

## **Increasing discrepancy between absolute and effective indexes of research output in a Brazilian academic department**

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We investigate possible effects from a strong encouragement for a large number of publications on the scientific production of a Brazilian cell biology department. An average increase in individual absolute production and a concomitant decrease in individual participation in each paper were detected by traditional bibliometric parameters, such as number of publications, citations, impact factors and h index, combined to their “effective” versions, in which co-authorship is taken into consideration. The observed situation, which might well represent a national trend, should be considered as a strong warning against current criteria of scientific evaluation heavily based on uncritical counting of publications.

### **Introduction**

Evaluation of scientific production is clearly necessary in any society which directly invests in research activities with the intention of increasing knowledge production. It is natural to assume, therefore, that adequate criteria for the distribution of necessarily limited resources should aim at the formation of an academic environment in which the probability of obtaining significant contributions is maximized. It is also intuitive that inadequate or misused criteria might easily lead to the opposite situation, in which a

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large fraction of available resources will be ultimately consumed in projects of small scientific relevance. The traditional and highly perceived as most trustful method of scientific merit evaluation is the impression caused on specialists in the subject. Paper acceptance in scientific journals, for example, rely on reports from reviewers who are supposed to emit a relevant opinion about the material not using any pre-established criterion. Intrinsic difficulties, however, like subjectivity and lack of automatization, might significantly decrease the viability of a system based exclusively on specialist opinion for ample evaluations of large groups of investigators with many contributions. Objective criteria might become desirable, therefore, as a guiding line for decisions regarding the selection of projects to be contemplated in public calls, the concession of research stipends, the evaluation of graduate programs, etc.

Currently available computational resources and electronic data bases containing all sort of bibliographic information, constantly updated as new papers are being published, might clearly provide easily computable quantities, or “indexes”, which reflect different facets of the scientific production. It is far from trivial, however, to identify a particular index which will correlate to the intuitive notion of quality and will not be easily “inflated” by a large number of scientifically irrelevant publications. The simple number of publications  $N_p$ , for example, might be a rather poor indicator of perceived quality of the overall contribution to scientific knowledge, since truly influential contributions are not distinguished from less important papers. A simple approach to decrease the influence of less relevant publications is to weigh individual papers,  $i$ , by some individual quality value such as number of citations,  $c_i$ , or impact factor of the journal in which they are published,  $I_i$ . An interesting debate can actually be found in the literature about potential problems of these individual indexes themselves, such as a possible over-valorization of reviews in the case of the total number of citations  $N_c = \sum_i c_i$  or, in the case of the sum of impact factors  $N_I = \sum_i I_i$ , an uneven distribution of citations among publications from the same journal [1–4].

As a very significant contribution to the subject, Hirsch has recently proposed the  $h$  index of a researcher as the number  $h$  of his publications which have received  $h$  or more citations [1]. Poorly cited papers, independently of their number, do not contribute to the  $h$ . Additionally, a researcher with just a couple of highly cited papers will not have a high value for this index. Artificial inflation is difficult since a large  $h$  requires a continued production of well cited papers. These advantages, combined to the empirical observation of correlation to academic success, have led to a rapid popularization of the  $h$  index as a quantifier of scientific production in different research areas [1, 5–8]. From its definition,  $h$  cannot decrease with time and might continue to increase for researchers who are no longer active, as long as they continue to be cited. A related quantity,  $m$ , obtained from the inclination of an expected linear dependence of  $h$  on years of scientific activity, was therefore suggested to provide a reasonably fair comparison between active researchers at different stages of their careers. It has also

been stressed that comparison between  $h$  indexes from different fields might be misleading since the average number of citations is heavily dependent on the specific area of research [1, 7]. This caveat is obviously shared with most indexes discussed above which, with the exception of  $N_p$ , are also ultimately dependent on citation counts [2].

In spite of this very productive international discussion about the possibility of objective quantification of scientific production, there is a strong perception among Brazilian researchers in many fields that national criteria for the evaluation of research output are still heavily dominated by the simplest but most problematic index  $N_p$ . Perceived likelihood of improving performance in national evaluation of graduate programs performed by the Ministry of Education agency CAPES, which might imply a significant increase in federal support, is actually the main alleged justification for locally imposed requirements of a minimal number of papers in a growing number of programs. In the present study it is suggested that the main effect of such a pressure for a large number of publications might turn out to be a simple increase in the number of coauthors in each paper, with no concomitant increase in quality or even, in extreme situations, in the “effective” number of papers.

