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Qualifying Scholarly Impact using an iCX (impact-Citations-Exergy) Analysis

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ABSTRACT

A scholarly 'index of quality and productivity' (*IQp*) was proposed as a better alternative to the *h*-index. This was intended to overcome some of the limitations of the *h*-index. Other recent studies have shown that an indicator called the performance index (*p*-index) can also effectively combine size and quality of scientific papers. The curious structure of the *p*-index led to an energy-like term, $X = iC = Pi^2 = C.(C/P)$, where, P is the number of papers, and i is a proxy for quality $Q = C/P$. The energy assessment technique (iCX audit for impact-Citations-Exergy) which emerges from this is seen to be a quick and simple tool for visualising the quality and productivity (size or quantity) of a scientist's oeuvre.

Keywords: Scientometrics, quality, iCX analysis, *h*-index, impact-Citations-Exergy

1. INTRODUCTION

The *h*-index[1] tries to capture in a single number, the quality and quantity of a scientist's (or at higher levels of aggregation, that of journals, groups of scientists, institutions, and even countries) output. This simplification of a very complex process has been found to be very effective, especially in instances where h tends to be high. It also has many shortcomings especially when h tends to be low or where there are tall cores or long tails[2-4]. The search for a rational strategy to rank entities (authors, groups, institutions, or countries) taking into account productivity (number of papers P) and quality (impact defined as the ratio of citations to papers, $i = C/P$) continues. Prathap[2] proposed a composite indicator $(C^2/P)^{1/3}$, which could mock the features of the *h*-index and having the same dimensions as h and P, connecting the number of papers and the mean citation rate per paper. Thus, $(C^2/P)^{1/3} = (C.(C/P))^{1/3}$ is an indicator that senses both size and quality. This leads to an interesting energy analogy. While the actual dispersion of citations c_j for papers j = 1 to P can have complex statistical and thermodynamic features, it would seem that an energy (or power) like property is reflected in the term C^2/P. Many physically intuitive situations can be found as parallels (e.g., flow of current in a circuit, hydraulic flow driven by pressure difference, etc.). The simplest analogy that can be used is found from Ohm's law. The impact of a body of scientific work (represented by a total of P papers), is here designated by i, as the current that flows through this. The higher the impact of the work, the greater will be the number of citations it will invite and thus C is analogous to the voltage that will build up across a resistance R through which a current i is passing through.

Table 1 shows the analogy. One can see immediately that a body of scientific work will have an illuminating power as shown in the last row of Table 1 ($X = iC = i^2P = C^2/P$). The physical picture that emerges has curious parallels.

The proxy for the energy of ideas turns out to be $X = Pi^2$, where, P is measured in the units in which ideas are conveyed (here, the number of papers) and i is a measure of the rate at which ideas are transmitted as citations (here, a proxy for quality $i = C/P$). It is more appropriate to call this energy-like term, exergy (as a useful externally available energy, rather than the total internal energy).

Table 1. Ohm's law for scientometrics

	Electrical	Scientometric
Resistance/papers	R	P
Current/impact	i	i
Voltage/citations	$V = iR$	$C = iP$
Power	$W = iV = i^2R = V^2/R$	$X = iC = i^2P = C^2/P$

However, a further elaboration of this is beyond the scope of this paper. To compare the research performance of entities, it will be more meaningful to compare exergies rather than papers and/or citations. It is illustrated this with reference to the research assessment of some leading research scientists and some with more modest contributions at early stages of their career as reported in Antonakis & Lalive[5].

Both the *h*-index and the *p*-index are attractive because of the simplicity with which a single number could be used to quantify the impact of scholarship and its quality. In this regard, Antonakis & Lalive[5] proposed a new index, the *IQp* (index of quality and productivity) and tested and calibrated this new index and compared its performance relative to the *h*-index using a sample of top scholars with bibliometric data from ISI's *Web of Knowledge*.

The spirit and scope of the *IQp* can be summed up as: Scholarly achievement is assumed to depend on the multiplicative association of quality and productivity[6,7]. The *IQp* measures a scholar's impact along two dimensions: Quality (i.e., citations) and productivity (i.e., output). Antonakis & Lalive[5] approximates quality by 'adjusting' for total number of citations (C) and for productivity by 'adjusting' for total number of papers (P) and this leads to a complex and non-trivial expression for *IQp*.

