UNIVERSITY OF SOUTHERN CALIFORNIA

Department of Civil Engineering

A STUDY ON THE RELATIVE RANKING OF TWELVE FACULTY OF THE USC CIVIL ENGINEERING DEPARTMENT— EXPERIMENTS WITH SCIENCE CITATION INDEX EXPANDED

by

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Motto:

"There is something still worse, however, than being either criticized or dismantled by careless readers: it is being ignored. Since the status of a claim depends on later users' insertions, what if there are no later users whatsoever? This is the point that people who never come close to the fabrication of science have the greatest difficulty in grasping. They imagine that all scientific articles are equal and arrayed in lines like soldiers, to be carefully inspected one by one. However, most papers are never read at all. No matter what a paper did to the former literature, if no one else does anything with it, then it is as if it never existed at all." (Latour, 1987, p.40; see Appendix B).

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1. INTRODUCTION

The impact of the published work of individual scientists and their institutions is increasingly being assessed on the basis of the number of times their work is cited, and this quantitative measure, derived from the Science Citation Index database developed by the Thomson Institute for Scientific Information (ISI) in 1963, is replacing the more informal peer recognition and esteem. By adopting the citations impact factors as a *de facto* measure of quality, the scientific community has turned a bibliometric measure into a measure of scholarly performance.

In the following, the ISI data will be used to explore how to quantify and rank the relative contribution (output) of twelve faculty members of the USC Department of Civil Engineering—eleven on the tenure track (nine Professors, one Associate Professor, and one Assistant Professor), and one on the research track (Research Associate Professor). To maintain confidentiality, we will assign to each faculty member a code name, such as USC-1, USC-2, etc. The assignment of the names to this sequence will be random. That is, it will not be based on alphabetical order of their names, seniority, discipline, or gender. However, all data we present are real and correspond to the performance period ending in December 2003.

Even though the journal impact factors (Appendix A) cannot be equated with excellence, universities in several European countries have started to use impact factors to help determine institutional funding. Many European investigators provide journal impact factors along the listing of their articles in their curricula vitae. Furthermore, promotion and appointment committees are now increasingly using impact factors to assess the quality of the candidates (Frank, 2003).

As noted by Garfield (2003), research administrators need objective criteria for evaluating the past performance and the implied future potential of individuals, departments, and institutions. The traditional criterion is the subjective so-called peer review by committees that invariably have strong biases. The new and emerging trend is to use citations. Citation analysis is not perfect, but after many years of use it has achieved a level of standardization that enables us to develop informed views of the influence or the impact of individuals, groups, and departments. By balancing the publication counts (input) with the citation counts (output) we can get a good idea of the past performance.

When the most recent papers of an individual have not yet had time to be cited, the journal impact factors can be used as a surrogate, based on the assumption that a paper published in a high-impact journal is likely to be of good quality. Of course, this is not a guarantee that the work will be cited, as the fact that a paper has been published in a good journal is only partial evidence about the significance of that research.

There are cases in which huge research grants are going to researchers with political connections even though there is little or no evidence of good research output. Also, it is very easy for entrenched researchers to hide their ineffectiveness by publishing in journals with little or no external peer review (Garfield, 2003). Such cases can now be identified and analyzed by use of the ISI database.

Recently, HighlyCited.com (Thomson/ISI) started to collect data on the work of the "world's most cited and influential researchers." It now offers information about the key contributors to science and technology during the period from 1981 to 1999. Its aim is to serve as "a resource for researchers, scientists, and professors, to identify key individuals, departments, and laboratories that have made fundamental contributions to the development of science and technology in recent decades." It is expected that corporations and government agencies will use HighlyCited.com to locate centers of excellence, to make policy decisions, and to optimize the distribution of funding. At present, the database of HighlyCited.com includes records of only 250 "top researchers" in each of 21 categories, including life sciences, medicine, physical sciences, engineering, and the social sciences. In May 2004, this list included 23 faculty from the University of Southern California (1 in geosciences, 3 in neuroscience, 4 in computer science, 2 in the social sciences, 2 in plant and animal science, 1 in clinical medicine, 1 in molecular biology and genetics, 1 in microbiology, 3 in materials science, 1 in psychology/psychiatry, 1 in mathematics, 2 in economics and business, 1 in chemistry—but none in engineering).

At the same time (May 2004), HighlyCited.com data included 212 members in the category of engineering, worldwide. Of those, 152 (72%) work in the United States, 5 (2%) in Australia, 9 (4%) in Japan, 3 (1%) in India, 9 (4%) in England, 7 (3%) in Germany, 3 (1%) in Switzerland, and 10 (5%) in Canada. Three other countries each had 2 (Belgium, France, and Denmark), and nine countries had one (Sweden, Israel, Austria, Italy, P.R. China, Singapore, Greece, and Norway). Of those members who work in the United States, 79% are at 49 universities and 21% are at 19 government laboratories or private corporations. Examples of organizations with the largest number of highly cited scientists in engineering are: Stanford University (10); Massachusetts Inst. of Tech. and California Inst. of Tech. (8); U.C. Berkeley (7); U.C. Santa Barbara and U. of Michigan (6); Northwestern University (5); U.C. San Diego (4); U.C. Riverside, U. of Texas at Austin, U. of Wisconsin-Madison, and U. of Virginia (3). Thirty-seven other universities had one or two members. As would be expected, the above order of institutions with the largest number of highly cited engineers correlates very well with the U.S. News and World Report rankings of the leading graduate schools of engineering in the U.S. At present, the School of Engineering at USC has no representatives in the category of engineering.

Perusal of the above list of 212 members of the engineering category in the ISI HighlyCited.com data shows that none of them belong to the field of earthquake engineering. There are several possible reasons for this: (1) citation rates in earthquake engineering may be lower than in the other fields of engineering; (2) the time window used by ISI HighlyCited.com (1981 to 1999) may be too restrictive, particularly for older researchers in earthquake engineering; and (3) the half life of citations in earthquake engineering may be longer than it is in more active and rapidly growing fields such as material science or computer science, so that the time window from 1981 to 1999 may be too short to capture all relevant citations in earthquake engineering. Some of these observations may become more plausible from the analysis presented in this report.

In the early 1990s, ISI staff showed that 55% of the papers published in journals covered by the ISI database did not receive a single citation in the five years after they were published (Hamilton, 1991a). When the data were grouped into broad categories it was found that physics and chemistry had the lowest rates of uncitedness, 37% and 39% respectively. Those were followed by the biological sciences (41%), the geosciences (44%), and medicine (46%). These subjects all fell below the uncitedness average of 47% for the “hard sciences” (disciplines including basic sciences and medicine but excluding the social sciences). The figure for engineering, however, was well above the average. More than 72% of all papers published in engineering had no citations at all.

Within the above broad categories there was wide variation among individual subdisciplines. Atomic, molecular, and chemical physics had only 9% of articles uncited, while virology had 14%. Those were followed by particle and field physics (17%), inorganic and nuclear chemistry (17%), nuclear physics (17%), fluid and plasma physics (18%), organic chemistry (19%), condensed matter physics (19%), and biochemistry and molecular biology (19%). The fields that did not fare so well were electro-chemistry (65%), developmental biology (62%), optics (49%), and acoustics (40%).

In engineering, all fields showed high rates of uncitedness, with civil engineering being highest at 78%. Next came mechanical (77%), aerospace (77%), electrical (66%), chemical (66%), and biomedical (60%) engineering. Other applied fields had similarly high rates of uncitedness: construction and building technology (84%), energy and fuels (80%), applied chemistry (78%), materials science—paper and wood (78%), metallurgy and mining (75%), and materials science—ceramics (73%).

Papers in the social sciences also had high levels of uncitedness: political science (90%), international relations (83%), language and linguistics (80%), anthropology (79%), and sociology (75%). Social psychology was an exception with only 35% of papers receiving no citations.

In the arts and humanities uncitedness figures were the highest. For example: theater (99%), American literature (99%), and philosophy (92%). The one exception was the history and philosophy of science (29%).

Even those papers that do get cited are not cited very often. An ISI study of articles in the hard sciences published between 1969 and 1981 showed that only 42% received more than one citation (Hamilton, 1991b). When asked whether this means that more than one half, and perhaps more, of the scientific literature is essentially worthless, some 20 academicians, federal officials, and science policy analysts converged on the explanation that "researchers are publishing far too many inconsequential papers in order to pad their resumes (Hamiltin, 1991b). The Assistant Director for Engineering at the National Science Foundation said that this "does suggest that a lot of work is generally without utility in the short-term sense." Frank Press, who was then the president of the National Academy of Sciences, noted that "There are obvious concerns which are worrisome—namely that the work is redundant, it's me-too type of follow-on papers, or the journals are printing too much."

To J. Duderstadt, President of the University of Michigan, the growing number of journals and the high number of uncited articles simply confirm a suspicion that academic culture encourages spurious publication. He said, "It is pretty strong evidence of how fragmented scientific work has become, and the kinds of pressures which drive people to stress number of publications rather than quality of publications." The chairman of the Astronomy Department at Columbia University said, "The obvious interpretation is that the publish or perish syndrome is still operating in force," while the editor of the *Journal of the American Chemical Society* concluded that "In many ways, publication no longer represents a way of communicating with your scientific peers, but a way to enhance your status and accumulate points for promotion and grants" (Hamilton, 1991b).

The conventional wisdom is that citations are the glue that bonds a research paper to the body of knowledge in particular field and a measure of the paper's importance. Thus, a careful analysis of the ISI data can offer academics, university administrators, and government officials a great deal to think about.

The quality of a researcher's performance and a quantitative evaluation in terms of citations received by each of his or her papers are but one component of an *n*-dimensional performance vector characterizing the overall faculty performance. In view of the widespread use and potential benefits of using the Citation Index database, we think it is important and timely to learn about it and to investigate how it can be used. To this end, we present the following preliminary study of a subset of faculty in the Civil Engineering Department at USC.

2. AVAILABLE DATA

Bibliometric indicators employed in this work to evaluate the published knowledge production will be derived from two sources of data. The first source is the ISI web of science. It consists of five databases containing information gathered from thousands of scholarly journals in all areas of research:

- Science Citation Index Expanded
- Social Sciences Citation Index
- Arts and Humanities Citation Index
- Index Chemicus, and
- Current Chemical Reactions

The three citation databases also contain the references cited by the authors of the journal articles they cover. These databases can be searched by topic, author, source title, and address. In this work, we will use the *Science Citation Index Expanded—Full Search, and Cited Ref. Search,* which cover the period from 1975 to present.

Dr. Eugene Garfield is ISI's founder and chairman emeritus. He is the editor of *Science Citation Index, Journal Citation Reports*—a bibliometric analysis of science journals in the ISI database by the Institute for Scientific Information (ISI, http://ww.isinet.com/), 3501 Market Street, Philadelphia, PA 19104, USA). Many of the Garfield's writings have been posted on his Web site at http://www.garfield.library.upenn.edu/. On June 7, 2001, Dr. Henry Small was named the chief scientist of ISI. He is recognized for his contributions to co-citation analyses, citation mapping and visualization techniques. Since 1992, ISI has been a Thomson Scientific Company and part of The Thomson Corporation (http://www.thomson.com/), which provides Web-based information for researchers, information specialists, and administrators. More information about ISI is available at http://www.isinet.com/ISI.

The second source of data used in this work—the Earthquake Engineering Abstracts (EEA) database—is much smaller but is focused on the subject area of earthquake engineering and the related fields (structural and geotechnical engineering, applied mechanics, engineering seismology, and engineering geology). The EEA database was developed by the National Science Foundation (NSF) through the National Information Service for Earthquake Engineering (NISEE), which during the past 30 years has been the leading repository for all relevant published work in earthquake engineering and related fields.

At present, the EEA database has more than 100,000 abstracts and can serve as a quantitative measure of the active contributors in this field. The database was available free of charge until January 2004, when it became part of Cambridge Scientific Abstracts (CSA), a privately owned information company located in Bethesda, MD, that publishes abstracts and indices for scientific and technical research literature.

3. PERFORMANCE INDICATORS AND DATA PROPERTIES

In the following, we describe the parameters and indicators we will use to analyze the publication productivity (input) of selected faculty and the significance and recognition of their work (output). We also discuss some properties and limitations of the databases we use.

3.1 Input Indicators

In the first part of the analysis, we study the performance of our sample of 12 faculty members of the USC Civil Engineering Department, using two indictors:

$\sum_i 1/a_i$ = cumulative number of publications, per author count (1)

and

$\sum_i q_i / a_i$ = cumulative *potential* impact of publications, per author count, (2)

where a_i is the number of authors of the *i*-th published journal paper, and q_i is the average Journal Impact Factor (JIF) for the corresponding journal (see Appendices A and B). To simplify the presentation, we adopt constant values for q_i, as listed in Table 3 of Appendix B. It is difficult to consider temporal variations of q_i because yearly variations are not available for all journals and for the entire period covered by our analysis. In a few cases, when the journal was not in the list in Appendix B but was recently added to the ISI list of citing journals, we used the currently available values as provided by ISI. In section 4, we plot $\sum_i 1/a_i$ and $\sum_i q_i / a_i$ versus time (years) and compare the trends for the faculty members in our sample with each other and with the average trends in the U.S. (Appendix C).

In the second part of this analysis, we compare ten of the faculty in our sample (all except the two whose research is in environmental engineering) with the leading researchers in Earthquake Engineering in the U.S., including a few from Europe. As we do not have the curricula vitae for the non-USC faculty, in this part of the analysis we use the number of abstracts in the NISEE database as a measure of the lower bound of the number of their published contributions. The validity of this approximation is discussed in Section 5.

3.2 Output Indicators

As an indicator of successful performance, we use the *number of cited papers* and the *number of citations per year* they receive, starting with the date of publication. We again compute the same type of sums as those for evaluation of the input, but now considering only the papers that have been cited at least once. Hence, we use as output indicators

$$\sum_i 1/a_i \text{ = cumulative number of cited publications, per author count} \quad (3)$$

and

$$\sum_i q_i/a_i \text{ = cumulative \textit{actual} impact of publications, per author count.} \quad (4)$$

We also compute the cumulative number of publications and the cumulative number of cited publications (at least once) separately for three categories of publications—journal papers, reports, and conference papers—as well as the percentage of publications in each of these categories, and we show that the conference papers have a very low citation yield—i.e. on the average only one in about five conference papers ever gets cited. Such results should help faculty who spend a considerable effort on publishing conference papers to prioritize their time so that they communicate their research results in the most effective way.

To quantify the relative significance of the papers that have been cited, we compute the number of citations per year for each article, the cumulative number of all citations versus time, and the corresponding fractional (per-author) number of citations, all using the ISI database. We study how the cumulative citations vary with time, what the average slope of that variation (average citation rate) is, and compute the ½ life and ¼ life of the citations (see Appendix F) for all cited papers.