### Methods

In the present study we intend to investigate possible effects on the scientific production of a typical academic department of a Brazilian university resulting from a strong encouragement for the publication of a large number of papers. The Department of Cell Biology of University of Brasilia turns out to be an adequate model for this study since professors with a number of publications in a period of three years smaller than a threshold value,  $N_p^{*3}$ , are not allowed to recruit new graduate students in the local Graduate Program in Molecular Biology. Apparently based on evaluation criteria from CAPES, cutoff values  $N_p^{*3} = 3$  and  $N_p^{*3} = 6$  have been recently established for M.Sc. and Ph.D. candidates, respectively. From the 32 professors in this department who have published at least one paper recorded in the ISI database, a group of 18 individuals, labeled G1, is currently allowed to recruit either Ph.D. or M.Sc. candidates, while a small group of 3, labeled G2, is currently allowed to recruit only M.Sc. candidates. The remaining 11 members of the department, forming a group labeled G3, are currently not allowed to recruit new graduate students.

We initially compared, for each professor, the total number of papers contained in the ISI database until November 2006,  $N_p$ , with four alternative indexes intended to be dependent on research quality:  $N_c$ ,  $N_f$ ,  $h$  and  $m$ . Since the number of coauthors,  $N_a$ , in each paper varies dramatically, from single-authored studies to large collaborations with more than a hundred contributors, we have also investigated simple variations of these indexes in which each paper was weighed by a “participation factor”,  $1/N_a$ , intended to

estimate the individual contribution from each author. In this way, a researcher with  $N_p$  papers will have only  $N_p' = \sum_i (1/N_a)_i \leq N_p$  “effective” papers with  $N_c' = \sum_i (1/N_a)_i c_i \leq N_c$  effective citations and  $N_I' = \sum_i (1/N_a)_i I_i \leq N_I$  sum of effective impact factors. Additionally, the effective  $h$  index, or  $h'$  index, is here defined as the number  $h'$  of papers with a number of effective citations equal or larger than  $h'$  while  $m'$  is obtained simply from the division of  $h'$  by the number of years of research activity. The number of citations used in these computations was also obtained from the ISI database. Impact factors were assigned to each paper, independently of the year of publication, as either the value published in 2004 for the corresponding journal or, for journals not appearing in the 2004 list, zero. The time of scientific activity used in the computation of  $m$  and  $m'$  was taken as the number of years from the first publication to the present year of 2006.

### Results

The relation between different indexes and the total number of papers,  $N_p$ , can be seen in Figure 1 ( $h$ ,  $h'$ ,  $m$  and  $m'$ ) and Figure 2 ( $N_c$ ,  $N_c'$ ,  $N_I$  and  $N_I'$ ). Absolute indexes are shown in the left column of these figures while corresponding effective indexes, where the number of coauthors in each paper is taken into consideration, are shown in the right column. Pearson’s correlation coefficients for the data shown in these plots range from moderate 0.58 to 0.82, as shown in the last column of Table 1. As a general important pattern, stronger correlations were actually observed in the less relevant region of small  $N_p \leq 25$  when compared to the region of large  $N_p \geq 25$ , as seen in the first two columns of Table 1.

Additionally, the correlation tends to be weaker for effective indexes when compared to absolute indexes, indicating that differences in the number of coauthors might significantly affect absolute indexes even for the comparison between members of a single department. Linear fits to the points in the region of small superimposed to the plots emphasize the qualitative difference between regions of large and small number of papers.

For the currently popular  $h$  index, for example, there is a strong correlation for  $N_p \leq 25$ , with Pearson’s correlation coefficient  $r=0.91$  for 26 points, but there is no correlation for  $N_p \geq 25$ , with  $r=0.07$  for 9 points (Figure 1a and Table 1). Additionally, from the five points with  $N_p > 30$ , three correspond to an  $h$  significantly lower than the value predicted from the linear extrapolation from the region of small  $N_p$  (Figure 1a).

