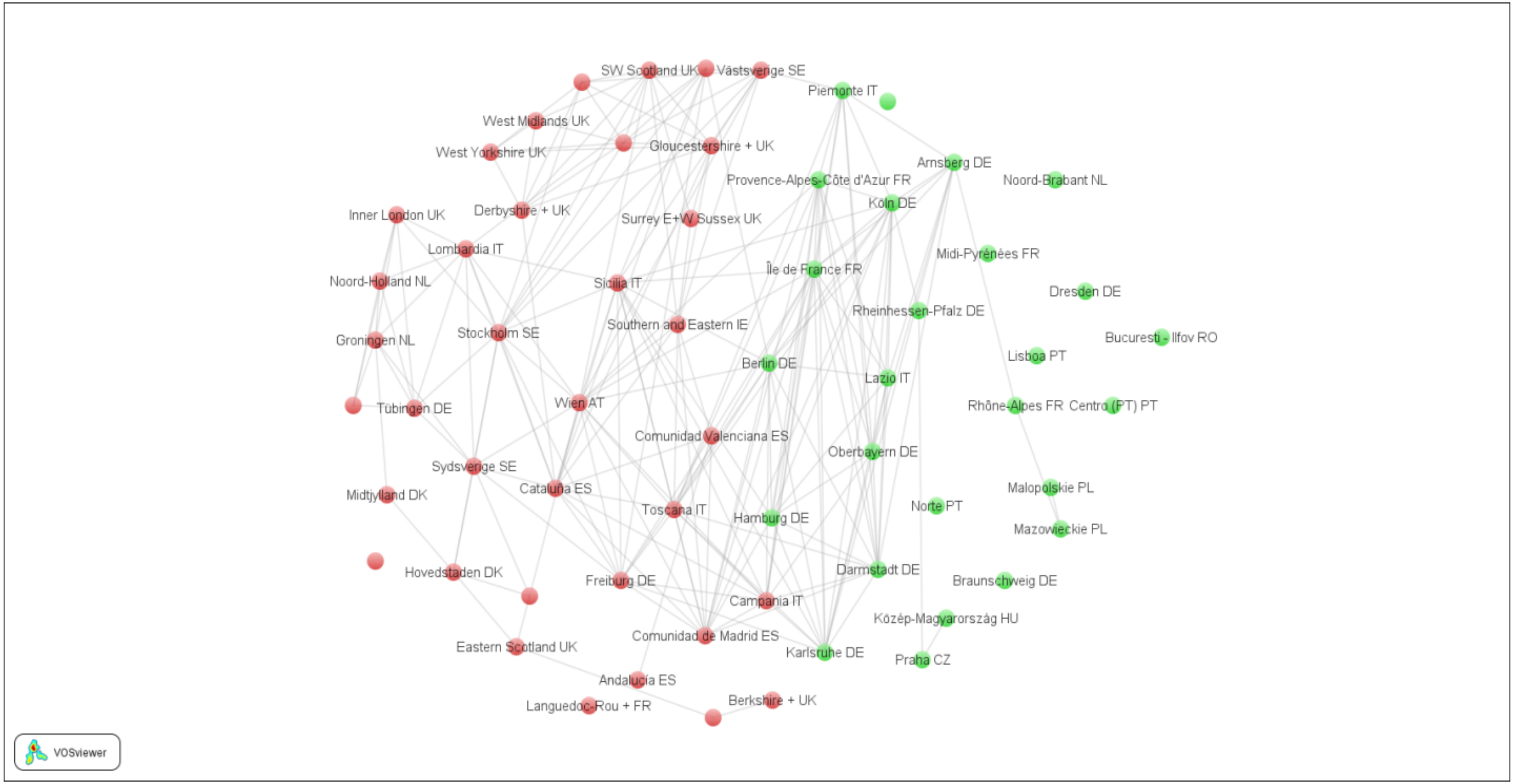


Figure 4. VoS-Viewer Map of the de degree of overlap of disciplinary profiles among 62 NUTS 2 regions. Results are based on an analysis of 62 NUTS2 regions. Due to inconsistencies in the primary data, regions from Belgium and Finland are missing in this graph. Not all circles have labels.