The ISI *Science Citation Index Expanded* covers the period from 1975 to the present—i.e. the citing papers were all published after 1975. Collecting citations from citing papers published prior to 1975 can be done manually from the old printed version of the *Science Citation Index*, which we did for all of the older members of our sample. For these older citations, only the first author is listed and credited, and they are not linked to the full paper title, list of authors, journal name, volume, page numbers, year of the publication, and the full text of the abstract, while for the more recent, fully linked citations, all authors are credited and the order of the authors can be seen from the citation record. Hence, these older faculty members in our sample received citation credit from citing articles prior to 1975 only when they appeared as first authors.

The self-citations can represent several to several tens of percents of the total citations. This percentage depends on many factors, which differ for different authors, and thus cannot be described reliably by some simple and general empirical law. We eliminated all self-citations by excluding citing articles authored or coauthored by the respective faculty member of our sample.

Several studies for twelve subject areas have indicated that the number of citations increases with the mean Journal Impact Factor and with the average number of authors per article, when it is in the range from about 2 to 4.5 (see Fig. A.3 in Appendix A). For our sample, the average number of authors per paper varies from 1.39 to 4.15 (see Table A.1 and Fig. A.3 in Appendix

A), suggesting that his effect could be significant for the relative comparison of the faculty in our sample. In the analysis that follows, we ignore the possible consequences from the different mean number of authors in published papers.

The frequency of citations also depends on the type of article and journal type (see Fig. A.4 in Appendix A). In contrast to regular journals, the papers published in *Nature* and *Science* tend to be short, to summarize past research, or to briefly address current and timely subjects. To maintain the homogeneity of our indicators, and in agreement with recommendations of several previous studies (e.g., Wanner et al., 1981) we do not include papers published in *Nature* and *Science* in computing $\sum_i q_i / a_i$.

4. PERFORMANCE INDICES FOR THE SAMPLE OF TWELVE USC FACULTY

This section presents results for the input and output indicators, defined by Eqs. (1) through (4). Section 5 compares 10 of the 12 USC faculty members in our sample (those in earthquake engineering and the related fields) with selected leading researchers in earthquake engineering elsewhere, mainly in the U.S.

4.1 Input

Figure 1 shows plots versus time (set to zero at the year when Ph.D. was awarded) for the two indices describing the productivity of the *input* into the pool of journal publications—$\sum_i 1/a_i$ (cumulative number of publications, per author count), and $\sum_i q_i/a_i$ (cumulative *potential* impact of publications, per author count). The shaded blue zone in the graph on the left shows the trend of $\sum_i 1/a_i$ for the national average (see Appendix C), and in the graph on the right it shows our projection of $\sum_i q_i/a_i$, assuming average q_i in engineering between 0.5 and 0.6 (see Appendices A and B). As mentioned earlier, $\sum_i 1/a_i$ is a measure of the author's productivity, while $\sum_i q_i/a_i$ is a measure of the *potential* impact of that productivity, assuming the impact will be proportional to the impact factors of the journals. Figure 1 shows that, for the 12 USC faculty members in our sample, these two indicators of their input are spread across both sides of the national average trend. For three of the faculty, low initial productivity (small $\sum_i 1/a_i$), combined with publication in journals with relatively low JIF, leads to a further decrease in $\sum_i q_i/a_i$. In two other cases, low initial productivity is compensated for by publications in journals with higher JIF.

Figure 2 shows the number of journal publications *per year* versus time measured since the year of Ph.D. degree award. The top graph shows the *normal* count, with the publications all being counted with unit weight, regardless of the number of authors, and the bottom part shows the *per author* count, which is a weighted sum with weights $1/a_i$, regardless of whether the researcher was the first, second, third, etc. author. All of the curves in Figure 2 have been smoothed to avoid clutter of oscillating and overlapping lines and to emphasize only the long-period trends. Detailed data (not smoothed) on all twelve faculty members can be found in Appendix F. This figure 2 shows that with one exception (USC-6), 7 of the 11 tenure-track faculty (more than 60 percent) start out and remain below the national average for the per-author case. Thus, the per-author count of journal publications may be a useful parameter to be considered by promotion committees in promotion and tenure decisions. Our sample is small, but in 6 out of 7 cases, initially small (approximately equal to or less than the national average) per-author productivity remains small.

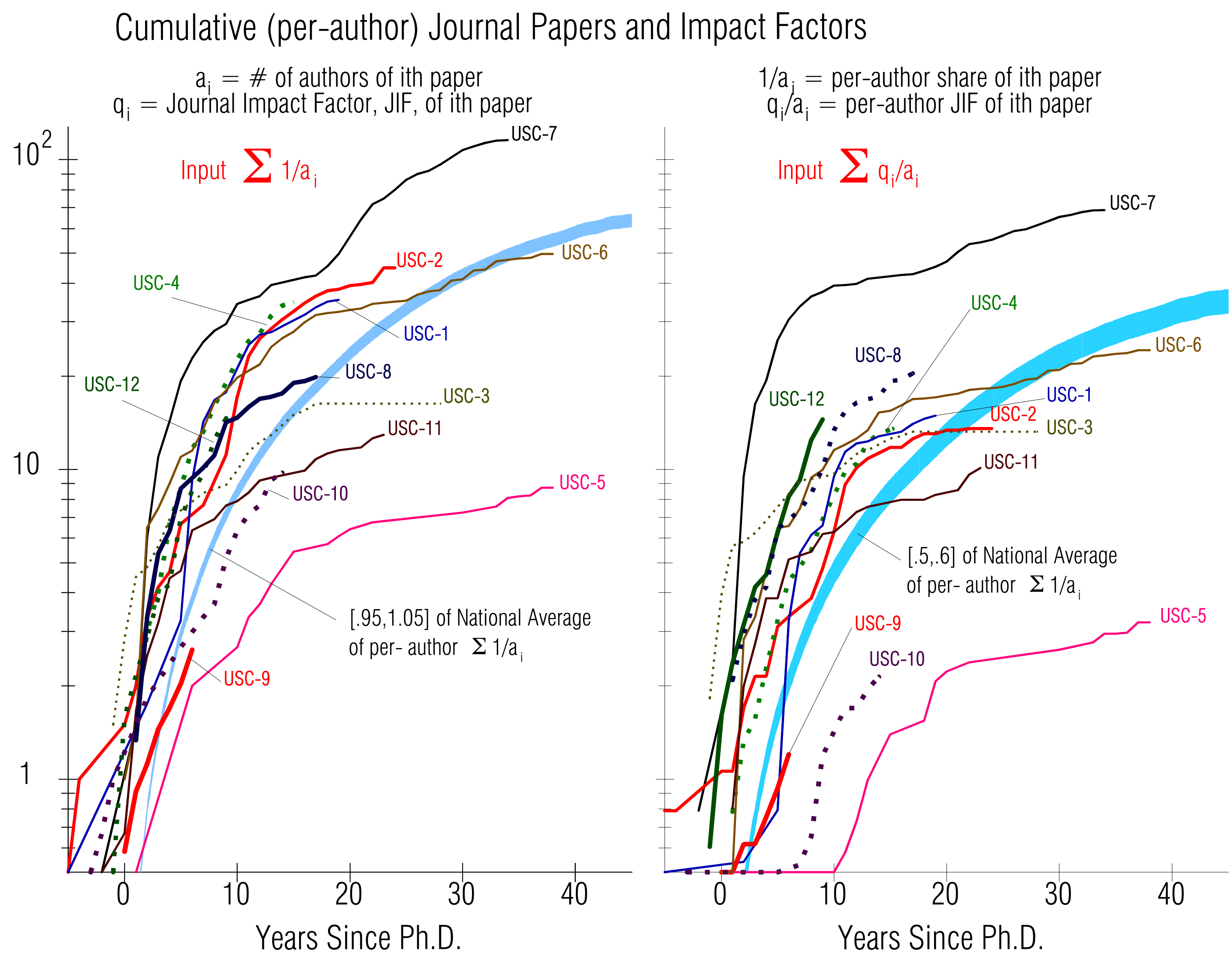

Fig. 1 (left): Cumulative (per-author) journal papers, and (right) cumulative (per-author) impact factors, for twelve faculty members in Civil Engineering, both plotted versus years since Ph.D. award. National Average trends (see Appendix C) are plotted for the assumed average impact factor in engineering journals between 0.5 and 0.6.

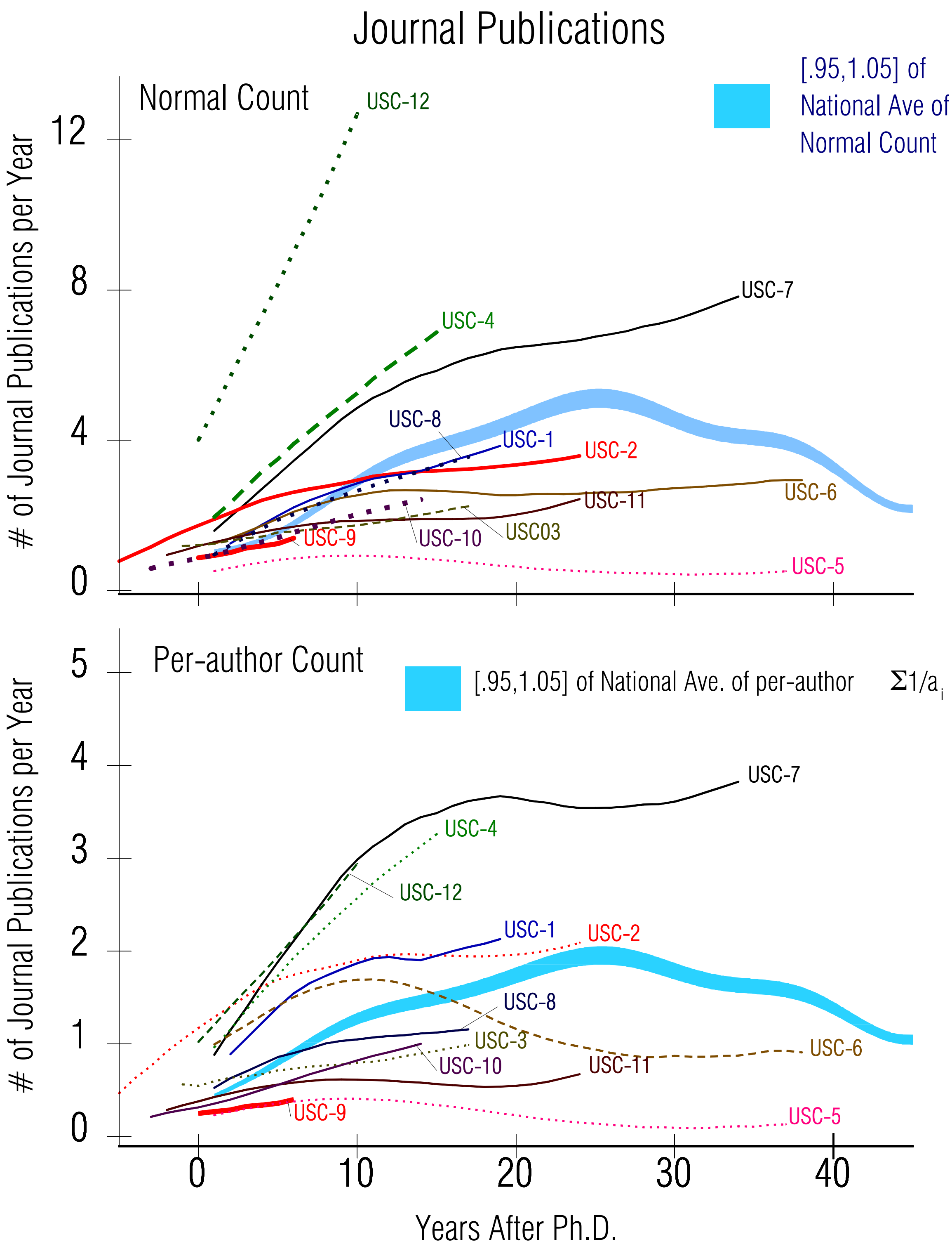

Fig. 2: Number of journal publications per year (top: normal count; bottom: per-author count), plotted versus years after Ph.D. The national average is shown in the range from 0.95 to 1.05 of average.

4.2 Output

First, we describe the output in terms of the percentage of publications that have been cited at least once. A detailed study of the time interval between publication and first citation for our sample (see Appendix F) suggests that, if a publication is ever cited, in about 90 percent of cases the first citations will begin to occur during the first five years after publication. To account for this time delay, we computed the percentage of publications that have been cited up to the end of 1998, which is five years before the date of our analysis (December, 2003). An exception to this rule was made for the two young faculty members in our sample (USC-9 and USC-12), due to the short observation period, implying that for them the corresponding estimates are less reliable.

Figure 3 shows the percentages of contributions that have been cited for the twelve faculty members, considering all contributions (total), journal articles only, reports only, and conference articles only. Note the relatively small percentage accounted for by cited conference papers. Clearly, in some cases, the time spent to prepare many conference papers would have been better spent on writing journal papers or comprehensive research reports. Figure 3 also shows that the citation rate for reports authored by USC-7, USC-4, USC-2 and USC-12 are relatively high. Since June 2003, all reports of the USC Strong Motion Group have been made available online (http://www.usc.edu/dept/civil_eng/Earthquake_eng/), and it is expected that this will further increase its members' citation rates.

Figure 4 is similar to Figure 1 and shows the cumulative number of journal publications versus time, but now only of those that have been cited. The graph on the left shows $\sum_i 1/a_i$, and the one on the right shows $\sum_i q_i / a_i$. It can be seen that, at present, 3 of the 12 researchers in the sample (or about 25%) are at or below the average trend. For $\sum_i q_i / a_i$, the trend is similar.

Next, we describe the output considering the frequency with which a publication has been cited. Figure 5 shows on the left the *normal* count and on the right the *per-author* count of the average number of citations per year. Figures 6 and 7 show the cumulative number of citations in the ISI database through the end of 2003, plotted versus years after award of Ph.D. degree, considering normal and per-author counts, respectively.