Prathap's approach is simpler in this respect: C is taken as a measure of size/quantity and this is then weighted by taking quality (impact, i.e., $i = C/P$) so that the multiplicative product $C^2/P = iC = X$ is a measure of the 'energy' of scholarship. Very interestingly, taking a lead from Glanzel's pioneering statistical studies, it can also be established that $X^{(1/3)} = p$ has the units of h and indeed can be used as a mock *h*-index[2-4]. In this paper, it is shown that i, C, and X can be combined graphically into an iCX map which can then be displayed as a two dimensional contour map which reproduces the essential topological features of Fig. 1 of Antonakis & Lalive[5].

2. TESTING IMPACT-CITATIONS-EXERGY APPROACH

The bibliometric statistics that was used by Antonakis & Lalive[5] is used here and Table 2 reflects this with i, X, and p added. The descriptive statistics for all the scholars and disciplines that goes along with Table 2 has been elaborately given in paper by Antonakis & Lalive[5] and will not be repeated here.

The relationship between quality and size is captured on an impact-Citations-Exergy (iCX) landscape shown in Fig. 1. On the *x*-axis, the quantity of output and on the *y*-axis, quality of output is represented.

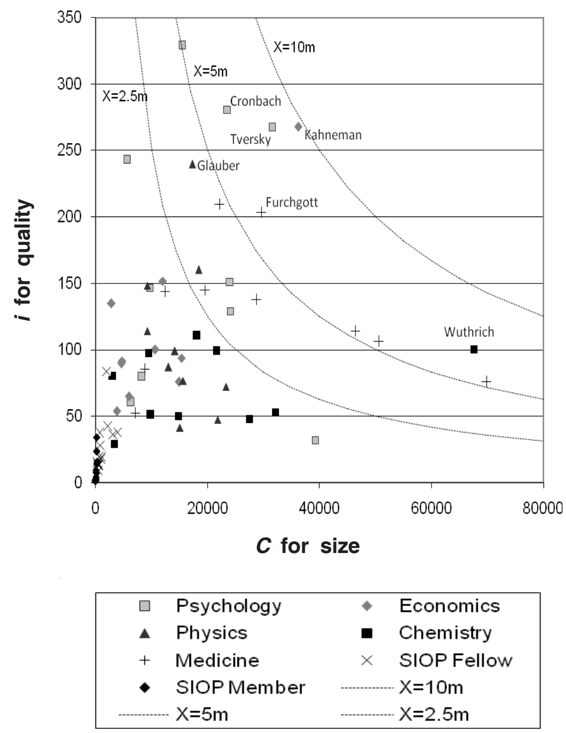

Figure 1. Relationship between quality and size in an iCX map is a topologically deformed equivalent of Figure 1 of Antonakis & Lavile[5].

It can be seen from Fig. 1 that the relationship between quality and size in an iCX map is a topologically deformed equivalent of Fig. 1 of Antonakis & Lavile[5]. However, since $X = iC$, contour lines can easily be plotted on the map and these are shown by dotted lines for $X = 2.5$ m, 5 m, and 10 m. Metaphorically, this can be interpreted as climbing a peak, equating higher levels of performance as having scaled higher heights of a quantity-quality landscape. It can be seen that the effect of citation rates being field-specific in some disciplines, it is easier to scale up to greater heights. It can be noted that the scientists at early stages of their career (randomly selected Society of Industrial and Organisational Psychology Fellows and Members) are understandably at the base of the energy mountain.

Taken together, Table 2 and Fig. 1 confirm the findings of Antonakis & Lalive[5], namely that, the *h*-index is not a useful indicator of scholarly performance. Here, it emphasises the distinction authors make between quality ($i = C/P$) and performance ($X = C/P.C = iC$).

