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Measuring diversity of research output: do the authors' field classification and the reference list approaches converge?

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Abstract

This study investigates the convergence of two bibliometric approaches to the measurement of interdisciplinary research: one based on analyzing disciplinary diversity in the reference list of publications, the other based on the disciplinary diversity of authors of publications. In particular we measure the variety, balance, disparity and integrated diversity index of, respectively, single author, multi author single field, and multi author multi field publications. We find that, in general, the diversity of the reference list grows with the number of fields reflected in a paper's byline and, to a lesser extent, with the number of authors given the same number of fields. Further, we find that when fields belonging to different disciplines are reflected in the byline, the disparity in the reference list is accordingly higher. However, this general tendency varies across different disciplines.

Introduction

The possibility of scientific and social gain through interdisciplinary research (IDR) is of increasing interest to both academics and policymakers.

Although present research policies often implicitly assume that IDR can be readily identified and tracked, this is far from true. Providing policymakers with measures and analyses that capture the intensity of IDR and knowledge integration is a scientific task of high practical importance, yet it is fraught with difficulties – see Wagner et al. (2011) and Rousseau et al. (2018) for a review. In this work, we focus on the issues associated with measuring IDR. More precisely, we investigate the convergence of two bibliometric approaches to measurement: one based on analyzing disciplinary diversity in the reference lists of publications (Porter, Cohen, Roessner, & Perreault, 2007; Rafols & Meyer, 2010; Wang, Thijs, & Glänzel, 2015; Mugabushaka, Kyriakou, & Papazoglou, 2016; Zhang, Rousseau, & Glänzel, 2016), the other based on the disciplinary diversity of a publications' authors (Schummer, 2004; Abramo, D'Angelo, & Di Costa, 2012). Measuring IDR has important benefits: learning about the collaboration behaviour of scientist, informing policy and initiatives aimed at fostering IDR, as well as monitoring its trends to assess the efficacy of policy, among others.

It is not possible to define a unique and absolute measure of IDR. Hence, scholars have developed a variety of proxy indicators, each one delivering different insights about the interdisciplinary nature of the research under study.

Bibliometric approaches take articles as the subject of study and measure IDR in terms of the co-occurrence of discipline-specific elements, such as keywords, classification headings, the publishing journals, the authors, or the articles' reference list. The most diffuse of these approaches is certainly citation analysis, where citations to papers in other disciplines are considered to be a signal of possible interactions or integration between different fields. According to Stirling (1994), "diversity" has three distinct components: "variety, "balance", and "disparity". Further, Stirling (2007) proposes suitable measurement indicators for each component. The variety indicator answers the question: "How many types of thing do we have?" For "balance", the question is: "How much of each type of thing do we have?" Finally, for "disparity" the question is: "How different from each other are the types of thing that we have?" In the bibliometric sphere, these concepts have been widely applied to investigate IDR, as demonstrated in Wagner et al.'s review (2011). Porter and Rafols (2009) proposed measuring Stirling's (1994) three basic properties of research diversity by mapping the subject categories of cited publications. The authors introduced an "integration score", which indexes the number of disciplines cited by a paper along with their "concentration" and "distance". Rafols and Meyer (2010) maintain that the most appropriate indicator for studying the interdisciplinarity of a paper is the proportion of citations to papers in other disciplines. Recently, Zhang, Rousseau, and Glänzel (2016) proposed a new measure, ${}^{2}D^{3}$, as a monotone transformation of the Rao-Stirling indicator of diversity (Rao, 1982; Stirling, 2007).

Very few works identify IDR from the bibliometric perspective of co-authorship. The disciplinary field of an author can be thought of as their knowledge contribution to the project. Schummer (2004) applied this approach to a data set of 600 papers published in "nano" journals in the 2002–2003 biennium. Using a similar approach, Abramo, D'Angelo, and Di Costa (2012) analyzed the degree of collaboration among scientists from different disciplines to identify the most frequent "combinations of knowledge" in research activity, drawing on the 2004-2008 Web of Science (WoS) publications by all Italian universities' professors working in the sciences.