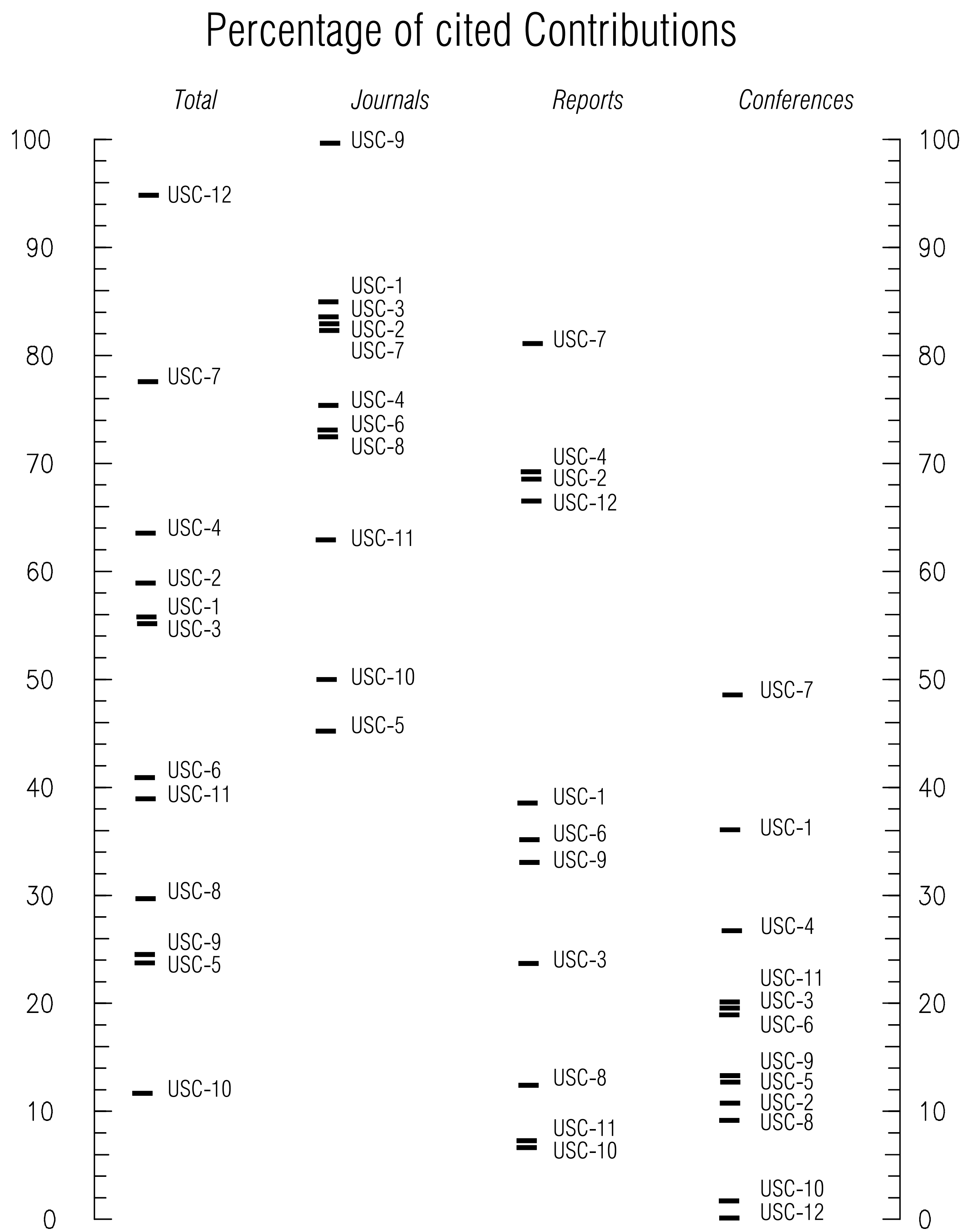

Fig. 3: Percentage of published articles receiving at least one citation, for all publications (total), and separately for journals, reports, and conference papers.

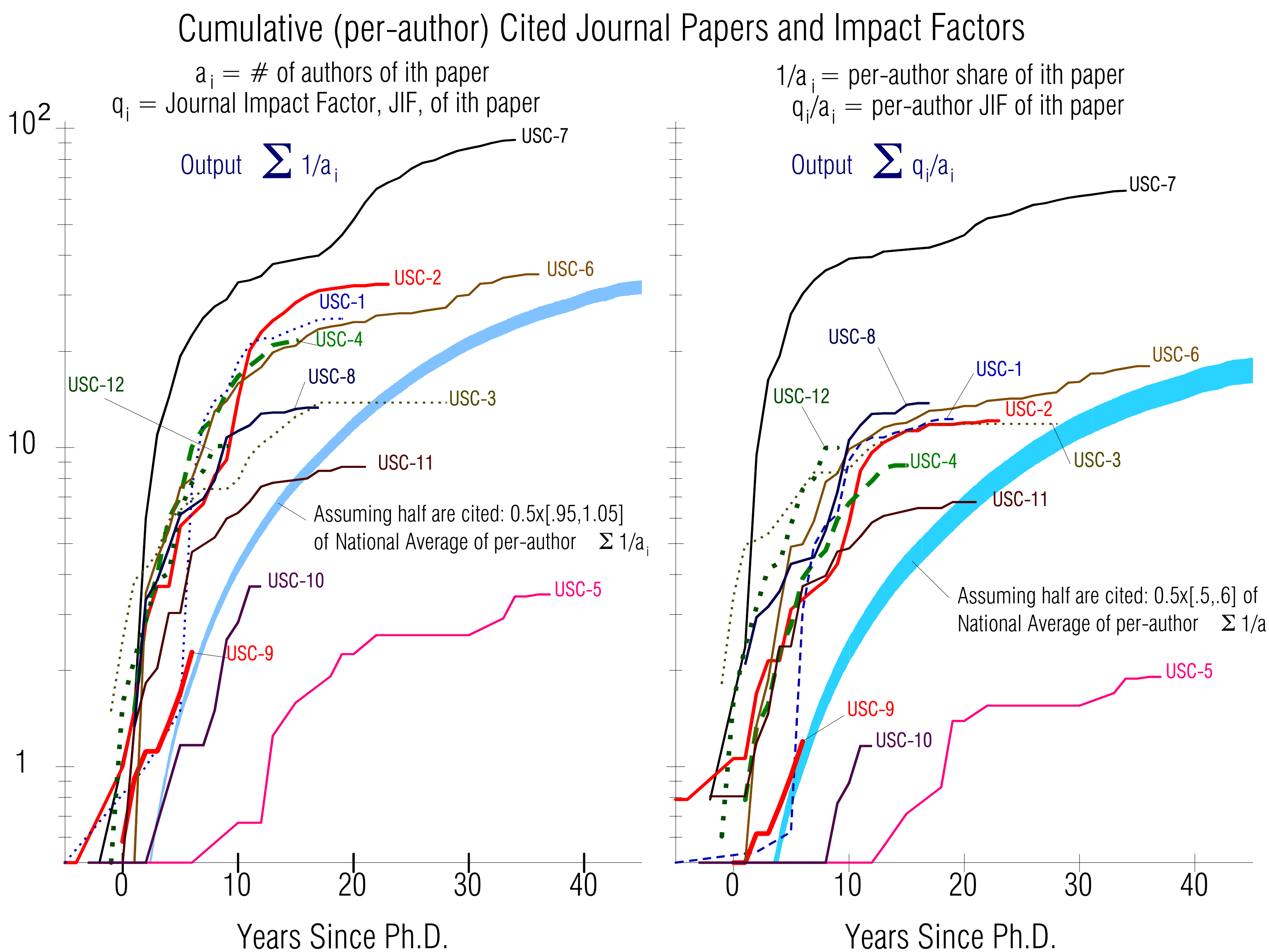

Fig. 4 (left): Cumulative (per-author) number of cited journal papers, and (right) cumulative (per-author) impact factors of cited papers, for the sample of twelve USC faculty members, both plotted versus years since Ph.D.

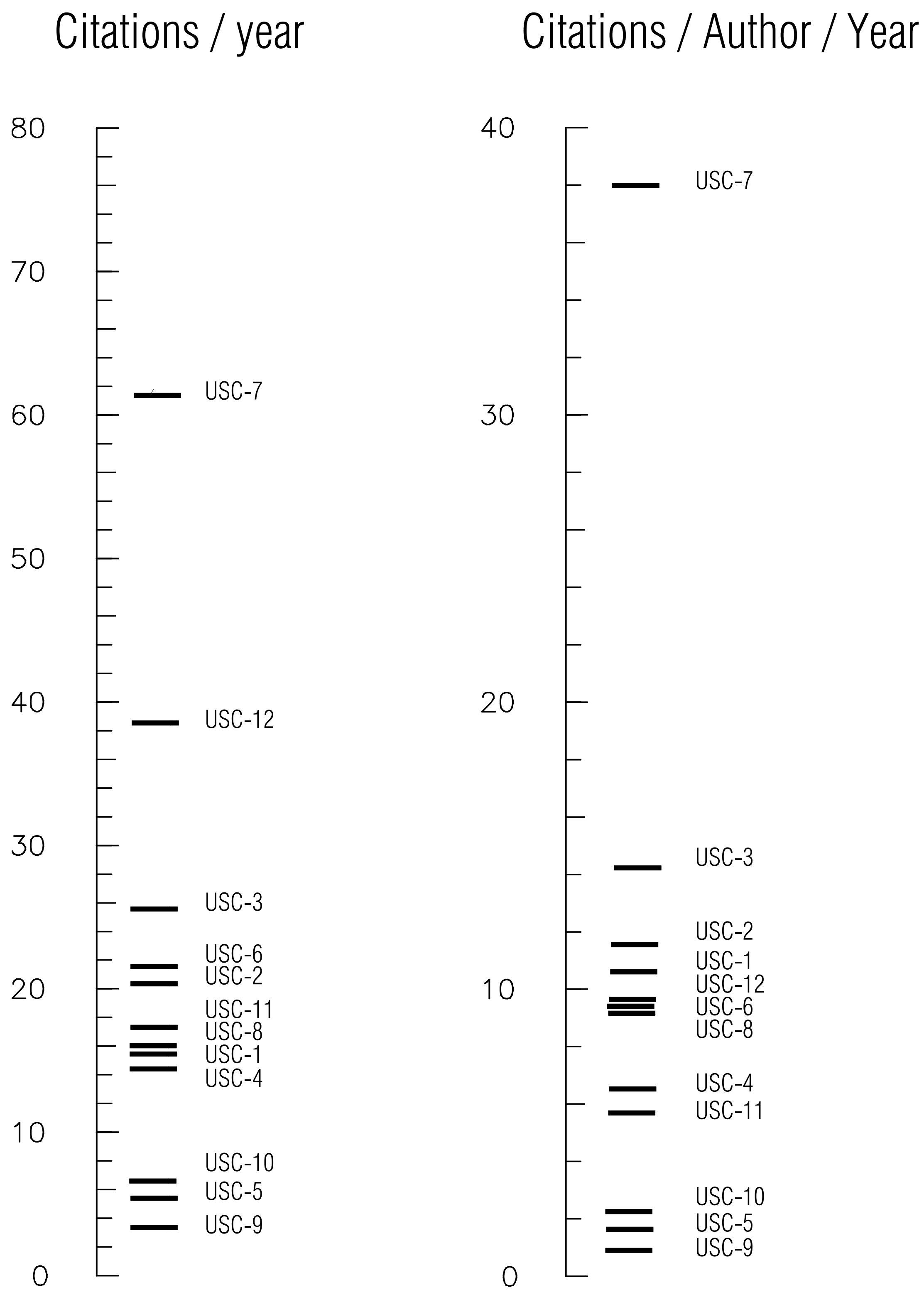

Fig. 5: (left) Number of citations per year (total count), and (right) number of citations per author per year.

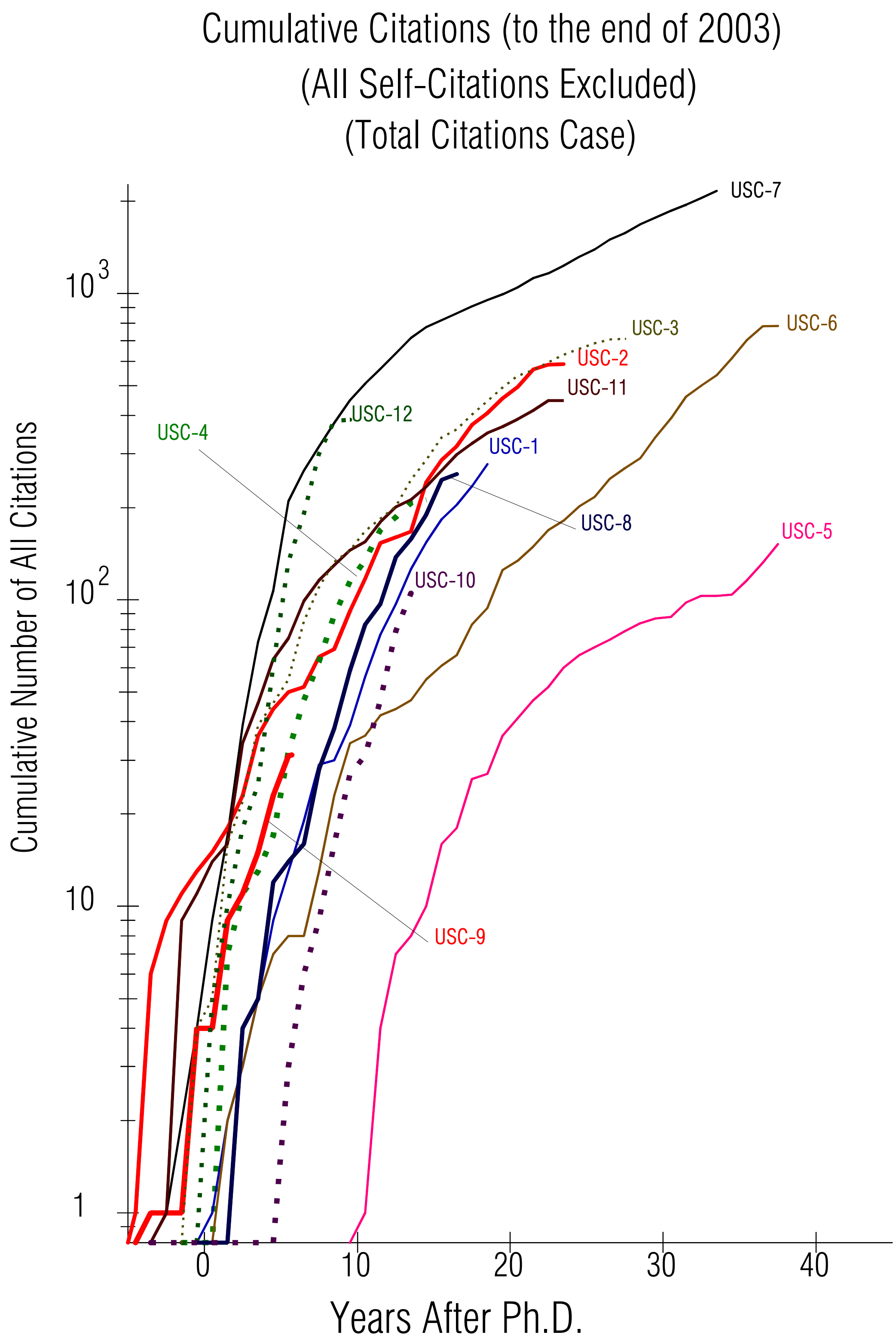

Fig. 6: Cumulative number of citations, for normal count, plotted versus years after Ph.D.