Figure 4 presents a VoS viewer map of the 62 NUTS2 regions in the top quartile in terms of number of articles published in 2012, and based on their degree of overlap between disciplinary specialization. As for countries, the clustering module identified two clusters: the one on the right hand side with red labels tend to cover the regions with a predominantly biomedical profile, and the cluster at the right hand side the regions with a focus on physical sciences. Due to particularities of the underlying primary data and of the visualization technique, this figure cannot be used to reliably assess regions in terms of their scientific performance. Its main function in this paper is analyzing the structure within the set of NUTS2 regions. A preliminary results that should be substantiated in further empirical analysis is that the variability of disciplinary profiles *among countries*, is of the same order of magnitude of the variability *among regions* within a country.

Analysis of distributions of overlap values

Figure 6 (see next page) illustrates the nonparametric kernel distributions (solid line) as well as the histogram of the overlap values calculated at the world, European and regional NUTS2 level. On the x-axe the overlap values are reported while on the y-axe the distribution of the overlap (F(q), given by the nonparametric kernel density and the histogram) is reported. The overlaps are calculated over the volume of publications in fractional count (PUBf) as well as on the average productivity (APUBf). Remarkably, all the distributions of the overlaps clearly show a pick on one reflecting, as explained in Bongioanni, Daraio & Ruocco (2014), the existence of a *convergence towards a unique disciplinary profile*, both in extensive and intensive measures. We observe however that the distributions of the average productivity (APUBf) is *less dispersed* than that of the corresponding extensive measure at all the three levels of analysis: world, European countries and European regions. A similar pattern was found for the citation-based indicator: the number of highly cited articles published from a country or a region (HCPUB). The relative figures are not reported to save space.

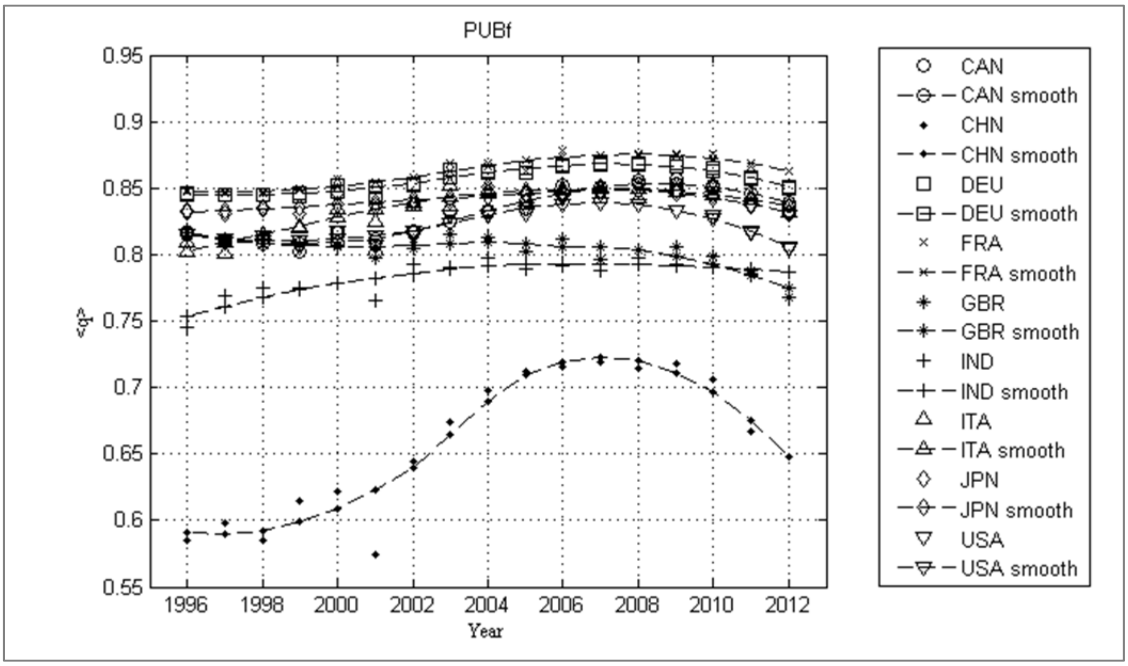
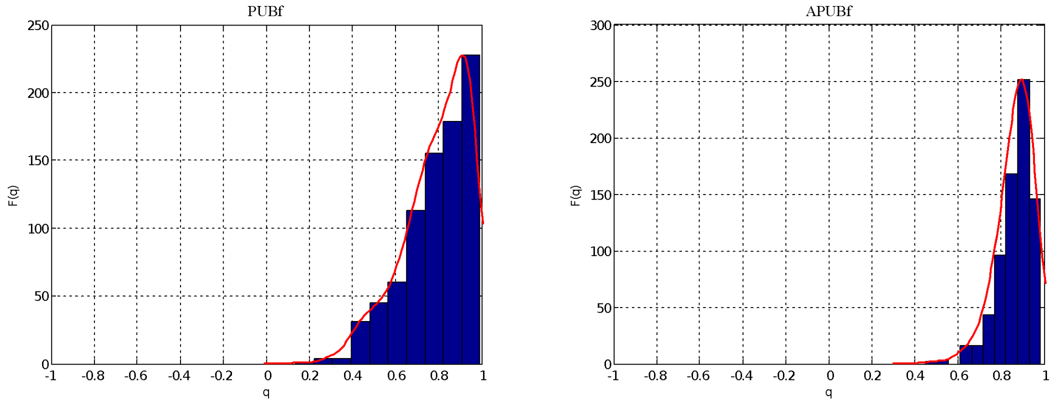
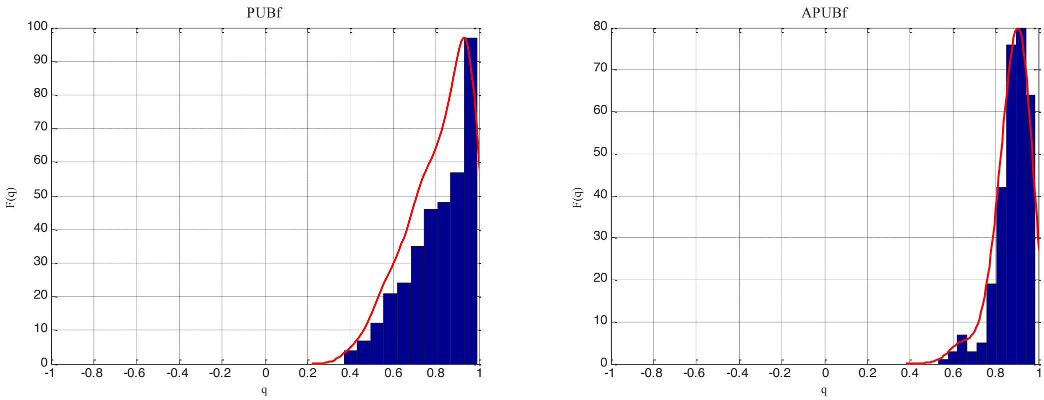