Thus, among the various disciplines, Kahneman is the highest performing Economist, Tversky, and Cronbach lead among the Psychologists in this sample, and Glauber, Wuthrich and Furchgott excel in the physics, chemistry, and medicine categories. These are identical to what the *IQp* would have led us to. However,

Table 2. Data from Fig. 1 of Anatonakis & Lalive[5] is re-arranged with *i*, *X*, and *p* computed

Name	Group	Papers	Cites	*i*	*iC=X*	*h*	*IQp*	*p*
Asch, S.E.	Psychology	23	5586	242.9	1356669	14	62.53	110.70
Cronba Ch, L.J.	Psychology	84	23572	280.62	6614752	23	191.18	187.72
Dawes, R.M.	Psychology	105	6335	60.33	382212	28	46.86	72.57
Eagly, A.H.	Psychology	104	8280	79.62	659215	36	62.23	87.03
Eysenck, H.J.	Psychology	1230	39246	31.91	1252235	50	30.65	107.79
Festinger, L.	Psychology	47	15457	328.87	5083380	24	156.33	171.94
Maslow, A.H.	Psychology	66	9673	146.56	1417681	17	77.69	112.34
Skinner, B.F.	Psychology	159	24011	151.01	3625963	33	104.38	153.63
Tulving, E.	Psychology	187	24092	128.83	3103874	65	95.63	145.87
Tversky, A.	Psychology	118	31537	267.26	8428664	59	224.83	203.51
Akerlof, G.A.	Economics	52	4757	91.48	435174	22	66.28	75.78
Aumann, R.J.	Economics	51	4570	89.61	409508	18	58.93	74.26
Engle, R.F.	Economics	79	11977	151.61	1815804	30	122.85	122.00
Granger, C.W.J.	Economics	164	15359	93.65	1438408	34	82.04	112.88
Heckman, J.J.	Economics	106	10607	100.07	1061400	34	87.01	102.01
Kahneman, D.	Economics	135	36153	267.80	9681773	52	207.97	213.13
Kydland, F.E.	Economics	21	2832	134.86	381915	10	79.67	72.55
Phelps, E.S.	Economics	71	3808	53.63	204238	18	41.9	58.89
Schelling, T.C.	Economics	92	5956	64.74	385586	13	52.61	72.78
Stiglitz, J.E.	Economics	197	14924	75.76	1130588	50	70.06	104.18
Abrikosov, A.A.	Physics	204	15606	76.50	1193859	30	60.66	106.08
Cornell, E.A.	Physics	81	9229	113.94	1051536	37	93.19	101.69
Ginzburg, V.L.	Physics	459	21775	47.44	1033008	42	38.57	101.09
Glauber, R.J.	Physics	72	17253	239.63	4134250	35	121.84	160.50
Hansch, T.W.	Physics	364	15046	41.34	621929	63	37.25	85.36
Ketterle, W.	Physics	150	13017	86.78	1129615	50	75.61	104.15
Leggett, A.J.	Physics	143	14141	98.89	1398377	41	73.72	111.83
Politzer, H.D.	Physics	62	9198	148.35	1364568	35	81.78	110.92
Smoot, G.F.	Physics	115	18428	160.24	2952967	45	104.98	143.47
Wilczek, F.	Physics	322	23270	72.27	1681655	73	62.58	118.92
Agre, P.	Chemistry	294	14747	50.16	739708	64	39.93	90.44
Chauvin, Y.	Chemistry	114	3303	28.97	95700	26	19.3	45.74
Ciechanover, A.	Chemistry	164	18132	110.56	2004692	62	81.15	126.09
Fenn, J.B.	Chemistry	97	9467	97.60	923960	33	56.92	97.40
Grubbs, R.H.	Chemistry	606	32104	52.98	1700770	88	48.97	119.37
Knowles W.S.	Chemistry	38	3057	80.45	245928	19	24.91	62.65
Kornberg, R.D.	Chemistry	218	21549	98.85	2130089	77	72.34	128.67
Rose, I.A.	Chemistry	194	9867	50.86	501844	56	32.03	79.47
Schrock, R.R.	Chemistry	573	27434	47.88	1313481	86	44.62	109.52
Wuthrich, K.	Chemistry	673	67559	100.38	6781900	113	89.76	189.29

