A proposal to revise the disruption index

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Abstract

The disruption index (*DI*) based on bibliographic coupling and uncoupling between a document and its references was first proposed by Funk & Owen-Smith (2017) for citation relations among patents and then adapted for scholarly papers by Wu *et al*. (2019). However, Wu & Wu (2019) argued that this indicator would be inconsistent. We propose revised disruption indices (*DI** and *DI*#) which make the indicator theoretically more robust and consistent. Along similar lines, Chen *et al.* (2020) developed the indicator into two dimensions: disruption and consolidation. We elaborate the improvements in simulations and empirically. The relations between disruption, consolidation, and bibliographic coupling are further specified. Bibliographic coupling of a focal paper with its cited references generates historical continuity. A two-dimensional framework is used to conceptualize discontinuity not as a residual, but a dimension which can further be specified.

Keywords

Disruption; Consolidation; Indicator; Revision; Bibliographic coupling.

1. Introduction

Wu *et al*. (2019) introduced the Disruption index (*DI*) for scholarly citation data, in analogy to the *CD* index proposed by **Funk** & **Owen-Smith** (2017) for studying patent citations. In the latter paper a seemingly complex formula for disruption is provided, as follows:

$$CD_t = \frac{1}{n}\sum_{i=1}^{n}\frac{-2f_{it}b_{it}+f_{it}}{w_{it}}, w_{it} > 0 \quad (1)$$

where

$$f_{it} = \begin{cases} 1 & \text{if } i \text{ cites the focal patent} \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

and

$$b_{it} = \begin{cases} 1 & \text{if } i \text{ cites a reference of the focal patent} \\ 0 & \text{otherwise} \end{cases} \quad (3)$$

Wu *et al*. (2019) rewrote Eq. 1 in a simpler form as follows:

$$DI = \frac{N_F - N_B}{N_F + N_B + N_R} \quad (4)$$

where

- N_B = Number of papers citing both the focal paper (FP) and at least one of its references; the citing papers couple the focal paper bibliographically with its references and would thus indicate "continuity" since they span two "generations" of papers in terms of citations;
- N_F = Number of papers citing exclusively the FP and not one of its references; this set is considered "disruptive" because the citations do not reach historically back to papers cited by FP;
- N_R = Number of papers citing references of FP, but not FP itself.

In other words: documents (patents or papers) can be coupled bibliographically to their own cited references by citing papers (**Kessler**, 1963) and thus indicate historical continuity across "generations" of citations. Alternatively, papers can be unrelated to previously cited research. The generation of continuity by bibliographic coupling can also be considered as a sign of "consolidation" (**Chen** *et al*., 2020). In Eq. 4, for example, $N_F = 0$ and $N_R = 0$ with $N_B > 0$ would mean $DI = -N_B/N_B = -1$ and thus extreme consolidation; vice versa, $N_B = 0$ and $N_R = 0$, while $N_F > 0$ leads to $DI = 1$ and thus extreme disruption. In this model, however, disruption and consolidation are traded-off on a single dimension, while one can also model the two concepts as two independent dimensions.

In the numerator of Eq. 4 (N_F - N_B), the number of papers bibliographically coupling FP with FP's references (N_B) is subtracted from N_F. The difference between the total number of citing papers ($N_F + N_B$) and the value in the numerator of Eq. 4 is $(N_F + N_B) – (N_F - N_B) = 2* N_B$.[1] One could argue that it would be more parsimonious to subtract N_B only once from the total citations ($N_F + N_B$). One then obtains an indicator *DI** for the disruption, which can be formulated as follows:

$$DI^* = \frac{N_F}{N_F + N_B + N_R} \quad (5)$$

Analogously, one can define an indicator for consolidation $DI^{\#}$ as follows:

$$DI^{\#} = \frac{N_B}{N_F + N_B + N_R} \quad (6)$$

*DI** is a measure of disruption and $DI^{\#}$ a measure of consolidation.