Table 1. Pearson's correlation coefficients between the total number of publications,  $N_p$ , and different absolute and effective indexes. The second column displays the correlation for 26 members with small number of publications  $N_p \leq 25$  while the third column corresponds to 9 members with  $N_p \geq 25$ . The last column displays the correlation for all 32 members of the department.

Three members have  $N_p = 25$  and contribute to the computed correlation in all three columns

index	$N_p \leq 25$	$N_p \geq 25$	all
$h$	0.91	0.07	0.76
$h'$	0.71	0.05	0.65
$m$	0.65	0.24	0.69
$m'$	0.55	0.20	0.64
$N_c$	0.51	0.06	0.59
$N_c'$	0.46	0.18	0.58
$N_I$	0.84	0.45	0.82
$N_I'$	0.62	0.32	0.70

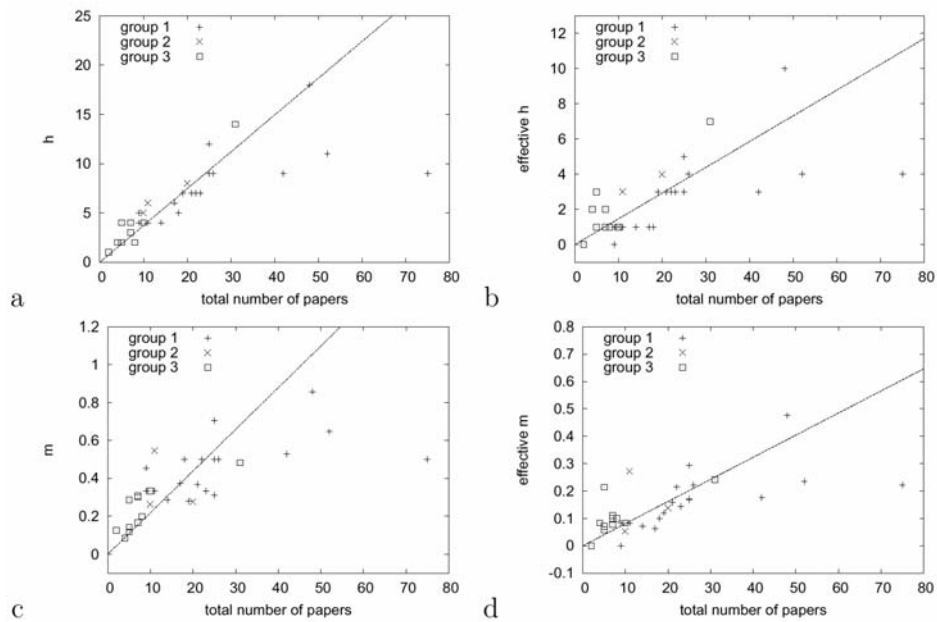


Figure 1. Relation between different absolute and effective indexes and the total number of publications,  $N_p$ :  $h$  (a), effective  $h$ , or  $h'$  (b),  $h$  divided by the number of years of activity, or  $m$  (c), and effective  $m$ , or  $m'$  (d). Straight lines are linear fits to the region of small  $N_p \leq 25$

It is also apparent that the largest fraction of points above the straight line, indicating a large  $h$  index for a given  $N_p$ , correspond to G2 and G3. This observation is likely to be connected, however, to a larger proportion of recent publications, which did not have

sufficient time to be cited, for members of G1 when compared to the other two groups. The correlation in the region of small  $N_p$  decreases when additional factors like the number of coauthors, time of activity or both, are taken into consideration, as seen in the plots for  $h'$ ,  $m$  and  $m'$ , where the correlations for the 26 points with  $N_p \leq 25$  are  $r=0.71$ ,  $r=0.65$  and  $r=0.55$ , respectively. Deviations from a putative linear dependence become accordingly more frequent. As seen in Table 1 and Figure 2, the same general behavior, with stronger correlation in the small  $N_p$  region when compared to the large  $N_p$  region as well as for absolute indexes when compared to effective indexes, is observed for  $N_c$ ,  $N_c'$ ,  $N_I$  and  $N_I'$ .