Name	Group	Papers	Cites	*i*	*iC=X*	*h*	*IQp*	*p*
Blobel, G.	Medicine	407	46373	113.94	5283674	120	93.1	174.17
Fire, A. Z.	Medicine	86	12362	143.74	1776966	46	85.83	121.12
Furchgott, R.F.	Medicine	146	29650	203.08	6021387	54	121.1	181.93
Greengard, P.	Medicine	921	69884	75.88	5302686	145	68.26	174.38
Hartwell, L.H.	Medicine	135	19579	145.03	2839535	66	82.08	141.61
Horvitz, H.R.	Medicine	209	28728	137.45	3948794	88	100.55	158.06
Kandel, E.R.	Medicine	477	50642	106.17	5376545	121	88.42	175.19
Lauterbur	Medicine	136	7081	52.07	368681	42	36.03	71.71
Mello, C.C.	Medicine	103	8782	85.26	748772	33	60.59	90.81
Sulston, J.E.	Medicine	106	22170	209.15	4636876	50	110.23	166.75
Aguinis, H.	SIOP Fellow	49	625	12.76	7972	13	10.95	19.98
Burke, W.W.	SIOP Fellow	41	530	12.93	6851	8	8.21	18.99
Cleveland, J.N.	SIOP Fellow	31	590	19.03	11229	12	12.93	22.39
Dunnette, M.D.	SIOP Fellow	87	3164	36.37	115068	25	26.87	48.64
Greenhaus, J.H.	SIOP Fellow	54	2267	41.98	95172	21	30.67	45.66
Hofmann, D.A.	SIOP Fellow	19	706	37.16	26233	11	25.82	29.71
Lance, C.E.	SIOP Fellow	42	547	13.02	7124	15	10.15	19.24
Martocchio, J.J.	SIOP Fellow	32	899	28.09	25256	17	20.95	29.34
Mobley, W.H.	SIOP Fellow	24	2008	83.67	168003	11	45.82	55.18
Offermann, L.R.	SIOP Fellow	22	330	15.00	4950	8	8.82	17.04
Perrewe, P.L.	SIOP Fellow	51	479	9.39	4499	12	7.62	16.51
Reilly, R.R.	SIOP Fellow	54	933	17.28	16120	15	12.53	25.26
Spector, P.E.	SIOP Fellow	103	3900	37.86	147670	27	32.48	52.86
Stone, D.L.	SIOP Fellow	29	415	14.31	5939	8	9.6	18.11
Thornton, G.C.	SIOP Fellow	55	1034	18.80	19439	14	13.42	26.89
Aronson, Z.H.	SIOP Member	5	15	3.00	45	2	1.53	3.56
Costanza, D.P.	SIOP Member	8	75	9.38	703	5	4.89	8.89
Druskat, V.U.	SIOP Member	10	139	13.90	1932	7	8.51	12.45
Hoyt, C.L.	SIOP Member	5	38	7.60	289	4	5.18	6.61
Jagacinski, C.M.	SIOP Member	22	349	15.86	5536	8	8.59	17.69
Karren, R.J.	SIOP Member	7	238	34.00	8092	4	9.23	20.08
la huis, D.M.	SIOP Member	5	7	1.40	10	1	0.84	2.14
La Pierre, L.M.	SIOP Member	6	12	2.00	24	2	1.23	2.88
Naidoo, L.	SIOP Member	2	2	1.00	2	1	0.49	1.26
Piccolo, R.F.	SIOP Member	5	46	9.20	423	3	7.34	7.51
Seijts, G.H.	SIOP Member	22	155	7.05	1092	7	5.39	10.30
Tonidandel, S.	SIOP Member	13	22	1.69	37	3	1.14	3.34
Westaby, J.D.	SIOP Member	12	52	4.33	225	4	2.27	6.09
Wrzesniewski, A.	SIOP Member	10	234	23.40	5476	7	12.19	17.63
Elicker, J.D.	SIOP Member	2	0	0.00	0	0	–	–

reliance on the *h*-index alone would have led us to different conclusions.

3. CONCLUSIONS

Studies introducing the performance index (*p*-index) as a mock *h*-index, which can effectively combine size and quality of scientific papers, led us to the curious possibility of using an energy approach. The power/energy basis for bibliometric research assessment allows us to argue that a body of scientific work will have an illuminating power given by $X = iC = i^2P = C^2/P$. This can easily be displayed on an *iCX* map. It is shown with recently published data[5] that the *iCX* analysis comes to the same conclusions as the more discriminating *IQp* approach in locating scholarship of the highest performance, but needing to use only the most parsimonious of data and assumptions.

As proposed in Antonakis & Lalive[5], one can easily introduce 'adjustments' to take into account field-specificity of citation rates, and scientific age to the *X*-index.

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