For reasons that we make apparent in the next section, the Italian case is particularly suited to the bibliometric analysis of IDR by the co-authorship method, and forms the case analysis for this paper. In Section 2, we present the field of observation and the way we apply the two

methods to measure IDR: the disciplinary diversity of authors vs the disciplinary diversity of the reference list. In section 3 we illustrate the results of the analysis, and in Section 4 we draw our conclusions.

Data and methods

Data

The application of the authorship analysis method to measure IDR requires identifying the specialization of a paper's authors. In the Italian academic system, professors must classify themselves in one, and only one, scientific field. These fields, called scientific disciplinary sectors (SDSs), are each grouped under one of 14 university disciplinary areas (UDAs); there are 370 SDSs in all.[1] With the exception of Norway, it seems that no other country classifies their academics by discipline, which makes the Italian case particularly appropriate for this kind of analysis. The bibliometric data used in this study is extracted from the Italian Observatory of Public Research, a database developed and maintained by the Italian authors of this paper, and derived under license from the WoS core collection. Beginning from the raw data of the WoS publications with affiliation Italy, and applying a complex algorithm to reconcile the author's affiliation and disambiguation of the true identity of the authors, each publication by Italian universities is attributed to the university professor or professors that produced it (D'Angelo, Giuffrida, & Abramo 2010).[2]

We observe the 2006-2016 WoS indexed publications by Italian universities. The publication types are restricted to articles, proceedings papers, and book chapters since these types of documents normally contain original research, unlike reviews, letters, etc. In particular, the knowledge integration revealed from a "review" may carry a different cognitive meaning than the original article. Additionally, papers with co-authors from foreign institutions or other Italian organizations are excluded, as only Italian universities' academics are classified in the SDS system. Finally, we exclude publications with no references indexed in the WoS (source items). The final data set comprises 43,667 publications: 19,286 with single-authors and 24,381 with multiple authors.

The disciplinary analysis of the reference list

According to the reference list method, interdisciplinarity of a publication is measured by the diversity of the research fields represented in a publication's reference list. Operationally, we identify the fields of a publication by the WoS subject categories (SCs) of the relevant journal (full counting). Diversity can be measured through the three components: variety, balance, and disparity, outlined in Stirling (2007). These three decompositions make it possible to explore different aspects of diversity in the cited references.

[1] In Italy, all personnel enter the university system and progress their careers through national public examinations. These examinations are given per field (SDS) and are assessed by members of the same SDS. Candidates must choose the SDS in which to compete and show their competence in that specific SDS through their research outputs. SDS classifications are governed by a very large committee of university professors across all scientific disciplines, called the CUN. Ministry intervention is limited to enacting the CUN's recommendations.

[2] The harmonic mean of precision and recall (F-measure) of authorships disambiguated by the algorithm is around 95% (2% margin of error, 98% confidence interval). Additional manual disambiguation correcting false positive and negative authorships increases the harmonic mean to 98.5%.

Variety is defined as the number of non-empty categories assigned to system elements. In this study, the system elements are the WoS-indexed references and the non-empty categories are the SCs in WoS. In formulae:

$$\mathbf{V} = \sum_{\mathbf{i}} \mathbf{SC_i} \quad \textbf{[1]}$$

Where SCi = 1 if represented in the reference list; 0 otherwise. The value of V ranges between 1 and the number of SCs (currently 252).

Balance is a function of the pattern of the element assignments across categories – called "evenness" in ecology and "concentration" in economics. The Gini index is a well-known concentration measure where, if G denotes the Gini concentration measure, then B = 1-G is the corresponding measure of evenness or balance. In this study, we adopt "B = 1-G" as the balance indicator. See Equation 2 below:

$$\mathbf{B} = \mathbf{1} - \frac{\sum(\mathbf{2}\boldsymbol{i}-\boldsymbol{V}-\mathbf{1})\boldsymbol{x_i}}{\boldsymbol{V}\sum \boldsymbol{x_i}} \quad \textbf{[2]}$$

Where *i* is the index ranging from 1 to V, x_i is the number of references falling in the *i-th* SC, and the SCs are sorted by x_i in non-decreasing order. The range of *B* is between 1/V (max concentration) and one (max balance).