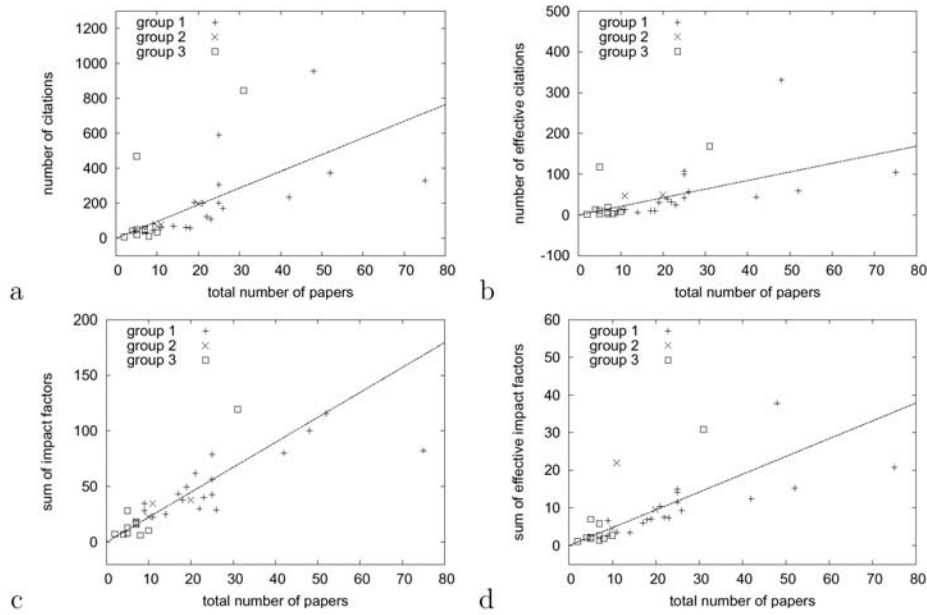


Figure 2. Relation between different absolute and effective indexes and the total number of publications,  $N_p$ : total number of citations,  $N_c$  (a), total number of effective citations,  $N_c'$  (b), sum of impact factors,  $N_I$  (c), and sum of effective impact factors,  $N_I'$  (d). Straight lines are linear fits to the region of small  $N_p \leq 25$

It is clear therefore that a classification based simply on the total number of papers, or on the number of recent publications, will not agree with alternative classifications based on parameters intended to reflect the quality of research. The four most productive members of the department according to  $N_p$ , with more than forty publications in the ISI data base, are all in G1. Only two of them, however, are among the four department members with  $h \geq 10$ , as seen in Figure 1a), being one of the other two members with high  $h$  actually in G3, currently not being allowed to recruit new

graduate students. A larger discrepancy arises when time of activity and number of coauthors is taken into consideration since only one researcher with  $N_p \geq 40$  is among the four most productive members according to the  $m'$  criterion, as seen in Figure 1d), while two of the other members inside this group are out of G1. Note that classifications according to  $N_c$ ,  $N_c'$  or  $N_l'$  would also result in a group of four most productive researchers with two members from G2 and/or G3.