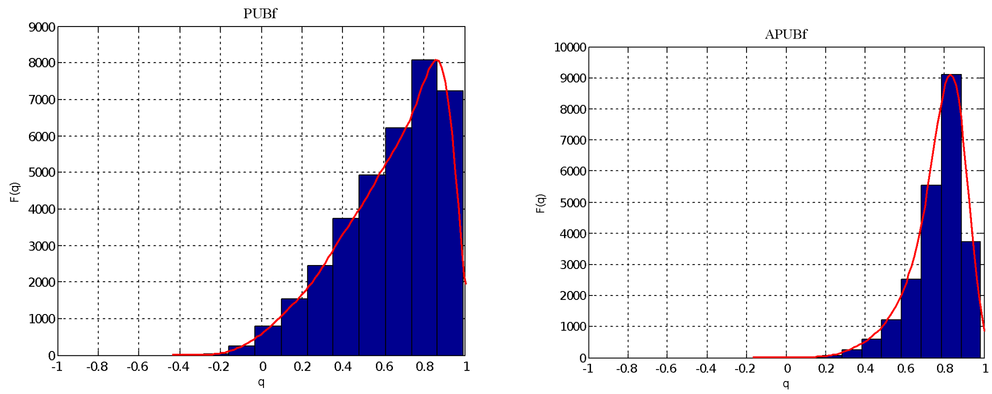
Figure 5. Dynamics of overlaps between 9 leading nations and all other countries for the fractional number of publications (PUBf).