Wu & **Wu** (2019) noted that N_F - N_B can be negative when most of the citations of FP couple FP bibliographically to its references. This leads to a negative value of *DI* between minus one and zero, indicating that "continuity" prevails as the opposite of disruption. Increases in the value of N_R (other references), however, lead to less disruption if $N_F - N_B > 0$, but enhance disruption when $N_F - N_B < 0$. **Wu** & **Wu** (2019) considered this effect as "inconsistent," and called for a revision of the indicator. Using the absolute values, however, N_F - N_B and N_B - N_F can be measures of both disruption and continuity. The problem can be solved by using *DI** or $DI^{\#}$ as independent indicators in a two-dimensional model.

2. DI_n: a further extension

Bornmann *et al*. (2020) and **Bornmann** & **Tekles**, (2020) extended *DI* to DI_n, where *n* denotes the threshold value for counting the bibliographic couplings between FP and its references in a single citing paper. Only papers which cite *n* or more references among the cited references of FP are counted in M_B^n, which is used in Eq. 4 instead of N_B. It follows that the original indicator is the same as DI_1. The problem in the background is that *DI* tends to indicate many papers as close to zero. By adding thresholds, the authors aimed to adjust the indicator in order to focus the indicator on identifying disruptive research (**Bornmann** *et al*., 2020).

A disadvantage of this computational strategy can be that the number of possible indicators proliferates into "families" of indicators (**Bu** *et al*., in press). For example, one can replace N_B with M_B^n in both the numerator and the denominator (Eq. 7) or only in the numerator and keep the denominator constant (Eq. 8).

$$DI_n^a = {(N_F - M_B^n)}\Big/{(N_F + M_B^n + N_R)} \quad (7)$$

$$DI_n^b = {(N_F - M_B^n)}\Big/{(N_F + N_B + N_R)} \quad (8)$$

Bornmann *et al*. (2020) used Eq. 7. In Eq. 7, the replacement of N_B has an effect on both the numerator and the denominator. In the case of Eq. 8, one keeps the domain in the denominator the same between *DI* and DI_n. One can thus compare among proportions.

3. An extreme example

An extreme and counter-intuitive case, for example, can be formulated as follows:

> Consider two papers A and B. For paper A: N_F = 10, N_B = 10, and N_R = 100; for paper B: N_F = 10, N_B = 100, and N_R = 10 (see Table 1).

Do these two papers have the same disruption or not? Table 1 explicates the computation for the two papers thus specified. Paper A scores *DI* = 0.0. While *DI* = –0.75 for paper B —an increase of 75 percentage points in the continuity— *DI** is 0.083 for both papers. DI* indicates that the papers have the same level of disruption; DI shows a different level of disruption. However, since *DI* is ≤ 0 for paper A, the difference between the papers is on the consolidation rather than the disruption dimension: both papers are consolidating, but paper B is more consolidating than paper A. This can also be seen when using *DI** and *DI*$^{\#}$: the two papers have the same levels of disruption (*DI**), while the level of consolidation (*DI*$^{\#}$) is different.

Table 1. *DI*, *DI**, and *DI*$^{\#}$ for an extreme case

		A	B
	N_F	10	10
	N_B	10	100
	N_R	100	10
DI	Numerator	0	-90
	Denominator	120	120
	DI	0	-0.75
*DI**	Numerator	10	10
	Denominator	120	120
	*DI**	0.083	0.083
DI$^{\#}$	Numerator	10	100
	Denominator	120	120
	DI$^{\#}$	0.083	0.83

The two effects —changes in the values of N_B or N_R— are combined and perhaps confusing in this example. However, one can distinguish the two effects —disruption and consolidation— analytically by using simulations. The ten-times larger value of N_B in the second paper leads to a ten times larger consolidation (*DI*$^{\#}$).

4. Simulations

Let us, for example, focus on the effects of increasing N_B. Given an initial configuration with N_F = 20, N_B = 10, and N_R = 20, we assume the addition of a single citation to N_B at each step from ten to one hundred (Table 2). This makes *DI* increasingly negative. In other words, the continuity increases and *DI* decreases. The numerator of *DI*$^{\#}$ increases, while *DI** decreases because of the increase of the denominator. Figure 1 shows the respective curves in the case of a stepwise increase of N_B from ten to one hundred for *DI*, *DI**, and *DI*$^{\#}$.