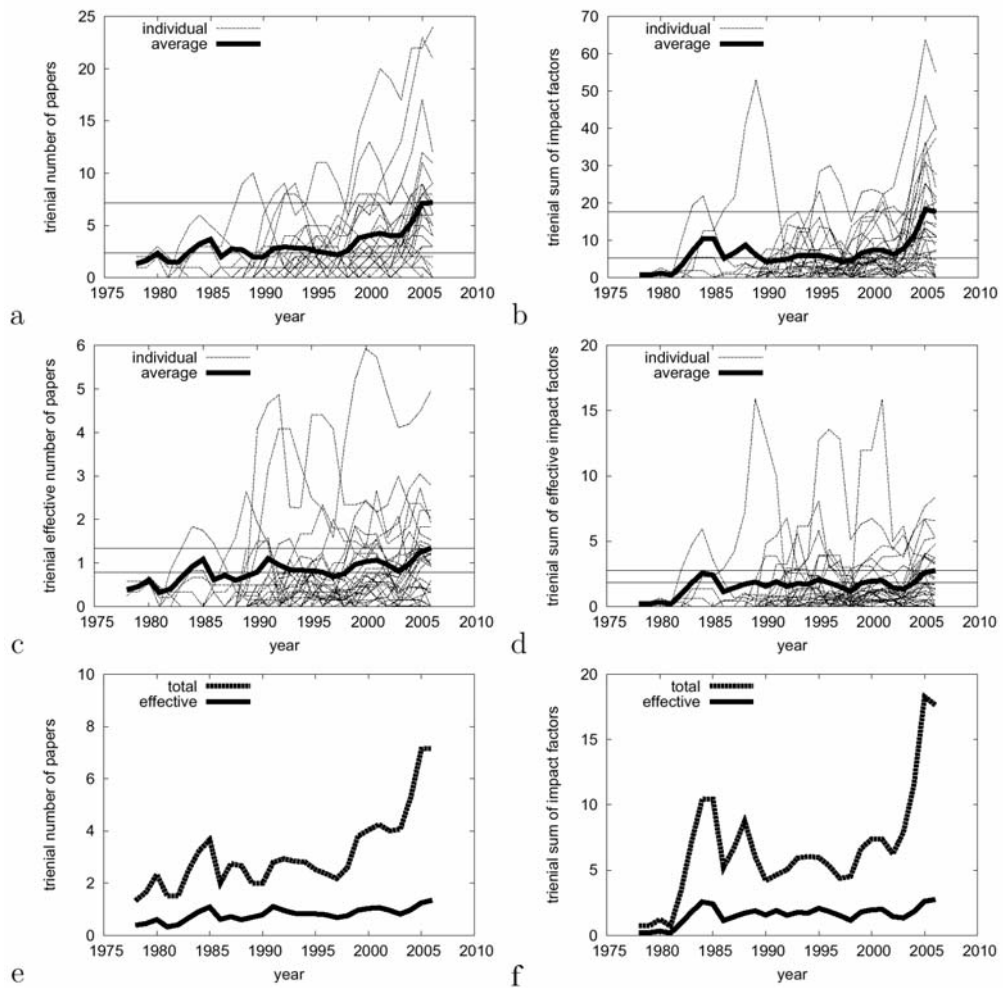


Figure 3. Absolute and effective number of papers and sum of impact factors computed from the production of periods of three years. Thick lines represent the average among department members with at least one publication in the corresponding period. Dashed lines in the background of (a–d) represent the contribution of each member

The evolution of the number of papers and sum of impact factors, computed for periods of three years, is shown in Figure 3, where the last year of the corresponding three-year period is shown in the  $x$ -axis. The total number of papers and sum of impact factors are shown in (a) and (b), respectively, while the corresponding effective parameters, the effective number of papers and sum of effective impact factors, are shown in (c) and (d). The thick line in each plot represents the average over all current department members with at least one publication in the corresponding three-year period while the background of dotted lines, corresponding to individual members, provides an estimate of the dispersion in each period and also of the strong individual oscillations along the years. Note that unlike  $h$  or  $N_c$ , for example,  $N_p$  and  $N_l$  from a specific three-year period depend exclusively on the production during that period and not on the elapsed time before the index is computed.

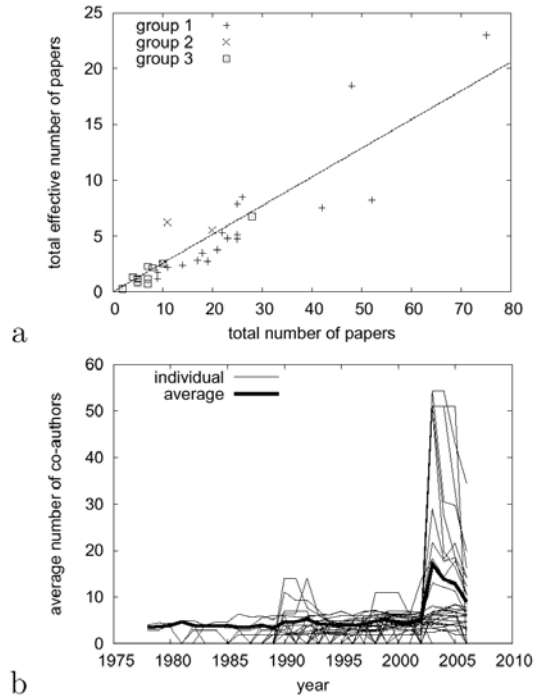


Figure 4. Relation between total effective number of papers and total absolute number of papers,  $N'_p \times N_p$  (a) and average number of coauthors in periods of three years (b). Thick line in (b) represents the average among department members with at least one publication in the corresponding period while dashed lines in the background represent individual members