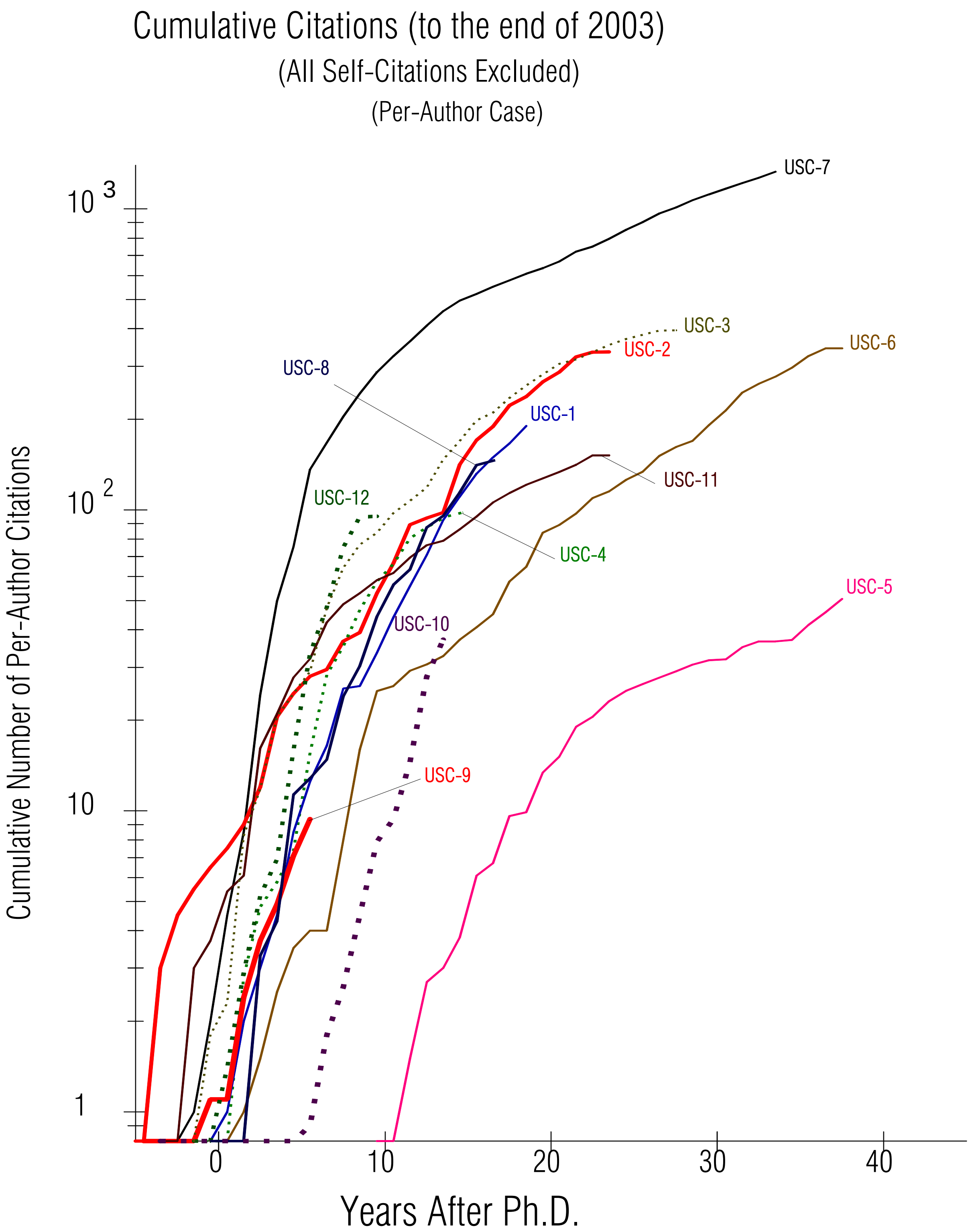

Fig. 7: Cumulative number of citations, for per-author count, plotted versus years after Ph.D. (all self-citations excluded).

4.3 Some Correlations and Trends

Figures 8 through 11 show various trends of the number of ISI citations for each member of the sample versus the cumulative JIFs and the number of published papers. Figure 8 shows the total number of ISI citations per author versus $\sum_i q_i / a_i$ = cumulative impact factor per author, both plotted on a logarithmic scale. For x = log ($\sum_i q_i / a_i$) and y = log (total number of ISI citations per author), the overall trend is $y = 1.1 + 1.1\,x$, and all of the points are between y = 0.8 + 1.1x and y = 1.5 + 1.1x, which on a linear amplitude scale corresponds to factors of 0.5 to 2.5 relative to the average. Figure 9 shows the same data but in terms of the corresponding yearly rates, and on linear scales. It shows the average number of citations per author per year (y) versus the average impact factor per author per year (x). It can be seen that the trends range from y = 10x to y = 25x. Excluding USC-5, USC-10, and USC-9, for whom the sample is too small to be interpreted with confidence, USC-2 and USC-3 have the highest citation rates per impact factor, while USC-12, USC-8, and USC-4 have the smallest.

Figure 10 shows the number of ISI citations per author per year (y), versus the number of ISI citations per year (x). In this figure, the slope of the correlation lines depends on the average number of authors per paper (see Table 1). The lines in this figure correspond to 1.4, 1.6, 2, 3 and 4 authors/paper.

Figure 11 describes the simplest robust correlation of y = total number of citations per author with x = total number of journal papers per author, both plotted on a logarithmic scale. The average trend is y = 0.4 + 1.275x, where y = log (number of citations per author) and x = log (number of journal papers per author).

Figures 12 through 17 and Tables 2 and 3 provide a further insight into the nature of the trends described above. On the input side, Table 2a shows the distribution of the total number of reported contributions (through 2003) among different categories of publications (journal papers, reports, and conference papers), and Fig. 12a shows the percentage of published journal papers and reports versus the percentage of published conference papers. It is remarkable that 5 of the 12 faculty members in our sample have more than half of all of their published contributions in the form of conference papers. In the extreme case (USC-9) the fraction of conference papers is 85 percent.

As a first step in the further analysis of the output of the 12 researchers in our sample, Table 2b shows the distribution of the *cited publications* among the same three categories of publications, and Figure 12b shows the percentage of *cited* journal articles and reports versus the percentage of *cited* conference papers, all considering normal count. Table 2c and Fig. 12 c show the same data but for the per-author count.

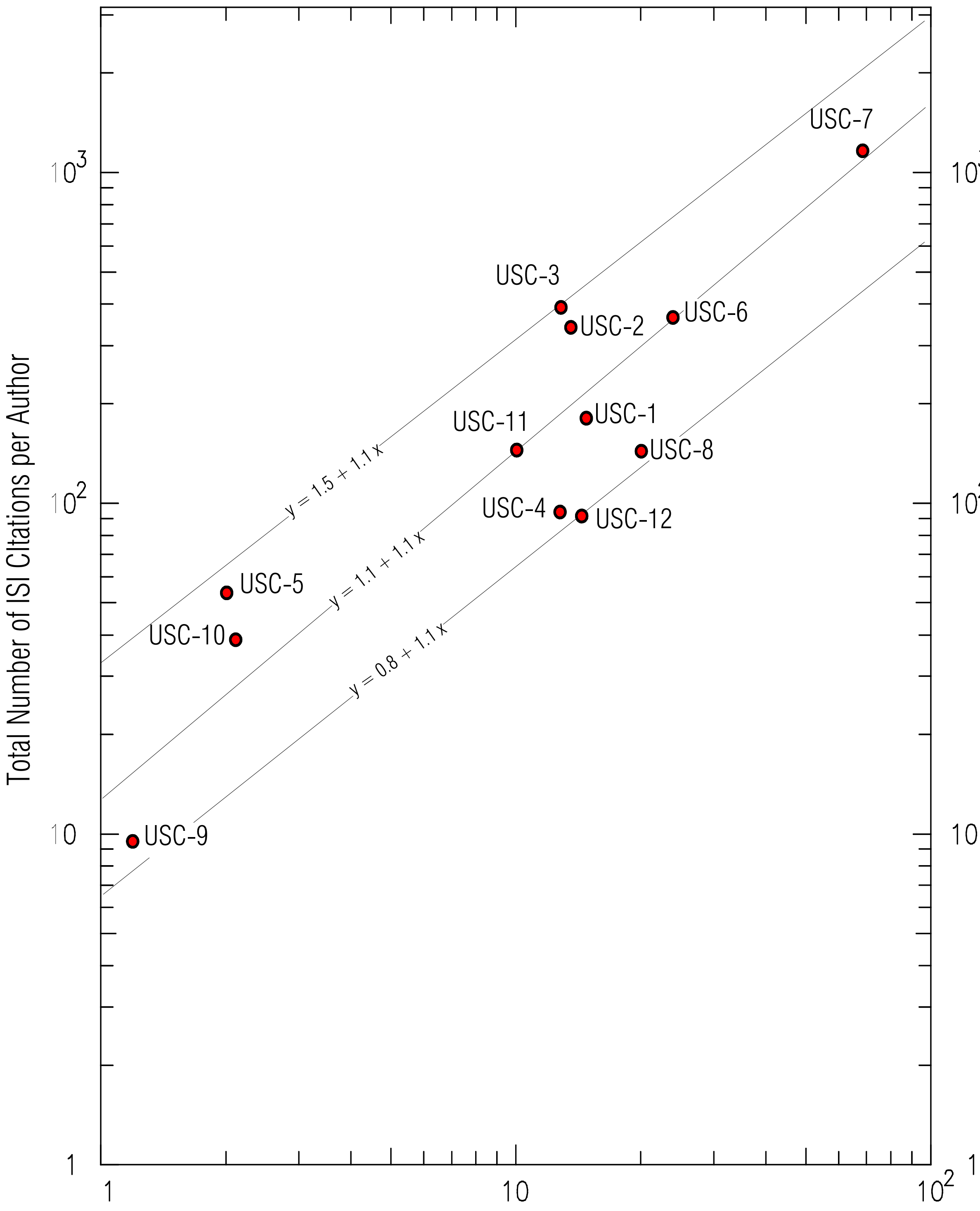

Fig. 8: Total number of ISI citations per author versus cumulative journal impact factor per author.

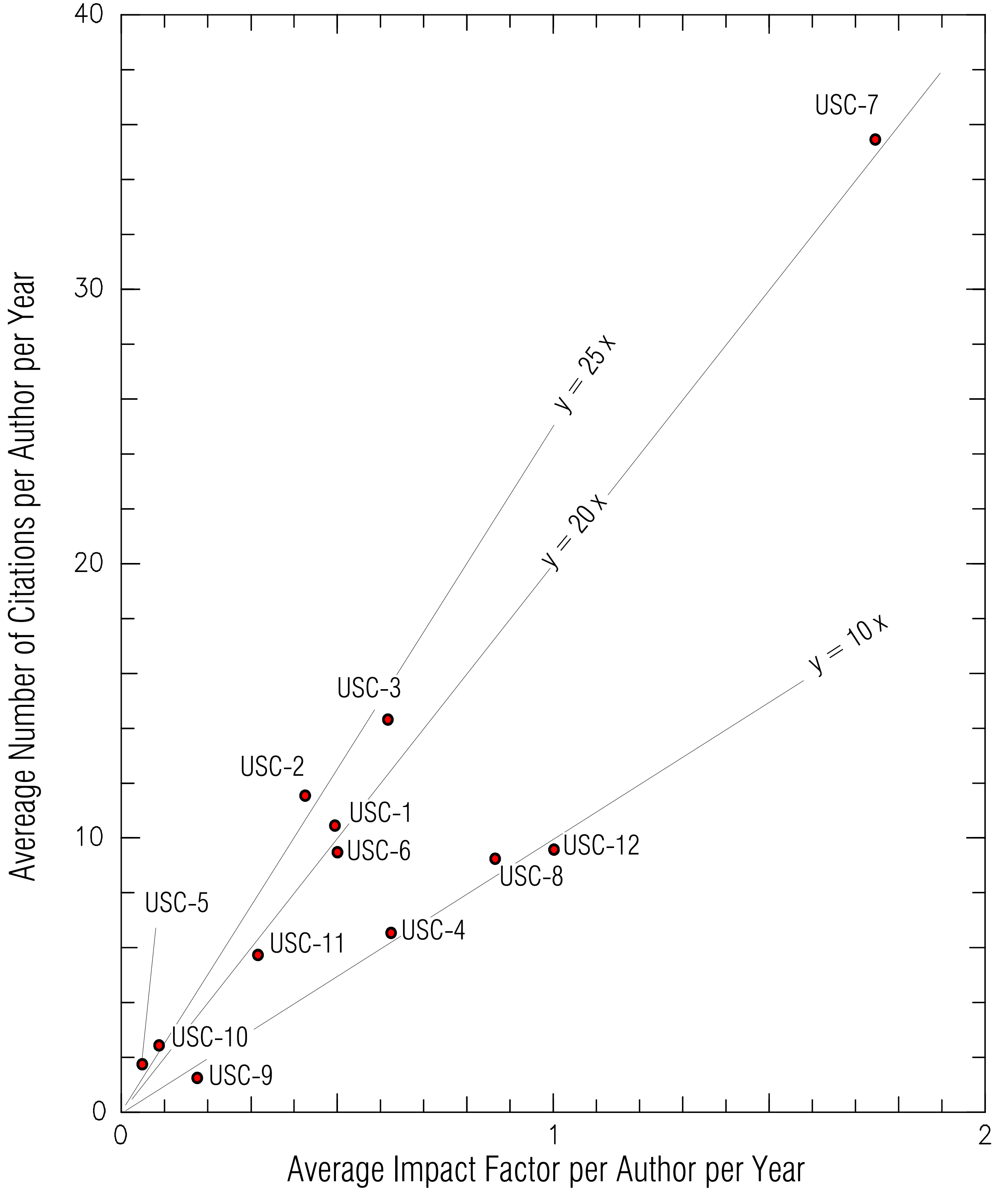

Fig. 9: Average number of citations per author per year plotted versus average impact factor per author per year.