Disparity refers to the manner and degree to which things are distinguished. Disparity is the complement of similarity. In formulae,

$$\mathbf{Dis_{ij}} = \mathbf{1} - \mathbf{S_{ij}} \quad \textbf{[3]}$$

Where S_{ij} is the cosine similarity between the *i-th* SC and *j-th* SC, based on a cross-citation matrix for the period 1991-2015.[3] The range of $\boldsymbol{Dis_{ij}}$ is between zero (max similarity) and one (max disparity).

In this study, we calculate the average disparity ($\overline{\mathbf{Dis}}$) between the referenced SCs. In formulae:

$$\overline{\mathrm{Dis}} = \frac{1}{\mathrm{V(V-1)}}\sum_{\mathrm{i}\neq\mathrm{j}} \mathrm{Dis_{ij}} \quad \textbf{[4]}$$

Additionally, we measure the Zhang, Rousseau, & Glänzel (2016) Integrated Diversity (ID) index, as the representative indicator of integrated diversity for the above three components.

Integrated diversity is defined as,

$$\mathrm{ID} = \frac{1}{\sum_{i\neq j} p_i p_j (1-Dis_{ij})} \quad \textbf{[5]}$$

Where $\boldsymbol{p_i} = {}^{\boldsymbol{x_i}}/_{\boldsymbol{X}}; \boldsymbol{X} = \sum \boldsymbol{x_i}$. In the case of one single SC, namely $\mathbf{Dis_{ij}} = 0$, the value of integrated diversity, ID is 1.

The disciplinary analysis of authors

[3] The cross-citation matrix of all SCs (1991-2015) was constructed by Lin Zhang based on an in-house database in ECOOM, Belgium.

The SDS of a researcher is a reflection of their educational background, their expertise, and their primary field of research. However, this does not mean that their research is necessarily always confined to their SDS, in fact research diversification occurs indeed (Abramo, D'Angelo, & Di Costa, 2017a, 2017b). For example, a statistician may join research teams in medicine, physics, social sciences, etc. giving rise to IDR. Once the true identity of each co-author is determined, a publication can be associated with one or more SDSs, and its disciplinary nature assessed. In this work we apply the disciplinary analysis of authors to distinguish interdisciplinary publications from non-interdisciplinary ones. The latter can be further subdivided into single-author and multi-author (whereby all co-authors belong to the same SDS) publications. For each subpopulation we then measure its discipline diversity by the reference list method, calculating the above four indicators. Differences in diversity are expected across subpopulations.

According the authorship analysis method, a single-author paper, by convention, cannot be interdisciplinary since the author belongs to one, and only one, SDS. Nor can a publication co-authored by academics belonging to the same SDS be interdisciplinary. In theory, one would expect to find nil diversity in these two cases when IDR is measured with the alternative approach, i.e. the reference list. In practice, however, there may be a low level of what we call "physiological" diversity. The reasons for this are:

1. Research fields generally present blurring boundaries and some overlapping domains.
2. Research scientists often have a broader educational background than their specialization (e.g., a vascular surgeon is, first of all, a physician), which allows them to integrate knowledge from cognitively close fields. Additionally, they may have had opportunities to diversify their research during their career, say, by joining multidisciplinary teams, which has provided exposure to theories and methods from different disciplines.
3. The SDS classification system (370 SDSs in all) differs from the WoS subject classification scheme (252 SCs), which is generally used to analyze diversity in reference lists.

For the above reasons, we expect that the "physiological" diversity of (non-interdisciplinary) papers co-authored by scientists belonging to the same SDS, will grow with the number of authors. For (interdisciplinary) papers co-authored by scientists belonging to different SDSs, we would expect that diversity in the reference list grow along with the number of SDSs reflected in the byline. To a lesser extent, we would expect diversity to increase with the number of authors, being the number of SDSs equal. Furthermore, the disparity in the reference list should be reflective of the cognitive distance between the SDSs represented in the byline (i.e. when the SDSs fall under different UDAs).