Table 2. Simulation based on increasing values for N_B, while holding N_F and N_R constant

N(B)	*N(F)*	*N(R)*	*DI*	*DI**	*DI*$^{\#}$
10	20	20	0.200	0.400	0.200
11	20	20	0.176	0.392	0.216
12	20	20	0.154	0.385	0.231
13	20	20	0.132	0.377	0.245
14	20	20	0.111	0.370	0.259
15	20	20	0.091	0.364	0.273
16	20	20	0.071	0.357	0.286
17	20	20	0.053	0.351	0.298
18	20	20	0.034	0.345	0.310
…	…	…	…	…	…
100	20	20	-0.600	0.133	0.733

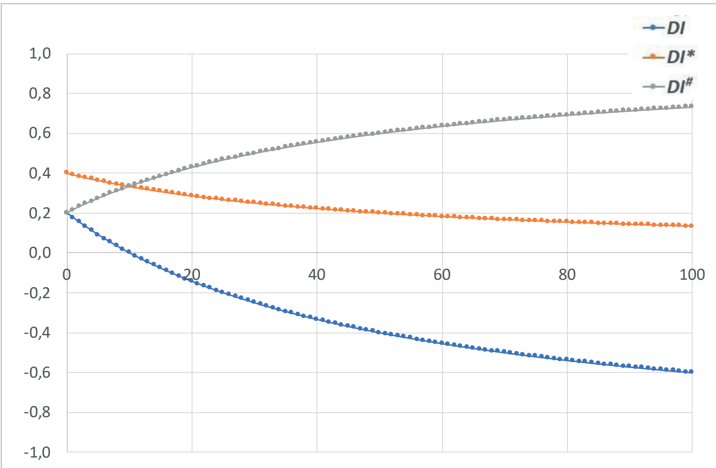

Figure 1. Development of *DI, DI*,* and *DI*$^{\#}$ with increasing values of N_B

Both *DI** and *DI*$^{\#}$ are by definition positive. As N_B and consequently the bibliographic coupling and *DI*$^{\#}$ increase, this seems to be the consolidation indicator, whereas *DI** is the disruption indicator. As noted, *DI* itself is complex since it combines disruption and consolidation in a single dimension.

5. Empirical examples

We compare the results for two empirical cases. In the first case, we use the set of **Bornmann** & **Tekles** (2019): that is, 566 papers published in *Scientometrics* between 2000 and 2010 with at least 10 citations and 10 cited references each (**Bornmann** *et al*., 2020). Table 4 shows the top-20 lists for *DI*, *DI**, *DI*$^{\#}$, and DI_5. The paper by **Heinze** *et al*. (2007) is listed at the first position in three of the four lists in Table 4; followed by **Glänzel** *et al*. (2003) in two of the four lists. However, **Glänzel** *et al*. (2003) is only on the tenth position using *DI* for the measurement. Both papers focus on the institutional conditions of creativity, novelty production, and disruption. In our opinion, since both papers are a bit programmatic, high disruption values can be expected.

Table 4. Rank-ordering of the top-20 papers in the sample of 566 papers published between 2000 and 2010 in *Scientometrics* using *DI*, *DI**, *DI*#, and DI_5.