It is observed that both the number of papers and the sum of impact factors have increased significantly in recent years, most likely in connection to the applied selective pressure. The average number of papers has jumped from 2.36 in 1994–1996 to 7.16 in 2004–2006, corresponding to the multiplication by a factor of 3, while the average sum of impact factors has also increased from 5.31 to 17.66, or a factor of 3.3, in the same time. The average effective number of papers, however, increased only from 0.79 to 1.34 while the average sum of effective impact factors increased from 1.82 to 2.74, or modest factors of 1.7 and 1.5, respectively. The discrepancies between these absolute and effective indexes are more clearly observed in Figure 3 (e) and (f), where just the average absolute and effective values are shown in the same plot. Differences in average number of coauthors among members of the department, as suggested by the previous discussion about the disagreement between classifications based on absolute and effective parameters, can be seen in Figure 4a. The plot of total effective number of papers against total number of papers, or  $N_p' \times N_p$ , confirms that many points, particularly for large  $N_p$ , do not fall on a straight line as would be expected for a uniform average number of coauthors. As seen in Figure 4b, the average number of coauthors over three-year periods from each member of the department tended to increase significantly in recent years, the average over members going from 3.95 in 1994–1996 to 9.04 in 2004–2006, after reaching a maximum of 17.12 in 2001–2003.

### Discussion

It is clear from the results shown in Figures 1 and 2 that the current criterion based on the number of publications does not agree with alternate classifications intended to reflect, at least to some extent, the quality of research. Note, however, that there is no agreement between the alternate criteria themselves, strongly suggesting that any individual criterion is not able to provide more than a limited perspective from an individual's scientific contribution. Individual indexes are unlikely to be useful, therefore, unless their intrinsic limitations are clearly understood. Consideration of different, possibly complementary parameters is also likely to provide a more balanced evaluation. The main purpose of the present study, however, is not to advocate any specific index, or a combination of them, for the evaluation of scientific research, but to stress that the use on any criterion is bound to produce obviously undesirable results unless constantly complemented by an indispensable critical judgement.

Results shown in Figures 3 and 4 indicate that absolute indexes might be particularly misleading when comparing scientific productions dominated by publications with very different numbers of coauthors. Differences in average number of coauthors between different areas of research have actually been widely recognized previously, as well as differences in average number of citations, impact factors,  $h$  index, etc. Usually, however, direct comparison is assumed to occur only between

researchers in the same area, in which case any problem arising from these “area-dependent” factors would be automatically minimized. Our results nevertheless show that differences in the number of coauthors among members of a single department, who must be compared to each other, might be actually very significant. Even for a single investigator, an apparent improvement in production as measured by an absolute index might turn out to result simply from a wider net of collaborations.

It is very important to stress that we are not suggesting that collaborations should be avoided. It is clear that many collaborations produce a significant improvement in research quality. Some scientifically relevant studies might actually be intrinsically dependent on contributions from many collaborators, like sequencing of genomes, for example, which has been particularly significant for the recent increase in the average number of coauthors in the department under consideration. But can the number of papers, or any absolute index proportional to this number, of an investigator working in one of these highly collaborative fields, be directly compared to the number of papers from another investigator working with a small research group? Or is it really desirable to concentrate resources in huge collaboration networks not necessarily justifiable from a purely academic perspective? It is intuitive, for example, that two investigators publishing each a number  $x$  of papers by themselves, corresponding to a value  $Ax$  for some quality-related absolute parameter, will not become more productive for the society supporting them if they decide to “collaborate” in every future paper to produce, together,  $2x$  papers corresponding to a value  $2Ax$  for the absolute parameter. According to absolute criteria, however, not only they would both be considered more productive than before but they would also be, against common sense, considered more productive than a third investigator publishing an average of  $1.9x$  papers in the same period of time. What about groups of 5 or 10 “collaborators”?