Analysis and Results

We divide the entire data set of 43,667 publications into three subpopulations:

a) single-author papers – 19,286 publications;
b) multi-author, single SDS papers – 16,624 publications; and
c) multi-author, multi-SDS papers – 7757 publications.

The three decomposed diversity indicators: variety, balance and disparity, in addition to the integrated diversity indicator, are calculated by the reference list method, for each individual publication in each of the three sub-populations.

Analysis of diversity of single-author papers

From our analysis of diversity in the reference lists of single-author papers (Table 1), we observe remarkable differences in each of the different UDAs.

Table 1. Average diversity values for the reference lists in single-author papers

UDA	No. Papers	% of Papers	Avg_Variety	Avg_Balance	Avg_Disparity	Avg_ID
Biology	695	3.60%	11.016	0.496	0.953	4.442
Chemistry	714	3.70%	10.629	0.485	0.957	4.276
Agricultural and Veterinary Sciences	347	1.80%	7.908	0.519	0.890	3.796
Civil Engineering and Architecture	1069	5.54%	6.776	0.595	0.902	3.743
Medicine	1046	5.42%	7.953	0.473	0.910	3.481
Industrial and Information Engineering	2789	14.46%	5.730	0.608	0.858	3.439
Earth Sciences	335	1.74%	7.322	0.524	0.921	3.426
Economics and Statistics	2410	12.50%	5.602	0.481	0.862	2.867
Physics	2206	11.44%	5.534	0.495	0.861	2.729
Political and Social Sciences	719	3.73%	4.127	0.509	0.752	2.694
History, Philosophy, Pedagogy, and Psychology	1645	8.53%	4.337	0.459	0.667	2.660
Mathematics and Computer Science	3843	19.93%	4.184	0.479	0.761	2.367
Law	340	1.76%	2.932	0.525	0.710	2.146
Ancient History, Philology, Literature, and Art	1128	5.85%	2.168	0.389	0.526	1.760
Total	19286	100%	5.565	0.503	0.811	2.950

Analysis of diversity of multi-author single-SDS papers

In our data set, 16,624 publications had multiple authors with the same SDS. Thus, a question arises as to whether the number of authors will affect diversity measured by references. Table 2 presents the average diversity values for the reference lists of these multi-author single-SDS papers.

Table 2. Average diversity values for the reference lists in single-SDS papers

No. Authors	No. Papers	Avg_Variety	Avg_Balance	Avg_Disparity	Avg_ID
1	19286	5.565	0.503	0.811	2.950
2	10820	6.375	0.530	0.868	3.268
3	4344	6.499	0.550	0.882	3.358
4	1116	7.008	0.554	0.905	3.516
5	248	9.480	0.497	0.925	4.088

Analysis of diversity of multi-SDS papers

This subsection focuses on the 7757 papers with collaborations across SDSs. Table 3 presents the average diversity values for the reference lists of these publications, Over 85% of papers only span two SDSs, while only five papers cover more than five SDSs. On average, the values for all diversity measures increases as the number of SDSs increases from 2 to 4. The results for the 18 papers with five SDSs are not statistically meaningful due to the limited sample size.

Table 3. Average diversity values for the reference lists in multi-SDS papers

No. SDS	No. Papers	% of Papers	Avg_ Variety	Avg_ Balance	Avg_ Disparity	Avg_ID
2	6629	85.46%	7.572	0.538	0.906	3.735
3	970	12.50%	9.292	0.547	0.936	4.458
4	135	1.74%	10.985	0.572	0.962	5.205
5	18	0.23%	12.889	0.498	0.920	5.834