	DI		***DI****		***DIi*#**		***DI*** $_5$
Heinze T, 2007, V70, P125	0.182	Heinze T, 2007, V70, P125	0.205	Glänzel W, 2003, V58, P571	0.125	Heinze T, 2007, V70, P125	0.205
Bordons M, 2002, V53, P195	0.138	Glänzel W, 2003, V58, P571	0.171	Bar-Ilan J, 2004, V59, P391	0.117	Glänzel W, 2003, V58, P571	0.171
Chiu WT, 2004, V61, P69	0.107	Bordons M, 2002, V53, P195	0.165	Burrell QL, 2005, V65, P381	0.109	Bordons M, 2002, V53, P195	0.165
Patra SK, 2006, V67, P477	0.106	Archambault E, 2006, V68, P329	0.149	Prpic K, 2002, V55, P27	0.102	Archambault E, 2006, V68, P329	0.149
Boshoff N, 2009, V81, P413	0.064	Glänzel W, 2002, V53, P171	0.116	Archambault E, 2006, V68, P329	0.101	Glänzel W, 2002, V53, P171	0.116
Van Eck NJ, 2010, V84, P523	0.063	Van Eck NJ, 2010, V84, P523	0.114	Schloegl C, 2010, V82, P567	0.093	Van Eck NJ, 2010, V84, P523	0.114
Glänzel W, 2002, V53, P171	0.063	Chiu WT, 2004, V61, P69	0.114	Burrell QL, 2002, V53, P309	0.089	Chiu WT, 2004, V61, P69	0.114
Van Raan AFJ, 2005, V62, P133	0.056	Patra SK, 2006, V67, P477	0.106	Porter AL, 2007, V72, P117	0.088	Patra SK, 2006, V67, P477	0.106
Archambault E, 2006, V68, P329	0.047	Van Raan AFJ, 2005, V62, P133	0.094	Burrell QL, 2001, V52, P3	0.073	Van Raan AFJ, 2005, V62, P133	0.094
Glänzel W, 2003, V58, P571	0.046	Ren SL, 2002, V53, P389	0.093	Schummer J, 2004, V59, P425	0.070	Ren SL, 2002, V53, P389	0.093
Weingart P, 2005, V62, P117	0.044	Nederhof AJ, 2006, V66, P81	0.079	Uzun A, 2004, V61, P457	0.068	Nederhof AJ, 2006, V66, P81	0.079
Keiser J, 2005, V62, P351	0.043	Boshoff N, 2009, V81, P413	0.079	Hagen NT, 2010, V84, P785	0.067	Boshoff N, 2009, V81, P413	0.079
Hsieh WH, 2004, V60, P205	0.040	Rinia EJ, 2001, V51, P293	0.076	Porter AL, 2009, V81, P719	0.066	Rinia EJ, 2001, V51, P293	0.076
Rinia EJ, 2001, V51, P293	0.038	Weingart P, 2005, V62, P117	0.071	Boyack KW, 2005, V64, P351	0.066	Weingart P, 2005, V62, P117	0.071
Glänzel W, 2006, V67, P67	0.036	Porter AL, 2007, V72, P117	0.067	Vaughan L, 2006, V67, P291	0.065	Porter AL, 2007, V72, P117	0.067
Liu CY, 2010, V82, P21	0.034	Glänzel W, 2006, V67, P67	0.062	Nederhof AJ, 2006, V66, P81	0.064	Glänzel W, 2006, V67, P67	0.062
Larsen PO, 2010, V84, P575	0.034	Boyack KW, 2005, V64, P351	0.059	Lewison G, 2005, V63, P341	0.063	Boyack KW, 2005, V64, P351	0.059
Tijssen RJW, 2002, V54, P381	0.034	Keiser J, 2005, V62, P351	0.058	Bordons M, 2003, V57, P159	0.063	Keiser J, 2005, V62, P351	0.058
Ren SL, 2002, V53, P389	0.032	Bornmann L, 2006, V68, P427	0.058	Ren SL, 2002, V53, P389	0.061	Bornmann L, 2006, V68, P427	0.058
Lewison G, 2001, V52, P29	0.029	Tijssen RJW, 2002, V54, P381	0.057	Glänzel W, 2002, V53, P171	0.054	Tijssen RJW, 2002, V54, P381	0.057

Table 5. Rank-ordering of the top-20 papers in the sample of 9,251 papers published between 2000 and 2010 in *Nature* using *DI*, *DI**, *DI*#, and DI_5.