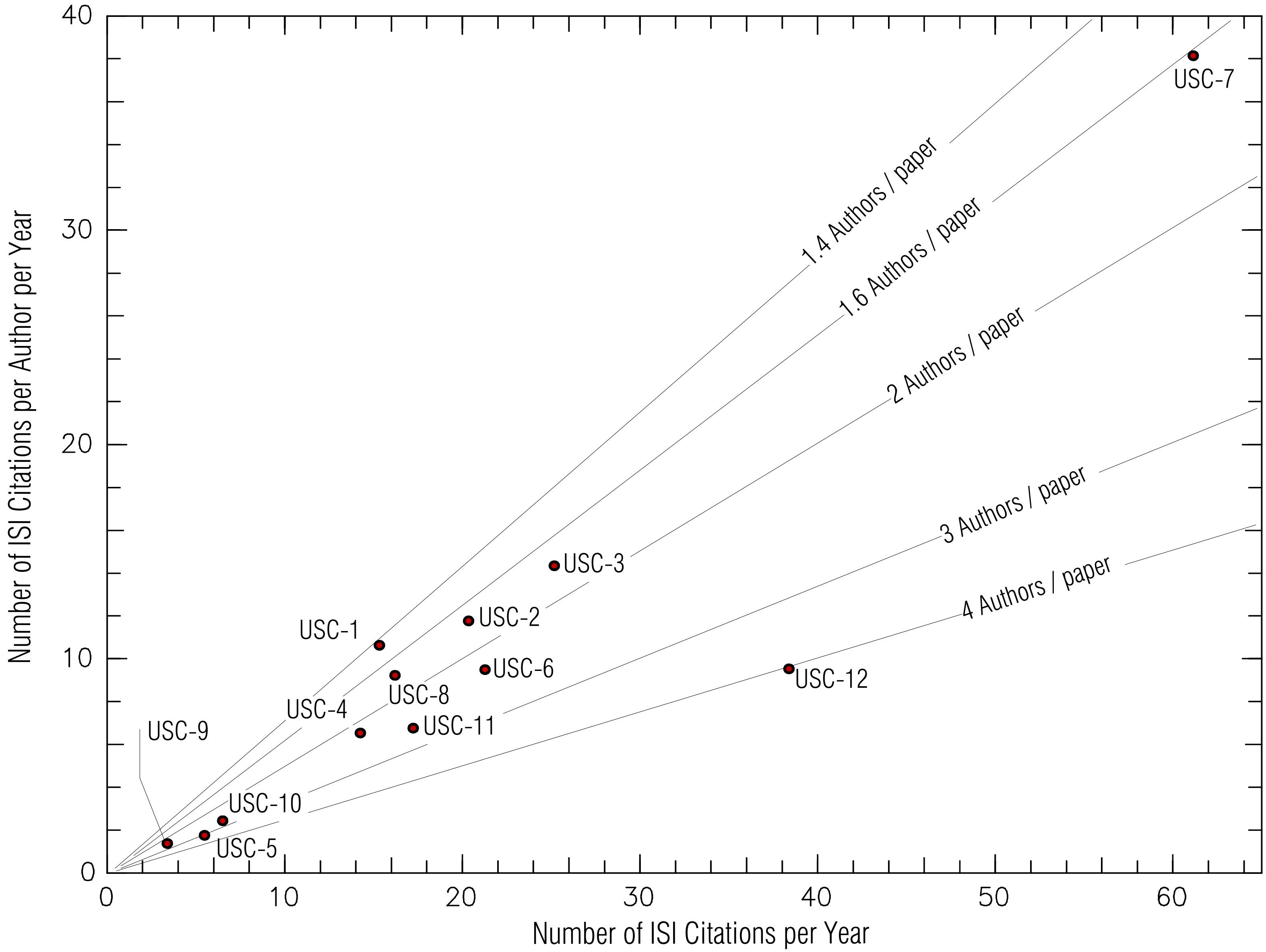

Fig. 10: Number of ISI citations per author per year plotted versus number of ISI citations per year.

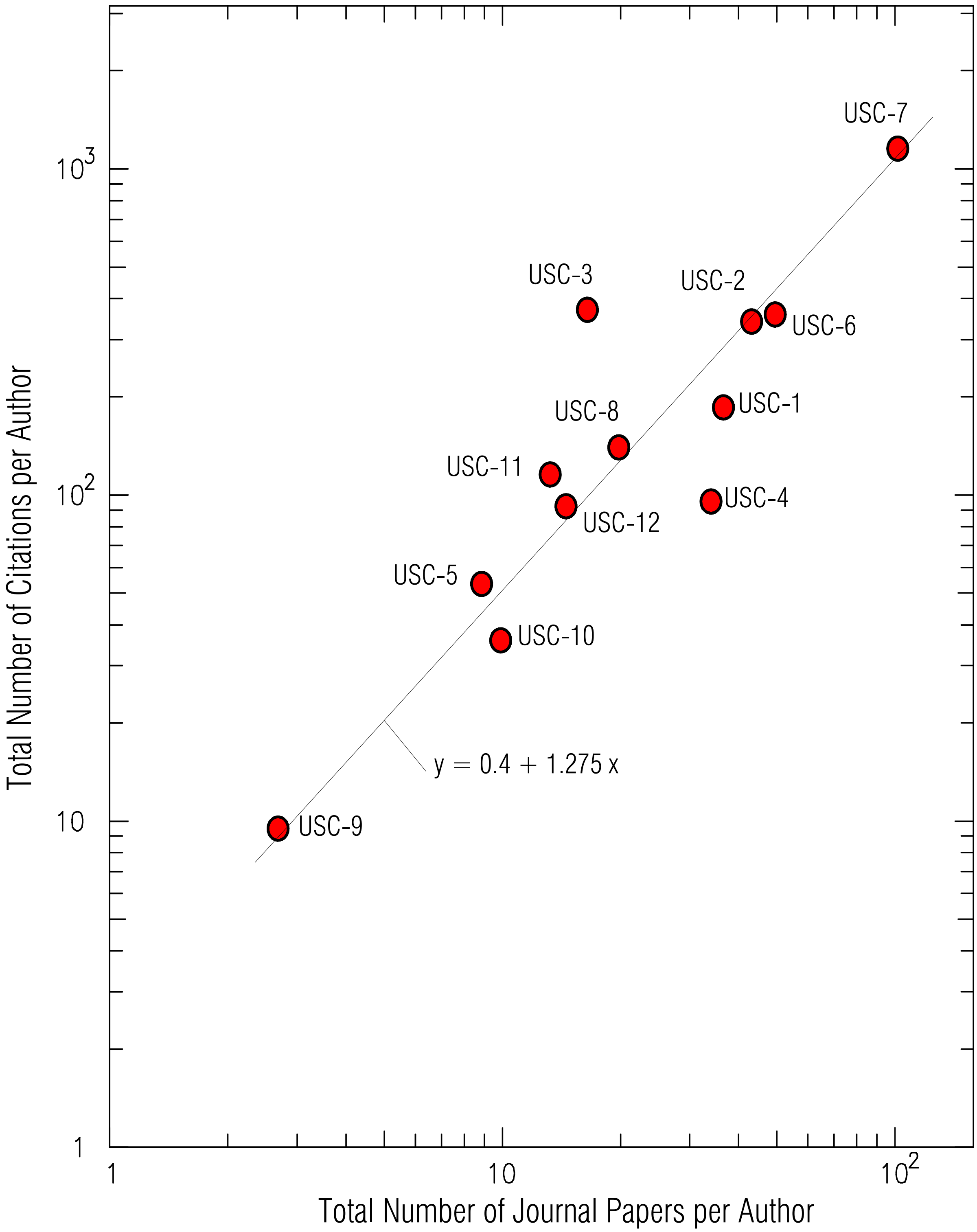

Fig. 11: Total number of citations per author versus total number of papers per author.

Table 1: Average Number of Authors per Paper for the Faculty in the Sample.

Faculty Member	Average Number of Authors per Paper
USC-1	1.39
USC-7	1.69
USC-2	1.46
USC-8	3.01
USC-3	1.83
USC-6	2.15
USC-4	2.18
USC-10	2.19
USC-11	3.00
USC-5	3.02
USC-9	3.06
USC-12	4.15

In the second stage of our analysis of the output we consider the distribution of the *number of citations* among the three categories of publications, shown in Tables 2d for the normal count, and plotted in Figure 12d as number of citations from journal papers and reports versus number of citations from conference papers. Table 2e and Fig. 12e show the same data but for the per-author count. Figures 12d and 12e emphasize the counter-productive effects of allocating too much time to writing conference papers.

Tables 3a through 3d provide further details on the output, showing the distribution of *cited* publications among journal papers, reports, and conference papers, but now differentiating between publications as a single author or as the 1st, 2nd, 3rd, 4th, and $\geq 5^{th}$ co-author. Tables 3a and 3b show the distributions of the *percentage of cited publications* among these groups respectively, for the normal and per-author counts, and Tables 3c and 3d show the *number of citations* for the normal and per-author counts. Figures 13a,b,c show graphically the trends in Tables 3a, c, and d, for the journal papers only. Figure 13a shows that, with one exception (USC-1), the faculty in our sample wrote less than one in five of their cited papers as a single author. USC-2, USC-6, USC-8, and USC-7 write about one in six of their cited papers as single authors, while USC-3 and USC-12 write one in thirty of their cited papers as single authors. USC-9, USC-5, USC-11, and USC-10 have no cited papers of which they are single authors.

Table 2a
Distributions among Publication Types
All Cited & Uncited Publications Included

Name	Journal	Report	Conference	Total
USC-01	54 40.91%	17 12.88%	61 46.21%	132 100.00%
USC-09	9 8.57%	7 6.67%	89 84.76%	105 100.00%
USC-02	72 42.60%	52 30.77%	45 26.63%	169 100.00%
USC-05	23 22.77%	4 3.96%	74 73.27%	101 100.00%
USC-06	99 34.86%	23 8.10%	162 57.04%	284 100.00%
USC-11	58 55.24%	16 15.24%	31 29.52%	105 100.00%
USC-12	77 80.21%	6 6.25%	13 13.54%	96 100.00%
USC-08	45 27.27%	9 5.45%	111 67.27%	165 100.00%
USC-04	69 59.48%	24 20.69%	23 19.83%	116 100.00%
USC-07	209 60.23%	94 27.09%	44 12.68%	347 100.00%
USC-03	36 50.00%	17 23.61%	19 26.39%	72 100.00%
USC-10	26 18.71%	37 26.62%	76 54.68%	139 100.00%

Table 2b
Distributions among Cited Publications
Normal (Total) Count

Name	Journal	Report	Conference	Total
USC - 01	35 59.32%	5 8.48%	19 32.20%	59 100.00%
USC - 09	8 47.06%	1 5.88%	8 47.06%	17 100.00%
USC - 02	51 57.30%	34 38.20%	4 4.49%	89 100.00%
USC - 05	9 39.13%	2 8.70%	12 52.17%	23 100.00%
USC - 06	67 70.53%	2 2.11%	26 27.37%	95 100.00%
USC - 11	25 75.76%	1 3.03%	7 21.21%	33 100.00%
USC - 12	36 90.00%	2 5.00%	2 5.00%	40 100.00%
USC - 08	26 72.22%	1 2.78%	9 25.00%	36 100.00%
USC - 04	43 70.49%	13 21.31%	5 8.20%	61 100.00%
USC - 07	161 64.14%	71 28.29%	19 7.57%	251 100.00%
USC - 03	30 75.00%	4 10.00%	6 15.00%	40 100.00%
USC - 10	10 62.50%	2 12.50%	4 25.00%	16 100.00%

Table 2c
Distributions among Cited Publications
Fractional (per-author) Count

Name	Journal	Report	Conference	Total
USC - 01	24.5 59.32%	3.8 9.06%	13.1 31.61%	41.4 100.00%
USC - 09	2.3 40.06%	1.0 17.54%	2.4 42.40%	5.7 100.00%
USC - 02	32.5 62.07%	15.8 30.27%	4.0 7.65%	52.3 100.00%
USC - 05	2.9 31.65%	1.5 16.28%	4.8 52.07%	9.2 100.00%
USC - 06	34.6 77.33%	1.3 2.80%	8.9 19.87%	44.7 100.00%
USC - 11	8.4 72.02%	1.0 8.61%	2.3 19.37%	11.6 100.00%
USC - 12	9.8 88.49%	1.0 9.01%	.3 2.49%	11.1 100.00%
USC - 08	12.8 67.24%	1.0 5.24%	5.3 27.52%	19.1 100.00%
USC - 04	21.3 72.89%	4.1 13.97%	3.8 13.14%	29.2 100.00%
USC - 07	91.9 66.03%	34.9 25.05%	12.4 8.92%	139.2 100.00%
USC - 03	13.8 64.84%	3.5 16.41%	4.0 18.75%	21.3 100.00%
USC - 10	3.7 48.67%	.7 8.85%	3.2 42.48%	7.5 100.00%

Table 2d
Distributions of Citations among Publication Types
Normal (Total) Count

Name	Journal	Report	Conference	Total
USC - 01	208 75.09%	32 11.55%	37 13.36%	277 100.00%
USC - 09	11 35.48%	1 3.23%	19 61.29%	31 100.00%
USC - 02	319 54.34%	252 42.93%	16 2.73%	587 100.00%
USC - 05	116 76.32%	6 3.95%	30 19.74%	152 100.00%
USC - 06	731 93.36%	8 1.02%	44 5.62%	783 100.00%
USC - 11	356 79.64%	10 2.24%	81 18.12%	447 100.00%
USC - 12	382 98.71%	2 .52%	3 .77%	387 100.00%
USC - 08	227 88.33%	10 3.89%	20 7.78%	257 100.00%
USC - 04	169 79.72%	34 16.04%	9 4.24%	212 100.00%
USC - 07	1746 80.80%	372 17.21%	43 1.99%	2161 100.00%
USC - 03	651 91.69%	50 7.04%	9 1.27%	710 100.00%
USC - 10	97 92.38%	3 2.86%	5 4.76%	105 100.00%

Table 2e
Distributions of Citations among Publication Type
Fractional (per-author) Count

Name	Journal	Report	Conference	Total
USC - 01	141.3 74.35%	24.0 12.63%	24.7 13.02%	190.0 100.00%
USC - 09	3.0 32.38%	1.0 10.68%	5.3 56.94%	9.4 100.00%
USC - 02	196.7 58.83%	121.6 36.39%	16.0 4.79%	334.3 100.00%
USC - 05	37.3 73.77%	5.0 9.88%	8.3 16.35%	50.6 100.00%
USC - 06	322.0 93.50%	7.3 2.11%	15.1 4.39%	344.4 100.00%
USC - 11	114.6 75.59%	10.0 6.60%	27.0 17.81%	151.6 100.00%
USC - 12	93.6 98.45%	1.0 1.05%	.5 .50%	95.1 100.00%
USC - 08	123.7 84.75%	10.0 6.85%	12.3 8.39%	146.0 100.00%
USC - 04	81.4 84.01%	9.0 9.28%	6.5 6.71%	96.9 100.00%
USC - 07	1140.4 85.74%	162.5 12.22%	27.2 2.04%	1330.1 100.00%
USC - 03	340.1 86.19%	49.0 12.42%	5.5 1.39%	394.6 100.00%
USC - 10	32.7 88.13%	1.0 2.70%	3.4 9.17%	37.1 100.00%

