INTERDISCIPLINARITY OF AN ARTICLE AS MEASURED THROUGH REFERENCES: IS SCALE-INVARIANCE REALLY NEEDED?

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ABSTRACT: I argue that scale-invariance may not be a necessary condition for measuring interdisciplinarity through the diversity of references.

Keywords: scale-invariance; Shorrocks' generalized Lorenz curve; references; interdisciplinarity

1. INTRODUCTION: INTERDISCIPLINARITY

When considering the term interdisciplinarity I first like to point out that defining a concept and measuring it are two different things. Moreover, the notion of interdisciplinarity includes another one, namely that of a *discipline*. I think it is safe to say that the notion of a *discipline* cannot be formulated in a way that covers all possible situations and applications. In practice, the notion of a discipline or knowledge domain is operationalized in three broad ways (Zitt et al., 2019): using ready-made classifications, using an algorithmic approach and determining the knowledge domain of an article through the domains to which its authors belong. In this note, I will not go deeper into this aspect and assume that an appropriate choice has been made.

Next, I focus on one way to determine the interdisciplinarity of an article, namely through the interdisciplinarity of its references, or of the set of references expanded with the set of references of references, i.e. using one or two backward generations (Rafols & Meyer, 2010; Hu et al., 2011). Further on in this note I will use the term *references* when referring to one or more generations of references. For the next step, there are again many alternatives, but I focus on one often applied method, namely applying a diversity measure on the set of disciplines covered/ used in these references.

This note is further subdivided as follows: first I give a short introduction about how interdisciplinarity can be measured. Next, I come to the main part of this note, namely introducing the question if scale-invariance is really a requirement when studying interdisciplinarity through the diversity of used references. One suggestion is offered to measure diversity in a way that is not scale-invariant. Finally, a short list is offered of problems that must be solved if one wants to continue in the direction of non-scale-invariance for studying interdisciplinarity.

2. MEASURING DIVERSITY

Traditionally diversity consists of two concepts: variety and balance. Variety refers to the number of cells, i.e., the number of nominal classes such as species in biology and disciplines in informetric studies, while evenness or balance is defined as the relative apportionment of abundances among cells, actually present, or assumed to be possibly present (Rousseau & Van Hecke, 1999). It has been shown that evenness on its own is best represented by a classical Lorenz curve (Lorenz, 1905; Nijssen et al., 1998). Yet, it has been convincingly argued that, besides variety and evenness, a third notion must be taken into account when measuring diversity, namely the disparity (or its opposite: proximity) between cells. Stirling (2007) points out that species in ecology or WoS categories in informetrics are not independent entities, but they are shaped by patterns of common developments or ancestry leading to proximities between units, see also (Leinster & Cobbold, 2012; Zhang et al., 2016). Finally, Jost (2006, 2009) pointed out that one should use measures that make it possible to discuss percentage changes in a meaningful way, see also (Leinster & Cobbold, 2012; Zhang et al., 2016). For a review on interdisciplinarity I refer to (Wagner et al., 2011; Rousseau et al., 2019).

Next, I introduce some notation. Let $X = [x_1, \ldots, x_N]$ be an array of N sources or cells (N a natural number larger than 1), ranked according to the number of items (a non-negative value) in each cell. In this note, I will refer to such arrays as diversity arrays. Let f be a diversity measure and f(X) the value of f for the array X. This measure f is said to be scale-invariant if, for each $c > 0$, $f(cX) = f(X)$. In most cases being scale-invariant is considered a necessary property for diversity (and concentration) measures. The idea behind this requirement is that diversity or concentration should not depend on monetary units (dollars, euros, Chinese yuan) in the case of income studies, or weight units (kg, g, pound) in case of biomass. All measures based on the Lorenz curve, such as the Gini index or the coefficient of variation, are by definition scale-invariant as the Lorenz curve is constructed using relative values (see further), not absolute ones.

3. IS SCALE-INVARIANCE REALLY NEEDED?

I return now to the specific case I want to study, namely measuring interdisciplinarity of an article through the diversity of its references. If article A1 is based on four disciplines occurring 10, 6, 2 and 1 times, while article A2 is also based on the same four disciplines occurring 20, 12, 4 and 2 times, which one reflects the most interdisciplinarity? In this hypothetical case, I assume that there are no spurious references and no redundancies: each reference is 'really' needed. Then classical approaches consider these two articles to be equally interdisciplinary.

Yet, because each article, theoretically, makes new and different knowledge claims, it is clear that the second article used the knowledge embedded in these four disciplines more thoroughly than article A1. For this reason, one may say that A2 bears testimony of more interdisciplinarity than A1. Consequently, I claim that depending on the purpose of the investigation, scale-invariance is not a necessary property.

4. HOW TO REPRESENT "NON-SCALE-INVARIANCE"?

How can the above observation be taken into account? Already in 1983 Shorrocks when studying income inequality, observed that, if for a fixed number of cells, the partial order introduced by the Lorenz curve, which is actually the dominance order as studied e.g. in (Hardy et al., 1934), is often inconclusive among two situations, as Lorenz curves tend to cross and for this reason, are intrinsically incomparable (Shorrocks, 1983). For this reason, he proposed the generalized Lorenz curve, constructed by scaling up the ordinary Lorenz curve by the mean of the distribution. This construction reduced the number of crossing curves.

I next recall the construction of the ordinary Lorenz curve (Lorenz, 1905; Rousseau et al., 2018) and then build on this to describe Shorrocks' generalized Lorenz curve. Given the diversity array X = [x_1, …, x_N], the ordinary Lorenz curve (Lorenz, 1905) is constructed as follows: for j = 1, …, N, let

$$S_j = \sum_{i=1}^{j} x_j$$

be the j-th partial sum and hence s_N = TOT the total number of items. Moreover, s_0 is set equal to 0. Now, take the points with coordinates

$$\left(\frac{k}{N}, \frac{s_k}{TOT}\right),$$

k = 0, …, N and connect them by line segments to obtain a curve joining the origin (0,0) with the point (1,1). This is the ordinary Lorenz curve. If x-values are equal the Lorenz curve is a straight line (the diagonal of the unit square). If the array X is ordered decreasingly, the Lorenz curve is concave and situated above this straight line; if X is ordered increasingly, as done by Shorrocks, then the Lorenz curve is convex and situated under the diagonal.

Now for Shorrocks' generalized Lorenz curve, the abscissa values are the same as for the ordinary Lorenz curve, but the ordinate values are multiplied by the average of the x-values. This means that now the points with coordinates

$$\left(\frac{k}{N}, \frac{s_k}{N}\right),$$

k = 0, …, N are connected by straight line segments.

Just as the Lorenz curves introduce a partial order in the set of diversity arrays, also Shorrocks' generalized Lorenz curves introduce a – finer – partial order. Acceptable diversity measures must then respect this partial order.

5. CONCLUSION AND SUGGESTIONS FOR FURTHER RESEARCH

In this note, I just want to put forward the idea that scale-invariance may not be a necessary requirement when using diversity measures to study interdisciplinarity via references. This leads to at least three questions to be studied in further investigations:

1. Is the Shorrocks curve an acceptable way to study interdisciplinarity in a way that is not scale-invariant? Or should it be adapted?

2. How to include the other diversity requirements into this study? A first step could be to take disparity "seriously" as proposed in (Rousseau, 2018), while adapting the Leydesdorff-Wagner-Bornmann approach (Leydesdorff et al., 2019) or intrinsic diversity profiles (Patil & Taillie, 1979; Rousseau et al., 1999) are other alternatives.

I hope to be able to answer these questions in further investigations.

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