	DI		***DI****		***DI*#**		***DI*** $_5$
Chen G, 2000, V407, P361	0.609	Chen G, 2000, V407, P361	0.670	Tegus O, 2002, V415, P150	0.346	Chen G, 2000, V407, P361	0.669
Myers N, 2000, V403, P853	0.543	Myers N, 2000, V403, P853	0.607	Aoki D, 2001, V413, P613	0.285	Myers N, 2000, V403, P853	0.605
Poizot P, 2000, V407, P496	0.523	Poizot P, 2000, V407, P496	0.598	Calvi L, 2003, V425, P841	0.244	Poizot P, 2000, V407, P496	0.598
Erlebacher J, 2001, V410, P450	0.347	Erlebacher J, 2001, V410, P450	0.481	Khriachtchev L, 2000, V406, P874	0.238	Erlebacher J, 2001, V410, P450	0.477
Bertotti B, 2003, V425, P374	0.325	Bertotti B, 2003, V425, P374	0.419	Parish M, 2003, V426, P162	0.236	Bertotti B, 2003, V425, P374	0.419
Saito Y, 2004, V432, P84	0.310	Forterre Y, 2005, V433, P421	0.395	Stone EC, 2008, V454, P71	0.229	Forterre Y, 2005, V433, P421	0.392
Forterre Y, 2005, V433, P421	0.300	Ernst M, 2002, V415, P429	0.379	Day J, 2007, V450, P853	0.224	Ernst M, 2002, V415, P429	0.378
White S, 2001, V409, P794	0.270	Saito Y, 2004, V432, P84	0.373	Rong H, 2005, V433, P725	0.223	Saito Y, 2004, V432, P84	0.372
Marescaux J, 2001, V413, P379	0.257	Strukov DB, 2008, V453, P80	0.338	Barland S, 2002, V419, P699	0.223	White S, 2001, V409, P794	0.334
Strukov DB, 2008, V453, P80	0.236	White S, 2001, V409, P794	0.337	Tschop M, 2000, V407, P908	0.221	Strukov DB, 2008, V453, P80	0.334
Margulies M, 2005, V437, P376	0.231	Marescaux J, 2001, V413, P379	0.319	Coles H, 2005, V436, P997	0.217	Marescaux J, 2001, V413, P379	0.315
Moss RH, 2010, V463, P747	0.227	James C, 2005, V434, P1144	0.309	Porath D, 2000, V403, P635	0.216	Steele B, 2001, V414, P345	0.302
Steele B, 2001, V414, P345	0.226	Greffet J, 2002, V416, P61	0.306	Loll B, 2005, V438, P1040	0.213	James C, 2005, V434, P1144	0.301
Magurran A, 2003, V422, P714	0.225	Steele B, 2001, V414, P345	0.302	Niemela J, 2000, V404, P837	0.202	Greffet J, 2002, V416, P61	0.301
Rost S, 2004, V427, P537	0.216	Rost S, 2004, V427, P537	0.298	Donnelly C, 2006, V439, P843	0.201	Rost S, 2004, V427, P537	0.294
Ernst M, 2002, V415, P429	0.212	Tomita M, 2003, V421, P517	0.291	Ritz T, 2004, V429, P177	0.197	Armand M, 2008, V451, P652	0.290
Cortright R, 2002, V418, P964	0.211	Gomes R, 2005, V435, P466	0.291	Takasaki T, 2000, V403, P913	0.193	Tomita M, 2003, V421, P517	0.287
Davies H, 2002, V417, P949	0.208	Armand M, 2008, V451, P652	0.290	Greiner M, 2002, V415, P39	0.192	Gomes R, 2005, V435, P466	0.284
Day P, 2003, V425, P817	0.207	Day P, 2003, V425, P817	0.277	Shelly DR, 2007, V446, P305	0.192	Magurran A, 2003, V422, P714	0.274
Reibold M, 2006, V444, P286	0.203	Corma A, 2001, V412, P423	0.275	Hu D, 2009, V461, P640	0.191	Day P, 2003, V425, P817	0.273

In the second example, we selected *Nature* papers with at least 10 citations and 10 cited references each (with N = 9,251 papers). Table 5 shows the top-20 lists for *DI*, *DI**, *DI*#, and DI_5. The comparison of Table 5 with Table 4 reveals that the disruption values in Table 5 are significantly higher than the values in Table 4: the highest values in Table 4 are on the level as the lowest values in Table 5. The comparably high values for *Nature* papers are expectable, since it is the mission of the journal to publish the