Table 3a - Distribution of Cited Publications: Normal (Total) Count

Author	Single	1st	2nd	3rd	4th	≥ 5th	Total
USC - 01							
Journal:	16, 27.1%	15, 25.4%	3, 5.1%	1, 1.7%	0, .0%	0, .0%	35, 59.3%
Report:	3, 5.1%	2, 3.4%	0, .0%	0, .0%	0, .0%	0, .0%	5, 8.5%
Conference:	9, 15.3%	10, 16.9%	0, .0%	0, .0%	0, .0%	0, .0%	19, 32.2%
Total:	28, 47.5%	27, 45.8%	3, 5.1%	1, 1.7%	0, .0%	0, .0%	59, 100.0%
USC - 09							
Journal:	0, .0%	8, 47.1%	0, .0%	0, .0%	0, .0%	0, .0%	8, 47.1%
Report:	1, 5.9%	0, .0%	0, .0%	0, .0%	0, .0%	0, .0%	1, 5.9%
Conference:	0, .0%	7, 41.2%	0, .0%	1, 5.9%	0, .0%	0, .0%	8, 47.1%
Total:	1, 5.9%	15, 88.2%	0, .0%	1, 5.9%	0, .0%	0, .0%	17, 100.0%
USC - 02							
Journal:	17, 19.1%	16, 18.0%	17, 19.1%	1, 1.1%	0, .0%	0, .0%	51, 57.3%
Report:	3, 3.4%	12, 13.5%	12, 13.5%	3, 3.4%	2, 2.2%	2, 2.2%	34, 38.2%
Conference:	4, 4.5%	0, .0%	0, .0%	0, .0%	0, .0%	0, .0%	4, 4.5%
Total:	24, 27.0%	28, 31.5%	29, 32.6%	4, 4.5%	2, 2.2%	2, 2.2%	89, 100.0%
USC - 05							
Journal:	0, .0%	3, 13.0%	0, .0%	6, 26.1%	0, .0%	0, .0%	9, 39.1%
Report:	1, 4.3%	1, 4.3%	0, .0%	0, .0%	0, .0%	0, .0%	2, 8.7%
Conference:	0, .0%	10, 43.5%	1, 4.3%	0, .0%	0, .0%	1, 4.3%	12, 52.2%
Total:	1, 4.3%	14, 60.9%	1, 4.3%	6, 26.1%	0, .0%	1, 4.3%	23, 100.0%
USC - 06							
Journal:	17, 17.9%	33, 34.7%	16, 16.8%	0, .0%	0, .0%	1, 1.1%	67, 70.5%
Report:	1, 1.1%	0, .0%	0, .0%	1, 1.1%	0, .0%	0, .0%	2, 2.1%
Conference:	0, .0%	14, 14.7%	10, 10.5%	0, .0%	1, 1.1%	1, 1.1%	26, 27.4%
Total:	18, 18.9%	47, 49.5%	26, 27.4%	1, 1.1%	1, 1.1%	2, 2.1%	95, 100.0%
USC - 11							
Journal:	0, .0%	13, 39.4%	9, 27.3%	2, 6.1%	1, 3.0%	0, .0%	25, 75.8%
Report:	1, 3.0%	0, .0%	0, .0%	0, .0%	0, .0%	0, .0%	1, 3.0%
Conference:	0, .0%	4, 12.1%	3, 9.1%	0, .0%	0, .0%	0, .0%	7, 21.2%
Total:	1, 3.0%	17, 51.5%	12, 36.4%	2, 6.1%	1, 3.0%	0, .0%	33, 100.0%
USC - 12							
Journal:	1, 2.5%	15, 37.5%	6, 15.0%	6, 15.0%	5, 12.5%	3, 7.5%	36, 90.0%
Report:	0, .0%	2, 5.0%	0, .0%	0, .0%	0, .0%	0, .0%	2, 5.0%
Conference:	0, .0%	1, 2.5%	0, .0%	0, .0%	0, .0%	1, 2.5%	2, 5.0%
Total:	1, 2.5%	18, 45.0%	6, 15.0%	6, 15.0%	5, 12.5%	4, 10.0%	40, 100.0%
USC - 08							
Journal:	6, 16.7%	4, 11.1%	11, 30.6%	1, 2.8%	2, 5.6%	2, 5.6%	26, 72.2%
Report:	1, 2.8%	0, .0%	0, .0%	0, .0%	0, .0%	0, .0%	1, 2.8%
Conference:	3, 8.3%	4, 11.1%	2, 5.6%	0, .0%	0, .0%	0, .0%	9, 25.0%
Total:	10, 27.8%	8, 22.2%	13, 36.1%	1, 2.8%	2, 5.6%	2, 5.6%	36, 100.0%
USC - 04							
Journal:	5, 8.2%	14, 23.0%	18, 29.5%	3, 4.9%	0, .0%	3, 4.9%	43, 70.5%
Report:	0, .0%	5, 8.2%	1, 1.6%	2, 3.3%	2, 3.3%	3, 4.9%	13, 21.3%
Conference:	3, 4.9%	1, 1.6%	1, 1.6%	0, .0%	0, .0%	0, .0%	5, 8.2%
Total:	8, 13.1%	20, 32.8%	20, 32.8%	5, 8.2%	2, 3.3%	6, 9.8%	61, 100.0%
USC - 07							
Journal:	36, 14.3%	48, 19.1%	67, 26.7%	8, 3.2%	1, .4%	1, .4%	161, 64.1%
Report:	9, 3.6%	20, 8.0%	29, 11.6%	8, 3.2%	2, .8%	3, 1.2%	71, 28.3%
Conference:	7, 2.8%	4, 1.6%	7, 2.8%	1, .4%	0, .0%	0, .0%	19, 7.6%
Total:	52, 20.7%	72, 28.7%	103, 41.0%	17, 6.8%	3, 1.2%	4, 1.6%	251, 100.0%
USC - 03							
Journal:	1, 2.5%	19, 47.5%	6, 15.0%	3, 7.5%	1, 2.5%	0, .0%	30, 75.0%
Report:	3, 7.5%	1, 2.5%	0, .0%	0, .0%	0, .0%	0, .0%	4, 10.0%
Conference:	2, 5.0%	3, 7.5%	1, 2.5%	0, .0%	0, .0%	0, .0%	6, 15.0%
Total:	6, 15.0%	23, 57.5%	7, 17.5%	3, 7.5%	1, 2.5%	0, .0%	40, 100.0%
USC - 10							
Journal:	0, .0%	5, 31.3%	1, 6.3%	4, 25.0%	0, .0%	0, .0%	10, 62.5%
Report:	0, .0%	2, 12.5%	0, .0%	0, .0%	0, .0%	0, .0%	2, 12.5%
Conference:	3, 18.8%	1, 6.3%	0, .0%	0, .0%	0, .0%	0, .0%	4, 25.0%
Total:	3, 18.8%	8, 50.0%	1, 6.3%	4, 25.0%	0, .0%	0, .0%	16, 100.0%

Table 3b - Distribution of Cited Publications: Fractional (per-author) Count

Author	Single	1^{st}	2^{nd}	3^{rd}	4^{th}	$\geq 5^{th}$	Total
USC - 01							
Journal:	16.0, 38.7%	7.3, 17.5%	1.0, 2.3%	.3, .8%	.0, .0%	.0, .0%	24.5, 59.3%
Report:	3.0, 7.3%	.8, 1.8%	.0, .0%	.0, .0%	.0, .0%	.0, .0%	3.8, 9.1%
Conference:	9.0, 21.8%	4.1, 9.9%	.0, .0%	.0, .0%	.0, .0%	.0, .0%	13.1, 31.6%
Total:	28.0, 67.7%	12.1, 29.2%	1.0, 2.3%	.3, .8%	.0, .0%	.0, .0%	41.4, 100.0%
USC - 09							
Journal:	.0, .0%	2.3, 40.1%	.0, .0%	.0, .0%	.0, .0%	.0, .0%	2.3, 40.1%
Report:	1.0, 17.5%	.0, .0%	.0, .0%	.0, .0%	.0, .0%	.0, .0%	1.0, 17.5%
Conference:	.0, .0%	2.1, 36.5%	.0, .0%	.3, 5.8%	.0, .0%	.0, .0%	2.4, 42.4%
Total:	1.0, 17.5%	4.4, 76.6%	.0, .0%	.3, 5.8%	.0, .0%	.0, .0%	5.7, 100.0%
USC - 02							
Journal:	17.0, 32.5%	7.2, 13.8%	7.9, 15.1%	.3, .6%	.0, .0%	.0, .0%	32.5, 62.1%
Report:	3.0, 5.7%	6.0, 11.5%	5.1, 9.7%	1.0, 1.9%	.4, .8%	.4, .7%	15.8, 30.3%
Conference:	4.0, 7.7%	.0, .0%	.0, .0%	.0, .0%	.0, .0%	.0, .0%	4.0, 7.7%
Total:	24.0, 45.9%	13.2, 25.3%	13.0, 24.8%	1.3, 2.6%	.4, .8%	.4, .7%	52.3, 100.0%
USC - 05							
Journal:	.0, .0%	.9, 9.9%	.0, .0%	2.0, 21.7%	.0, .0%	.0, .0%	2.9, 31.7%
Report:	1.0, 10.9%	.5, 5.4%	.0, .0%	.0, .0%	.0, .0%	.0, .0%	1.5, 16.3%
Conference:	.0, .0%	4.3, 46.1%	.5, 5.4%	.0, .0%	.0, .0%	.0, .5%	4.8, 52.1%
Total:	1.0, 10.9%	5.7, 61.5%	.5, 5.4%	2.0, 21.7%	.0, .0%	.0, .5%	9.2, 100.0%
USC - 06							
Journal:	17.0, 38.0%	11.6, 26.0%	5.9, 13.1%	.0, .0%	.0, .0%	.1, .2%	34.6, 77.3%
Report:	1.0, 2.2%	.0, .0%	.0, .0%	.3, .6%	.0, .0%	.0, .0%	1.3, 2.8%
Conference:	.0, .0%	5.3, 11.7%	3.2, 7.2%	.0, .0%	.2, .4%	.2, .4%	8.9, 19.9%
Total:	18.0, 40.3%	16.8, 37.7%	9.1, 20.4%	.3, .6%	.2, .4%	.3, .7%	44.7, 100.0%
USC - 11							
Journal:	.0, .0%	4.6, 39.3%	3.0, 26.0%	.5, 4.6%	.3, 2.2%	.0, .0%	8.4, 72.0%
Report:	1.0, 8.6%	.0, .0%	.0, .0%	.0, .0%	.0, .0%	.0, .0%	1.0, 8.6%
Conference:	.0, .0%	1.3, 11.5%	.9, 7.9%	.0, .0%	.0, .0%	.0, .0%	2.3, 19.4%
Total:	1.0, 8.6%	5.9, 50.8%	3.9, 33.9%	.5, 4.6%	.3, 2.2%	.0, .0%	11.6, 100.0%
USC - 12							
Journal:	1.0, 9.0%	4.2, 37.5%	1.3, 12.1%	1.8, 16.1%	1.0, 8.6%	.6, 5.1%	9.8, 88.5%
Report:	.0, .0%	1.0, 9.0%	.0, .0%	.0, .0%	.0, .0%	.0, .0%	1.0, 9.0%
Conference:	.0, .0%	.2, 1.8%	.0, .0%	.0, .0%	.0, .0%	.1, .7%	.3, 2.5%
Total:	1.0, 9.0%	5.4, 48.4%	1.3, 12.1%	1.8, 16.1%	1.0, 8.6%	.6, 5.8%	11.1, 100.0%
USC - 08							
Journal:	6.0, 31.4%	1.1, 5.8%	4.6, 24.0%	.3, 1.7%	.5, 2.6%	.3, 1.6%	12.8, 67.2%
Report:	1.0, 5.2%	.0, .0%	.0, .0%	.0, .0%	.0, .0%	.0, .0%	1.0, 5.2%
Conference:	3.0, 15.7%	1.6, 8.3%	.7, 3.5%	.0, .0%	.0, .0%	.0, .0%	5.3, 27.5%
Total:	10.0, 52.4%	2.7, 14.1%	5.3, 27.5%	.3, 1.7%	.5, 2.6%	.3, 1.6%	19.1, 100.0%
USC - 04							
Journal:	5.0, 17.1%	6.8, 23.4%	8.0, 27.4%	1.0, 3.4%	.0, .0%	.4, 1.5%	21.3, 72.9%
Report:	.0, .0%	2.0, 7.0%	.5, 1.7%	.6, 2.0%	.4, 1.5%	.5, 1.7%	4.1, 14.0%
Conference:	3.0, 10.3%	.3, 1.1%	.5, 1.7%	.0, .0%	.0, .0%	.0, .0%	3.8, 13.1%
Total:	8.0, 27.4%	9.2, 31.5%	9.0, 30.8%	1.6, 5.4%	.4, 1.5%	.9, 3.2%	29.2, 100.0%
USC - 07							
Journal:	36.0, 25.9%	21.6, 15.5%	31.4, 22.6%	2.6, 1.9%	.3, .2%	.0, .0%	91.9, 66.0%
Report:	9.0, 6.5%	9.2, 6.6%	13.3, 9.5%	2.4, 1.7%	.4, .3%	.5, .4%	34.9, 25.1%
Conference:	7.0, 5.0%	1.8, 1.3%	3.3, 2.4%	.3, .2%	.0, .0%	.0, .0%	12.4, 8.9%
Total:	52.0, 37.4%	32.7, 23.5%	48.0, 34.5%	5.2, 3.7%	.7, .5%	.6, .4%	139.2, 100.0%
USC - 03							
Journal:	1.0, 4.7%	9.0, 42.2%	2.7, 12.5%	.9, 4.3%	.3, 1.2%	.0, .0%	13.8, 64.8%
Report:	3.0, 14.1%	.5, 2.3%	.0, .0%	.0, .0%	.0, .0%	.0, .0%	3.5, 16.4%
Conference:	2.0, 9.4%	1.5, 7.0%	.5, 2.3%	.0, .0%	.0, .0%	.0, .0%	4.0, 18.8%
Total:	6.0, 28.1%	11.0, 51.6%	3.2, 14.8%	.9, 4.3%	.3, 1.2%	.0, .0%	21.3, 100.0%
USC - 10							
Journal:	.0, .0%	2.2, 28.8%	.3, 4.4%	1.2, 15.5%	.0, .0%	.0, .0%	3.7, 48.7%
Report:	.0, .0%	.7, 8.8%	.0, .0%	.0, .0%	.0, .0%	.0, .0%	.7, 8.8%
Conference:	3.0, 39.8%	.2, 2.7%	.0, .0%	.0, .0%	.0, .0%	.0, .0%	3.2, 42.5%
Total:	3.0, 39.8%	3.0, 40.3%	.3, 4.4%	1.2, 15.5%	.0, .0%	.0, .0%	7.5, 100.0%