Conclusions

In this study, we compare two approaches to measure interdisciplinary research outputs. We find that, in general, the disciplinary diversity of the reference list grows with the number of SDSs reflected in a paper's byline and, to a lesser extent, with the number of authors given the same number of SDSs. Further, we find that when SDSs belonging to different UDAs are reflected in the byline, the disparity between SCs in the reference list is higher than in the case SDSs belong to the same UDA. However, this general tendency varies across different UDAs. With the exception of Norway, it seems that no other country classifies their academics by discipline, which poses a serious problem in generalizing the above approach. Nonetheless, drawing on the data from such system could serve as a useful benchmark for investigating any convergence with other approaches, such as those based on analyzing the diversity of cited references as examined in this paper. Our study confirms that more research is needed on IDR measurement. Different proxy indicators and approaches may deliver different insights about the interdisciplinary nature of the research under study. A multi-perspective framework for measuring interdisciplinarity in any unit of research combined with expert reviews and content interpretations is probably necessary and more informative.

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References

Abramo, G., D'Angelo, C.A., & Di Costa, F. (2017a). Specialization vs diversification in research activities: the extent, intensity and relatedness of field diversification by individual scientists. *Scientometrics*, 112(3), 1403–1418.

Abramo, G., D'Angelo, C.A., & Di Costa, F. (2017b). The effects of gender, age and academic rank on research diversification. *Scientometrics*, 114(2), 373–387.

Abramo, G., D'Angelo, C.A., & Di Costa, F. (2012). Identifying interdisciplinarity through the disciplinary classification of coauthors of scientific publications. *Journal of the American Society for Information Science and Technology*, *63*(11), 2206–2222.

D'Angelo, C.A., Giuffrida, C. & Abramo, G. (2010). A heuristic approach to author name disambiguation in large-scale bibliometric databases. *Journal of the American Society for Information Science and Technology*, 62(2), 257–269.

Mugabushaka, A.-M., Kyriakou, A., & Papazoglou, T. (2016). Bibliometric indicators of interdisciplinarity: the potential of the Leinster–Cobbold diversity indices to study disciplinary diversity. *Scientometrics*, *107*(2), 593–607.

Porter, A. L. & Rafols, I. (2009). Is science becoming more interdisciplinary? Measuring and mapping six research fields over time. *Scientometrics*, *81*(3), 719-745.

Porter, A. L., Cohen, A. S., Roessner, J., & Perreault, M. (2007). Measuring researcher interdisciplinarity. *Scientometrics*, *72*(1), 117–147.

Rafols, I., & Meyer, M. (2010). Diversity and network coherence as indicators of interdisciplinarity: Case studies in bionanoscience. *Scientometrics*, 82(2), 263–287.

Rao, C.R. (1982). Diversity: Its measurement, decomposition, apportionment and analysis. *Sankhya: The Indian Journal of Statistics*, Series A, 44(1), 1-22.

Rousseau, R., Zhang, L. & Hu, X.J. (2018). Knowledge Integration: its meaning and measurement. Book Chapter. *Springer Handbook of Science and Technology Indicators*, edited by Wolfgang Glänzel, Henk Moed, Ulrich Schmoch and Mike Thelwall.

Schummer, J. (2004). Multidisciplinarity, interdisciplinarity, and patterns of research collaboration in nanoscience and nanotechnology. *Scientometrics*, *59*(3), 425–465.

Stirling, A. (1994). Diversity and ignorance in electricity supply investment. *Energy Policy*, *22*(3), 195–216.

Stirling, A. (2007). A general framework for analysing diversity in science, technology and society. *Journal of The Royal Society Interface*, *4*(15), 707-719.

Wagner, C. S., Roessner, J. D., Bobb, K., Klein, J. T., Boyack, K. W., Keyton, J., … Börner, K. (2011). Approaches to understanding and measuring interdisciplinary scientific research (IDR): A review of the literature. *Journal of Informetrics*, *5*(1), 14–26.

Wang, J., Thijs, B., & Glänzel, W. (2015). Interdisciplinarity and Impact: Distinct Effects of Variety, Balance, and Disparity. *PLOS ONE*, *10*(5).

Zhang, L., Rousseau, R., & Glänzel, W. (2016). Diversity of references as an indicator of the interdisciplinarity of journals: Taking similarity between subject fields into account. *Journal of the Association for Information Science and Technology*, *67*(5), 1257–1265.