> "finest peer-reviewed research in all fields of science and technology on the basis of its originality, importance, interdisciplinary interest, timeliness, accessibility, elegance and surprising conclusions"
> *https://www.nature.com/nature/about*

Table 6a (columns a to d). Correlations among *DI*, *DI**, *DI*#, and DI_S in the study of 566 papers in *Scientometrics* during the period 2000-2010. Lower triangle: Spearman rank-order correlations; upper triangle: Pearson correlations. All correlations are statistically significant at the 1%-level.
Table 6b (columns f to i). Correlations among *DI*, *DI**, *DI*#, and DI_S in the study of 9,251 papers in *Nature* during the period 2000-2010. Lower triangle: Spearman rank-order correlations; upper triangle: Pearson correlations. All correlations are statistically significant at the 1%-level.

Correlations *Scientometrics*					Correlations *Nature*			
DI (a)	***DI**** (b)	***DI*#** (c)	**DI_S** (d)	(e)	***DI*** (f)	***DI**** (g)	***DI*#** (h)	**DI_S** (i)
1	.636	-.301	.699	***DI***	1	.525	-.408	.636
.217	1	.544	.986	***DI****	.525	1	.563	.976
-.443	.680	1	.458	***DI*#**	-.408	.563	1	.429
.386	.918	.485	1	**DI_S**	.636	.976	.429	1

These correlation matrices are not so different when compared among both tables. For example, *DI*# is always negatively correlated with *DI*. Unlike *DI*, *Di**, and DI_S, *DI*# is exclusively an indicator of consolidation, whereas *DI** is a disruption indicator. Despite the high correlations between *DI** and *DI* ($r > 0.9$), the zero-hypothesis that the median of these two distributions is the same, is rejected using the Related Samples Wilcoxon Signed Rank Test at the 5% level. None of the *DI*# top papers occurs in the top papers for the other indicators and vice versa.

5. Conclusions and discussion

Following **Chen** *et al.* (2020), we have taken the two dimensions of disruption and continuity or consolidation apart. *DI* can be considered as a continuity indicator more than a disruption indicator since the operation is grounded in bibliographic coupling. The bibliographic coupling of a focal paper to its references generates a representation of continuity. From this perspective, discontinuity is indicated when the bibliographic coupling is not sufficiently generating continuity. This is analogous to the graphical representations that one can make with programs such as *HistCite*™ (**Garfield** *et al*., 2003) or *CitNetExplorer* (**Van Eck**; **Waltman**, 2014). One sees the lines of continuity along trajectories. Discontinuities are inferred where the lines are interrupted. However, the semantics of using two words for a single indicator with opposite sign can be confusing.

In our opinion, the choice for parameters should be legitimated by theoretical reasoning. The subtraction of N_B for a second time, for example, may not be necessary to detect disruptive papers and —as shown by **Wu** & **Wu** (2019)— can lead to confusion in the results. The revised indicators *DI**and *DI*# solve these problems and simplify both the computation and the semantics.

It may appear that this issue concerns a detail, since in many cases the values of *DI** and *DI* will be approximately the same. For analytical reasons, however, $DI^* \geq DI$. *DI* adds to bibliographic coupling —a theoretical instrument in bibliometrics— by focusing specifically on the couplings and un-couplings between a paper and its references. In a follow-up paper, we envisage to discuss disruption in relation to critical transitions in a time-series of events (cf. **Leydesdorff** *et al.* 2018; **Leydesdorff**, 1991). Both measures (disruption and critical transition) seek to analyze change at the level of the system. While preparing that paper, we stumbled into the problems of semantics and operationalization that we hope to have clarified with this more methodologically oriented paper.

6. Note

1. This value explains the number two in Eq. 1 which can be made more visible by rewriting the equation as follows:

$$CD_t = \frac{1}{n}\sum_{i=1}^{n}\frac{f_{it}(1-2b_{it})}{w_{it}}, w_{it} > 0$$

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