Table 3c - Distribution of Citations: Normal (Total) Count

Author	Single	1st	2nd	3rd	4th	≥ 5th	Total
USC - 01							
Journal:	84, 30.3%	110, 39.7%	12, 4.3%	2, .7%	0, .0%	0, .0%	208, 75.1%
Report:	17, 6.1%	15, 5.4%	0, .0%	0, .0%	0, .0%	0, .0%	32, 11.6%
Conference:	15, 5.4%	22, 7.9%	0, .0%	0, .0%	0, .0%	0, .0%	37, 13.4%
Total:	116, 41.9%	147, 53.1%	12, 4.3%	2, .7%	0, .0%	0, .0%	277, 100.0%
USC - 09							
Journal:	0, .0%	11, 35.5%	0, .0%	0, .0%	0, .0%	0, .0%	11, 35.5%
Report:	1, 3.2%	0, .0%	0, .0%	0, .0%	0, .0%	0, .0%	1, 3.2%
Conference:	0, .0%	18, 58.1%	0, .0%	1, 3.2%	0, .0%	0, .0%	19, 61.3%
Total:	1, 3.2%	29, 93.5%	0, .0%	1, 3.2%	0, .0%	0, .0%	31, 100.0%
USC - 02							
Journal:	88, 15.0%	116, 19.8%	109, 18.6%	6, 1.0%	0, .0%	0, .0%	319, 54.3%
Report:	14, 2.4%	99, 16.9%	111, 18.9%	10, 1.7%	14, 2.4%	4, .7%	252, 42.9%
Conference:	16, 2.7%	0, .0%	0, .0%	0, .0%	0, .0%	0, .0%	16, 2.7%
Total:	118, 20.1%	215, 36.6%	220, 37.5%	16, 2.7%	14, 2.4%	4, .7%	587, 100.0%
USC - 05							
Journal:	0, .0%	69, 45.4%	0, .0%	47, 30.9%	0, .0%	0, .0%	116, 76.3%
Report:	4, 2.6%	2, 1.3%	0, .0%	0, .0%	0, .0%	0, .0%	6, 3.9%
Conference:	0, .0%	17, 11.2%	2, 1.3%	0, .0%	0, .0%	11, 7.2%	30, 19.7%
Total:	4, 2.6%	88, 57.9%	2, 1.3%	47, 30.9%	0, .0%	11, 7.2%	152, 100.0%
USC - 06							
Journal:	108, 13.8%	431, 55.0%	99, 12.6%	0, .0%	0, .0%	93, 11.9%	731, 93.4%
Report:	7, .9%	0, .0%	0, .0%	1, .1%	0, .0%	0, .0%	8, 1.0%
Conference:	0, .0%	30, 3.8%	12, 1.5%	0, .0%	1, .1%	1, .1%	44, 5.6%
Total:	115, 14.7%	461, 58.9%	111, 14.2%	1, .1%	1, .1%	94, 12.0%	783, 100.0%
USC - 11							
Journal:	0, .0%	165, 36.9%	117, 26.2%	70, 15.7%	4, .9%	0, .0%	356, 79.6%
Report:	10, 2.2%	0, .0%	0, .0%	0, .0%	0, .0%	0, .0%	10, 2.2%
Conference:	0, .0%	6, 1.3%	75, 16.8%	0, .0%	0, .0%	0, .0%	81, 18.1%
Total:	10, 2.2%	171, 38.3%	192, 43.0%	70, 15.7%	4, .9%	0, .0%	447, 100.0%
USC - 12							
Journal:	1, .3%	190, 49.1%	110, 28.4%	15, 3.9%	53, 13.7%	13, 3.4%	382, 98.7%
Report:	0, .0%	2, .5%	0, .0%	0, .0%	0, .0%	0, .0%	2, .5%
Conference:	0, .0%	2, .5%	0, .0%	0, .0%	0, .0%	1, .3%	3, .8%
Total:	1, .3%	194, 50.1%	110, 28.4%	15, 3.9%	53, 13.7%	14, 3.6%	387, 100.0%
USC - 08							
Journal:	69, 26.8%	28, 10.9%	88, 34.2%	3, 1.2%	13, 5.1%	26, 10.1%	227, 88.3%
Report:	10, 3.9%	0, .0%	0, .0%	0, .0%	0, .0%	0, .0%	10, 3.9%
Conference:	6, 2.3%	12, 4.7%	2, .8%	0, .0%	0, .0%	0, .0%	20, 7.8%
Total:	85, 33.1%	40, 15.6%	90, 35.0%	3, 1.2%	13, 5.1%	26, 10.1%	257, 100.0%
USC - 04							
Journal:	21, 9.9%	55, 25.9%	71, 33.5%	5, 2.4%	0, .0%	17, 8.0%	169, 79.7%
Report:	0, .0%	12, 5.7%	2, .9%	8, 3.8%	4, 1.9%	8, 3.8%	34, 16.0%
Conference:	5, 2.4%	3, 1.4%	1, .5%	0, .0%	0, .0%	0, .0%	9, 4.2%
Total:	26, 12.3%	70, 33.0%	74, 34.9%	13, 6.1%	4, 1.9%	25, 11.8%	212, 100.0%
USC - 07							
Journal:	616, 28.5%	568, 26.3%	487, 22.5%	29, 1.3%	11, .5%	35, 1.6%	1746, 80.8%
Report:	31, 1.4%	115, 5.3%	116, 5.4%	91, 4.2%	7, .3%	12, .6%	372, 17.2%
Conference:	13, .6%	16, .7%	12, .6%	2, .1%	0, .0%	0, .0%	43, 2.0%
Total:	660, 30.5%	699, 32.3%	615, 28.5%	122, 5.6%	18, .8%	47, 2.2%	2161, 100.0%
USC - 03							
Journal:	64, 9.0%	469, 66.1%	82, 11.5%	27, 3.8%	9, 1.3%	0, .0%	651, 91.7%
Report:	48, 6.8%	2, .3%	0, .0%	0, .0%	0, .0%	0, .0%	50, 7.0%
Conference:	2, .3%	6, .8%	1, .1%	0, .0%	0, .0%	0, .0%	9, 1.3%
Total:	114, 16.1%	477, 67.2%	83, 11.7%	27, 3.8%	9, 1.3%	0, .0%	710, 100.0%
USC - 10							
Journal:	0, .0%	23, 21.9%	1, 1.0%	73, 69.5%	0, .0%	0, .0%	97, 92.4%
Report:	0, .0%	3, 2.9%	0, .0%	0, .0%	0, .0%	0, .0%	3, 2.9%
Conference:	3, 2.9%	2, 1.9%	0, .0%	0, .0%	0, .0%	0, .0%	5, 4.8%
Total:	3, 2.9%	28, 26.7%	1, 1.0%	73, 69.5%	0, .0%	0, .0%	105, 100.0%

Table 3d - Distribution of Citations: Fractional (per-author) Count

Author	Single	1st	2nd	3rd	4th	≥ 5th	Total
USC - 01							
Journal:	84.0, 44.2%	54.5, 28.7%	2.1, 1.1%	.7, .4%	.0, .0%	.0, .0%	141.3, 74.3%
Report:	17.0, 8.9%	7.0, 3.7%	.0, .0%	.0, .0%	.0, .0%	.0, .0%	24.0, 12.6%
Conference:	15.0, 7.9%	9.7, 5.1%	.0, .0%	.0, .0%	.0, .0%	.0, .0%	24.7, 13.0%
Total:	116.0, 61.1%	71.2, 37.5%	2.1, 1.1%	.7, .4%	.0, .0%	.0, .0%	190.0, 100.0%
USC - 09							
Journal:	.0, .0%	3.0, 32.4%	.0, .0%	.0, .0%	.0, .0%	.0, .0%	3.0, 32.4%
Report:	1.0, 10.7%	.0, .0%	.0, .0%	.0, .0%	.0, .0%	.0, .0%	1.0, 10.7%
Conference:	.0, .0%	5.0, 53.4%	.0, .0%	.3, 3.6%	.0, .0%	.0, .0%	5.3, 56.9%
Total:	1.0, 10.7%	8.0, 85.8%	.0, .0%	.3, 3.6%	.0, .0%	.0, .0%	9.4, 100.0%
USC - 02							
Journal:	88.0, 26.3%	53.2, 15.9%	53.5, 16.0%	2.0, .6%	.0, .0%	.0, .0%	196.7, 58.8%
Report:	14.0, 4.2%	49.5, 14.8%	51.3, 15.3%	3.3, 1.0%	2.8, .8%	.7, .2%	121.6, 36.4%
Conference:	16.0, 4.8%	.0, .0%	.0, .0%	.0, .0%	.0, .0%	.0, .0%	16.0, 4.8%
Total:	118.0, 35.3%	102.7, 30.7%	104.8, 31.3%	5.3, 1.6%	2.8, .8%	.7, .2%	334.3, 100.0%
USC - 05							
Journal:	.0, .0%	21.7, 42.8%	.0, .0%	15.7, 31.0%	.0, .0%	.0, .0%	37.3, 73.8%
Report:	4.0, 7.9%	1.0, 2.0%	.0, .0%	.0, .0%	.0, .0%	.0, .0%	5.0, 9.9%
Conference:	.0, .0%	6.8, 13.3%	1.0, 2.0%	.0, .0%	.0, .0%	.5, 1.0%	8.3, 16.3%
Total:	4.0, 7.9%	29.4, 58.1%	1.0, 2.0%	15.7, 31.0%	.0, .0%	.5, 1.0%	50.6, 100.0%
USC - 06							
Journal:	108.0, 31.4%	168.4, 48.9%	36.3, 10.5%	.0, .0%	.0, .0%	9.3, 2.7%	322.0, 93.5%
Report:	7.0, 2.0%	.0, .0%	.0, .0%	.3, .1%	.0, .0%	.0, .0%	7.3, 2.1%
Conference:	.0, .0%	10.5, 3.0%	4.2, 1.2%	.0, .0%	.2, .1%	.2, .1%	15.1, 4.4%
Total:	115.0, 33.4%	178.9, 51.9%	40.5, 11.8%	.3, .1%	.2, .1%	9.5, 2.8%	344.4, 100.0%
USC - 11							
Journal:	.0, .0%	61.1, 40.3%	37.7, 24.9%	14.8, 9.8%	1.0, .7%	.0, .0%	114.6, 75.6%
Report:	10.0, 6.6%	.0, .0%	.0, .0%	.0, .0%	.0, .0%	.0, .0%	10.0, 6.6%
Conference:	.0, .0%	2.1, 1.4%	24.9, 16.4%	.0, .0%	.0, .0%	.0, .0%	27.0, 17.8%
Total:	10.0, 6.6%	63.2, 41.7%	62.6, 41.3%	14.8, 9.8%	1.0, .7%	.0, .0%	151.6, 100.0%
USC - 12							
Journal:	1.0, 1.1%	52.3, 54.9%	23.6, 24.8%	4.8, 5.0%	9.6, 10.0%	2.5, 2.6%	93.6, 98.4%
Report:	.0, .0%	1.0, 1.1%	.0, .0%	.0, .0%	.0, .0%	.0, .0%	1.0, 1.1%
Conference:	.0, .0%	.4, .4%	.0, .0%	.0, .0%	.0, .0%	.1, .1%	.5, .5%
Total:	1.0, 1.1%	53.7, 56.4%	23.6, 24.8%	4.8, 5.0%	9.6, 10.0%	2.5, 2.7%	95.1, 100.0%
USC - 08							
Journal:	69.0, 47.3%	6.1, 4.2%	39.6, 27.1%	1.0, .7%	3.3, 2.2%	4.8, 3.3%	123.7, 84.8%
Report:	10.0, 6.9%	.0, .0%	.0, .0%	.0, .0%	.0, .0%	.0, .0%	10.0, 6.9%
Conference:	6.0, 4.1%	5.6, 3.8%	.7, .5%	.0, .0%	.0, .0%	.0, .0%	12.3, 8.4%
Total:	85.0, 58.2%	11.7, 8.0%	40.3, 27.6%	1.0, .7%	3.3, 2.2%	4.8, 3.3%	146.0, 100.0%
USC - 04							
Journal:	21.0, 21.7%	27.2, 28.0%	30.7, 31.7%	1.7, 1.7%	.0, .0%	.9, .9%	81.4, 84.0%
Report:	.0, .0%	3.7, 3.9%	1.0, 1.0%	2.1, 2.2%	.9, 1.0%	1.2, 1.3%	9.0, 9.3%
Conference:	5.0, 5.2%	1.0, 1.0%	.5, .5%	.0, .0%	.0, .0%	.0, .0%	6.5, 6.7%
Total:	26.0, 26.8%	31.9, 32.9%	32.2, 33.2%	3.8, 3.9%	.9, 1.0%	2.1, 2.2%	96.9, 100.0%
USC - 07							
Journal:	616.0, 46.3%	275.0, 20.7%	236.0, 17.7%	9.6, .7%	2.8, .2%	1.1, .1%	1140.4, 85.7%
Report:	31.0, 2.3%	55.7, 4.2%	47.5, 3.6%	24.4, 1.8%	1.7, .1%	2.2, .2%	162.5, 12.2%
Conference:	13.0, 1.0%	7.8, .6%	5.8, .4%	.5, .0%	.0, .0%	.0, .0%	27.2, 2.0%
Total:	660.0, 49.6%	338.5, 25.4%	289.3, 21.8%	34.5, 2.6%	4.4, .3%	3.4, .3%	1330.1, 100.0%
USC - 03							
Journal:	64.0, 16.2%	231.2, 58.6%	34.7, 8.8%	8.0, 2.0%	2.3, .6%	.0, .0%	340.1, 86.2%
Report:	48.0, 12.2%	1.0, .3%	.0, .0%	.0, .0%	.0, .0%	.0, .0%	49.0, 12.4%
Conference:	2.0, .5%	3.0, .8%	.5, .1%	.0, .0%	.0, .0%	.0, .0%	5.5, 1.4%
Total:	114.0, 28.9%	235.2, 59.6%	35.2, 8.9%	8.0, 2.0%	2.3, .6%	.0, .0%	394.6, 100.0%
USC - 10							
Journal:	.0, .0%	10.7, 28.8%	.3, .9%	21.7, 58.5%	.0, .0%	.0, .0%	32.7, 88.1%
Report:	.0, .0%	1.0, 2.7%	.0, .0%	.0, .0%	.0, .0%	.0, .0%	1.0, 2.7%
Conference:	3.0, 8.1%	.4, 1.1%	.0, .0%	.0, .0%	.0, .0%	.0, .0%	3.4, 9.2%
Total:	3.0, 8.1%	12.1, 32.6%	.3, .9%	21.7, 58.5%	.0, .0%	.0, .0%	37.1, 100.0%