Effective indexes proposed in the present study can be seen, therefore, as an attempt to make any comparison between these hypothetical situations more meaningful. Note that the estimate for individual participation in each paper could possibly be improved. The participation factor,  $1/N_a$ , could be modified to reflect a more important participation of first and/or corresponding authors, for example. Even more specific participation factors could be eventually computed from information about the specific contribution of each coauthor as has been recently provided by some journals, or even by considering the number of coauthors under direct supervision of each principal investigator, if this information will happen to be available. It might also be pertinent to note that presently proposed effective indexes are not equivalent to some previous attempts to take co-authorship into consideration by dividing absolute indexes by some average number of coauthors. As an instructive example, an  $h$ -related index  $h_I = h/\langle N_a \rangle = h^2/N_a^T$ , where  $N_a^T$  is the total number of coauthors in the papers contributing to  $h$  and  $\langle N_a \rangle = N_a^T/h$  is the average number of coauthors in these papers, has been recently suggested to provide a reasonable starting point for comparison between researchers

acting in different fields [7]. The correspondence to  $h$  is less transparent for  $h_I$ , however, when compared to  $h'$ . In clear opposition to  $h$  and  $h'$ , for example,  $h_I$  can decrease in time, as would be the case if a single publication with an atypically large number of coauthors would begin contributing to  $h$ .

It remains to be investigated to what extent the situation observed in a single department reflects a more general national trend, as it is implicitly assumed in this investigation. Extensive studies using effective indexes would be useful to clarify this point. Many recent studies on Brazilian research output, however, have already indicated that a significant continuous increase in the number of Brazilian publications in indexed journals has not been associated to a comparable increase in the number of citations [9–12]. This observation indicates that national criteria of scientific evaluation have been more successful in promoting an increase in the quantity rather than quality of publications, suggesting that the perceived importance of  $N_p$  in the national evaluation system might be quite general among Brazilian researchers. Although possibly a positive preliminary result, the increase in Brazilian visibility associated to the increase in number of publications should ideally be followed now by an increase in the perceived quality of research.

A very significant incidence of collaborations, both national and international, have also been detected not only in Brazil and other Latin American nations [9, 13–16] but also in developed countries [17–20], clearly indicating a general global trend. Undeniable positive aspects of collaborations, like productive academic discussions, possibly in the context of interdisciplinary investigations, and cost reductions, combined to evaluations guided by absolute indexes of research output, might have contributed to the present situation in which some serious potential problems of indiscriminate collaborations tend to be overlooked. A greater emphasis on  $N_c$ ,  $N_I$  and  $h$ , with all due precautions, over the simple  $N_p$ , might encourage the desirable improvement in Brazilian scientific quality but our present results indicate that the effective versions of these indexes, where number of coauthors is taken into consideration, would be better suited to encourage really productive collaborations, in which the results would be more than the simple addition of what could be obtained in the absence of collaboration.

### Conclusion

Simplistic criteria for the evaluation of scientific production based on uncritical counting of publications do not agree with alternate criteria intended to reflect some idea of research quality, particularly when time of activity and co-authorship are taken into consideration. A significant recent increase in the number of publications and sum of impact factors from individual members of the investigated department appears to have resulted mainly from an increase in the average number of coauthors. Effective

quantity and/or quality indexes, which consider an estimate for the individual participation in each paper, are suggested to be more informative in this situation. Although based on the production from a single department, the observed trend is likely to be more general, since many graduate programs in the nation receive a similar pressure to have their members publishing a large number of papers. This possible increase in number of coauthors as a response to evaluation criteria, supposedly intended to improve research quality, could be anecdotally compared to an increase in hair dying in a society in which young age is considered to be valuable. As already noted since ancient times, however, and neatly illustrated by the following second century epigram by Martial, hair color in itself does not make immediate death less likely.

Mentiris iuvenem tinctis, Laetine, capillis,<sup>1</sup>  
tam subito corvus, qui modo cygnus eras.  
non omnes fallis; scit te Proserpina canum:  
personam capiti detrahet illa tuo.

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<sup>1</sup> You simulate youth, Laetinus, by dying your hair; so suddenly a raven, who were but now a swan. You don't fool everybody; Proserpina knows your hair is white: She will drag the mask from your head [21].

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