TOP PANEL. World Distribution of the overlaps calculated on each country against all other countries in the world for the *extensive* (size dependent) indicator of scientific production PUBf (top-left panel) and the *intensive* average productivity indicator APUBf (top -right panel).



MIDDLE PANEL. European Distribution of the overlaps calculated on each European country against all other European countries for the *extensive* indicator of scientific production PUBf (middle-left panel) and the *intensive* average productivity indicator APUBf (middle-right panel).



BOTTOM PANEL. European Regions (NUTS2 units) Distribution of the overlaps calculated on each European region against all other European regions for the *extensive* indicator of scientific production PUBf (bottom-left panel) and the *intensive* average productivity indicator APUBf (bottom-right panel).

Figure 6. Distributions of the overlaps calculated at World, European and Regional level for extensive (PUBf) and intensive (APUBf) indicators.

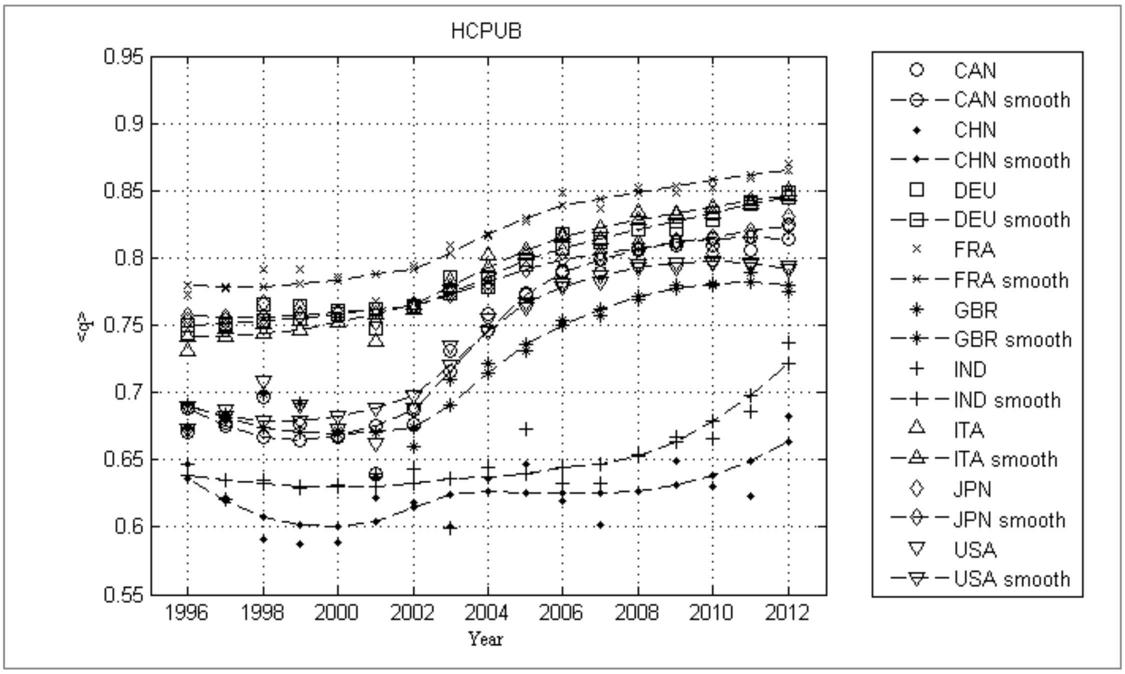


Figure 7. Dynamics of overlaps between 9 leading nations and all other countries for the number of highly cited publications (HCPUB)

An important aspect is the *dynamics* of the overlap values: how do the overlap distributions develop over time, and how does the position of specific countries evolve. Figures 5 and 7 present for 9 leading nations the development over time of the average overlap with all other countries, for the fractional number of publications (PUBf) and the number of highly cited publications (HCPUB), respectively. Although Figure 6 shows during the last 4 years a slight decline in overlap for most countries, Figure 7 reveals a trend towards convergence, especially for India and China. Perhaps the latter two countries increased their contribution to the international research front, but they maintained to some extent their own disciplinary profiles.

Conclusions

A tentative conclusion that should be substantiated in future empirical research is that the *variability of disciplinary profiles among countries is of the same order of magnitude of the variability among regions within a country and that the same happens for their convergence* rates, as shown by the distributions of the overlap calculated and displayed in this paper. The same dynamics observed for the extensive measures of scientific production is observed for the intensive average productivity, which appears to have a more concentrated distribution for all the level of the analysis carried out. Further research is in progress to support these preliminary findings and to illustrate the advantages of our approach, including the application of the ultrametric property of the overlap values to determine "automatic" clustering of the investigated national and regional systems of research. The step further will be then to link the scientific structure of national and regional systems with their technological structure to evaluate their dynamics at national and regional level.

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References

Barro, R. J. & Sala-i-Martin, X. (1992), Convergence, *Journal of Political Economy, 100*(2), 223–251.

Bongioanni, I., Daraio, C., & Ruocco, G. (2014), A Quantitative Measure to Compare the Disciplinary Profiles of Research Systems and their evolution over time, *Journal of Informetrics*, *8*, 710-727.

Bongioanni, I., Daraio, C., Moed, H.F., & Ruocco, G. (2014), Disciplinary Profiles and Performance of Research Systems: a World Comparison at the Country level, *Proceedings of the Science and Technology Indicators Conference 2014 "Context Counts: Pathways to Master Big and Little Data",* 3-5 September 2014, edited by E. Noyons, published by Universiteit Leiden CWTS 2014, pp. 50-63, ISBN 978-90-817527-1-8.

Camagni, R., & Capello, R. (2013). Regional innovation patterns and the EU regional policy reform: Toward smart innovation policies. *Growth and Change*, 44(2), 355-389.

Durlauf, S. (2000), "Econometric Analysis and the Study of Economic Growth: A Skeptical Perspective," in *Macroeconomics and the Real World*, R. Backhouse and A. Salanti, eds., Oxford: Oxford University Press.

Durlauf, S. N., Kourtellos, A., & Tan, C. M. (2005). Empirics of growth and development. *International Handbook of Development Economics*, 1.

Glanzel, W., Debackere, K., & Meyer, M. (2008). 'Triad' or 'tetrad'? On global changes in a dynamic world. *Scientometrics*, *74*, 71-88.

Glänzel, W., Leta, J., & Thijs, B. (2006). Science in Brazil. Part 1: A macro-level comparative study. *Scientometrics*, *67*(1), 67-86.

Glanzel, W. (2000). Science in Scandinavia: A bibliometric approach. *Scientometrics 48*, 121-150.

Glanzel, W. & Schlemmer, B. (2007). National research profiles in a changing Europe (1983–2003): An exploratory study of sectoral characteristics in the triple helix. *Scientometrics*, *70*(2), 267–275.

Hu, X. J., & Rousseau, R. (2009). Comparative study of the difference in research performance in biomedical fields among selected Western and Asian countries. *Scientometrics*, *81*(2), 475–491.

Horlings, E. & van den Besselaar, P. (2013), Convergence in science growth and structure of worldwide scientific output, 1993-2008, Rathenau Instituut, Working Paper 1301.

McCann, P. & Ortega-Argilés, R. (2013). Smart specialization, regional growth and applications to European Union cohesion policy. *Regional Studies*, 1-12.

Radosevic, S., & Yoruk, E. (2014). Are there global shifts in the world science base? Analysing the catching up and falling behind of world regions. *Scientometrics*, *101*(3), 1897-1924.

Tang, L. & Shapira, P. (2011). Regional development and interregional collaboration in the growth of nanotechnology research in China. *Scientometrics*, *86*, 299–315.

Tian Y., Wen, C., & Hong, S. (2008). Global scientific production on GIS research by bibliometric analysis from 1997 to 2006. *Journal of Informetrics,* 2, 65-74.

Wong, C. Y. (2013). On a path to creative destruction: science, technology and science-based technological trajectories of Japan and South Korea. *Scientometrics*, *96*, 323–336.

Wong, C. Y. & Goh, K. L. (2012). The pathway of development: science and technology of NIEs and selected Asian emerging economies. *Scientometrics*, *92*, 523–548.

Yang, L. Y., Yue, T., Ding, J. L., & Han, T. (2012). A comparison of disciplinary structure in science between the G7 and the BRIC countries by bibliometric methods. *Scientometrics*, *93*, 497–516.

Zhou, P., Thijs, B., & Glänzel, W. (2009), Regional analysis on Chinese scientific output, *Scientometrics*, *81*(3), 839-857.