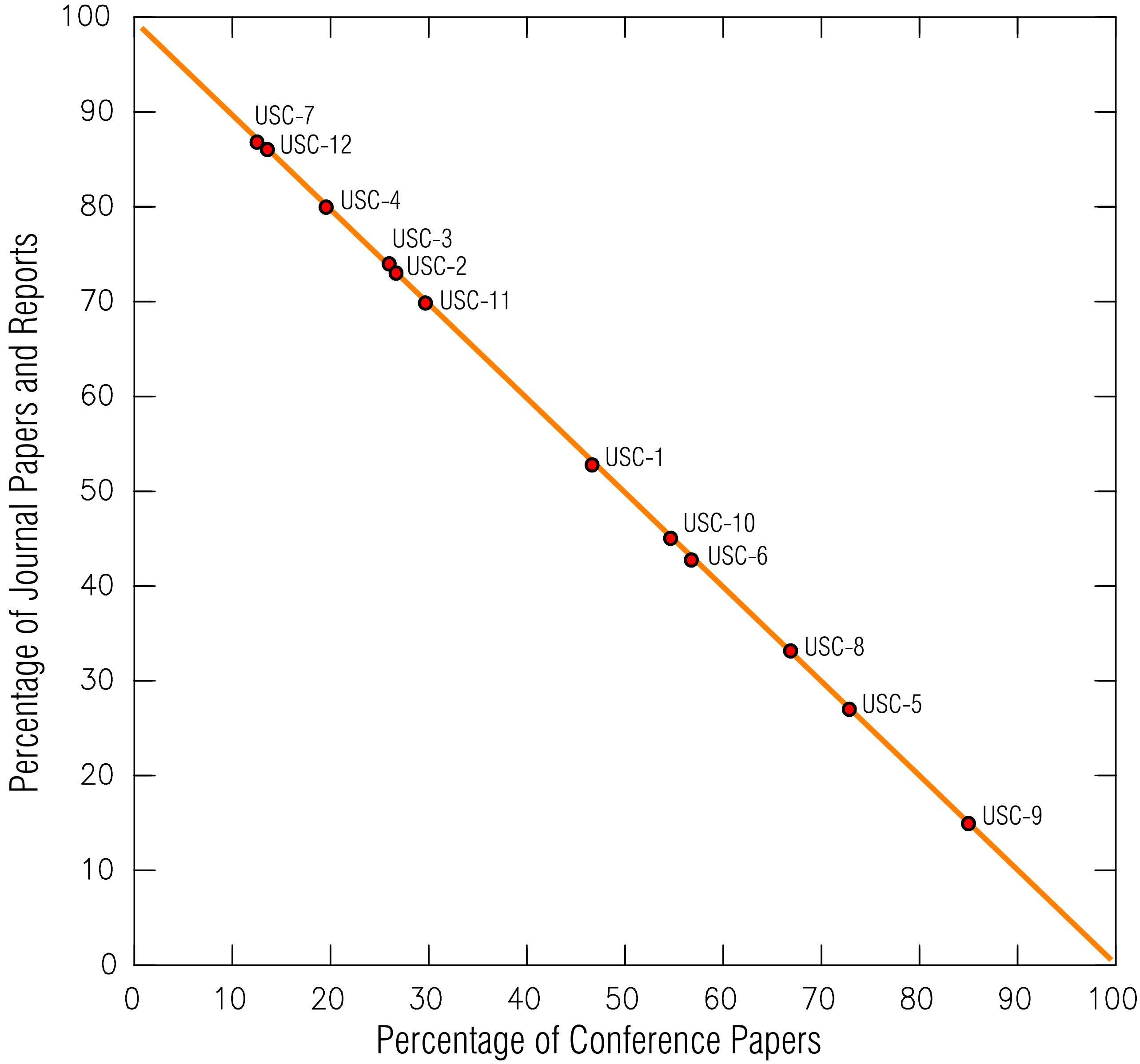

Fig. 12a: Percentage of published journal papers and reports versus percentage of conference papers.

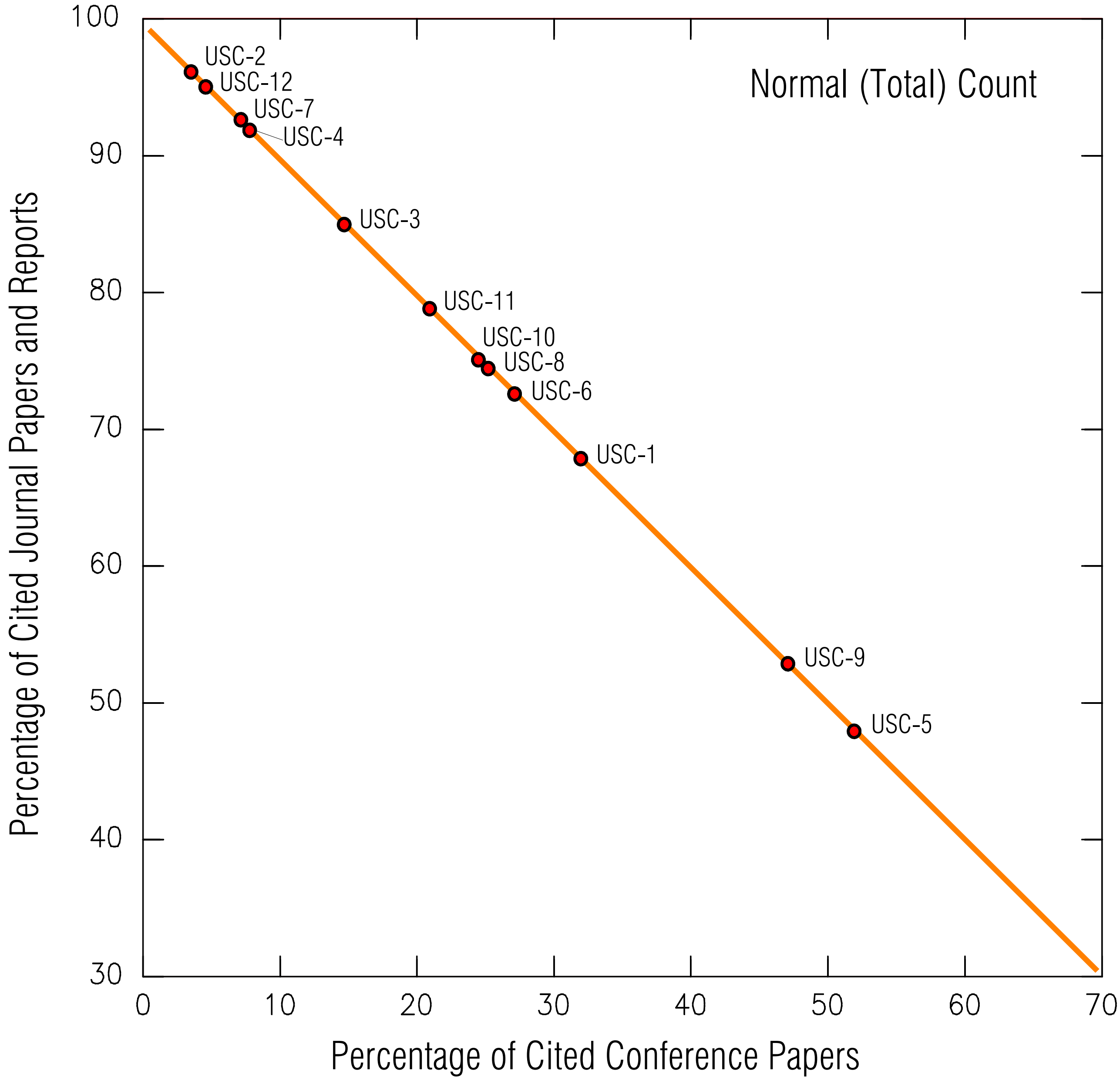

Fig. 12b: Percentage of cited journal papers and reports versus percentage of cited conference papers, for normal (total) count.

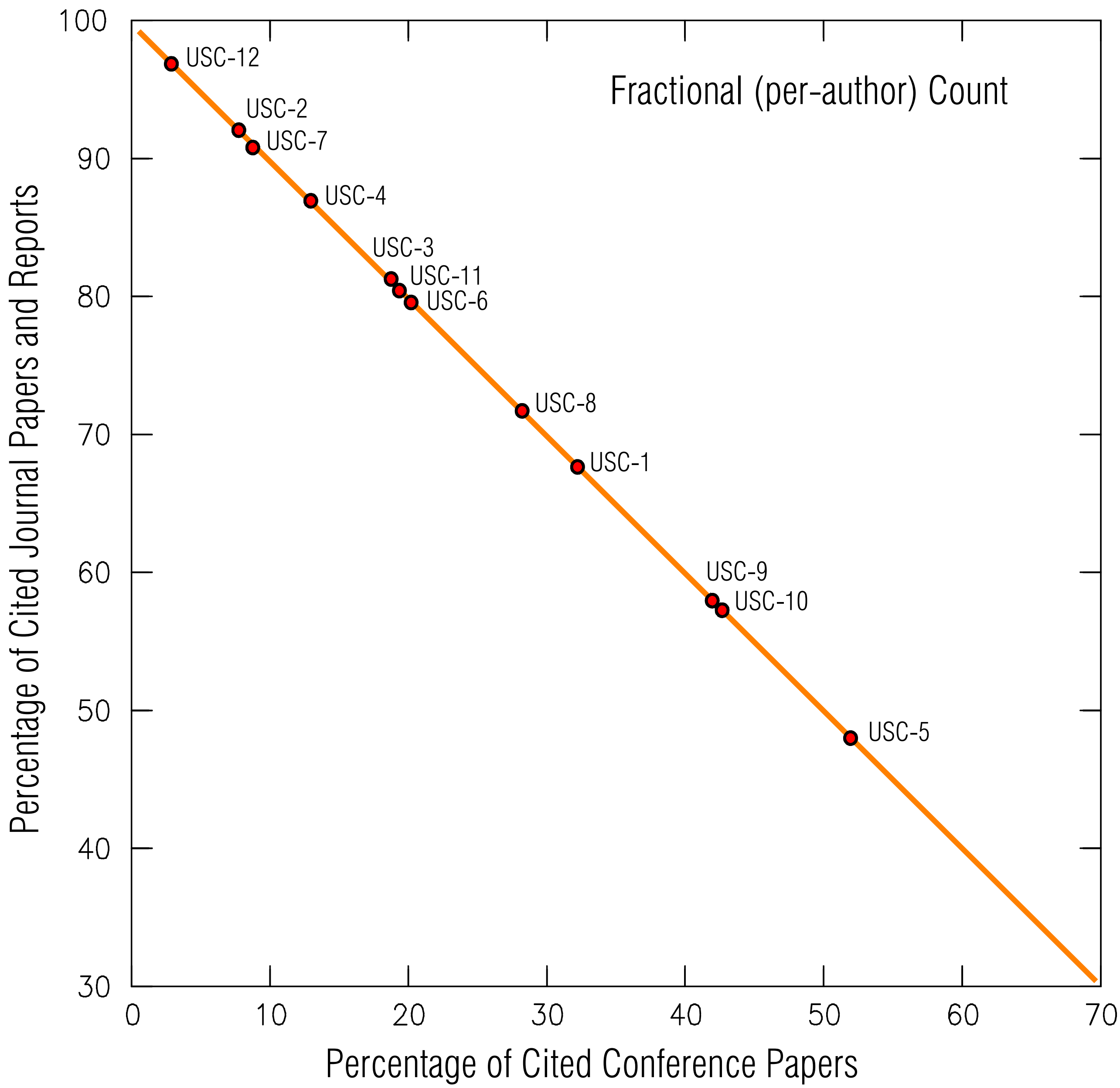

Fig. 12c: Percentage of cited journal papers and reports versus percentage of cited conference papers, for fractional (per-author) count.

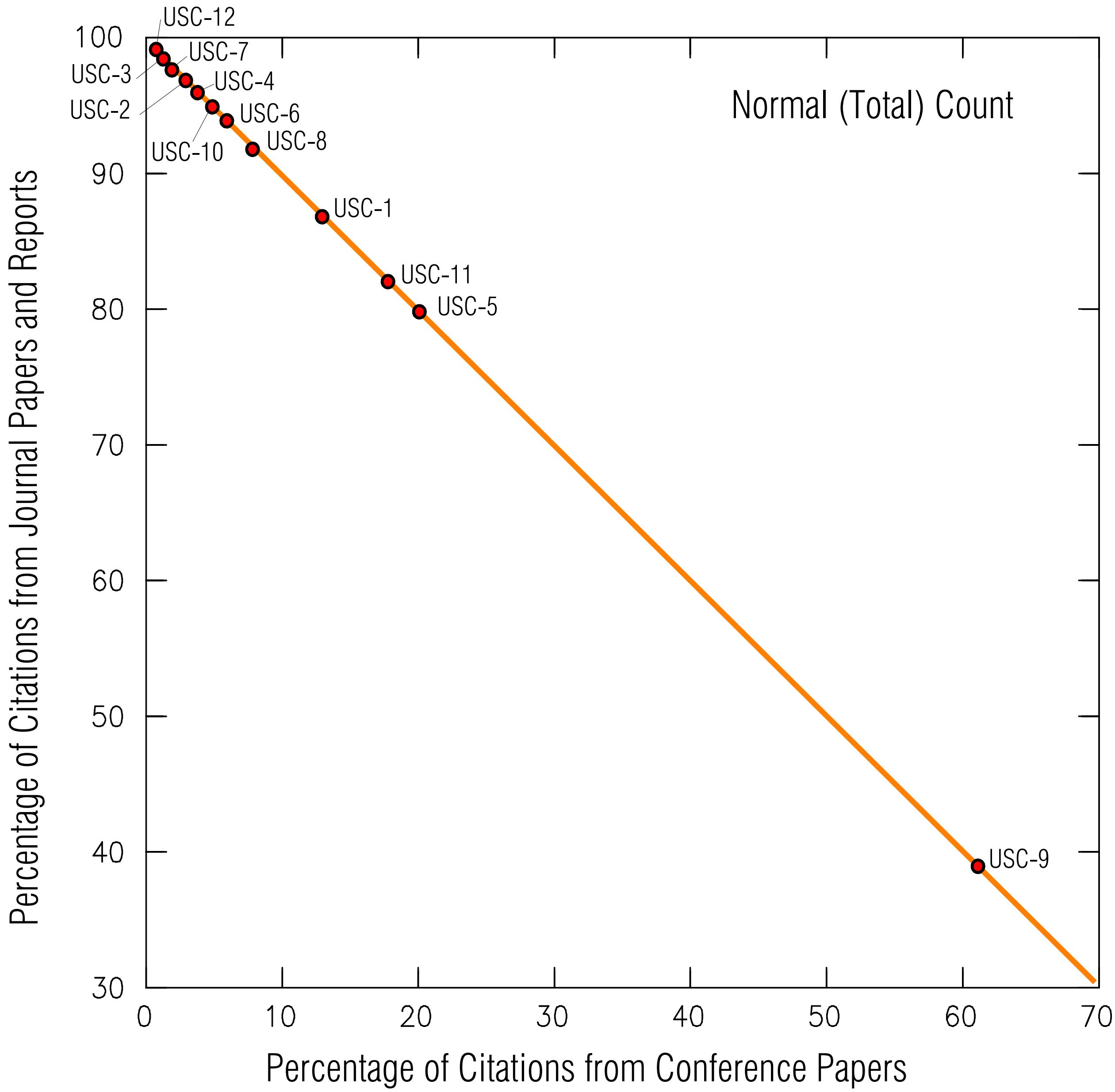

Fig. 12d: Percentage of citations from journal papers and reports versus percentage of citations from conference papers, for normal (total) count.

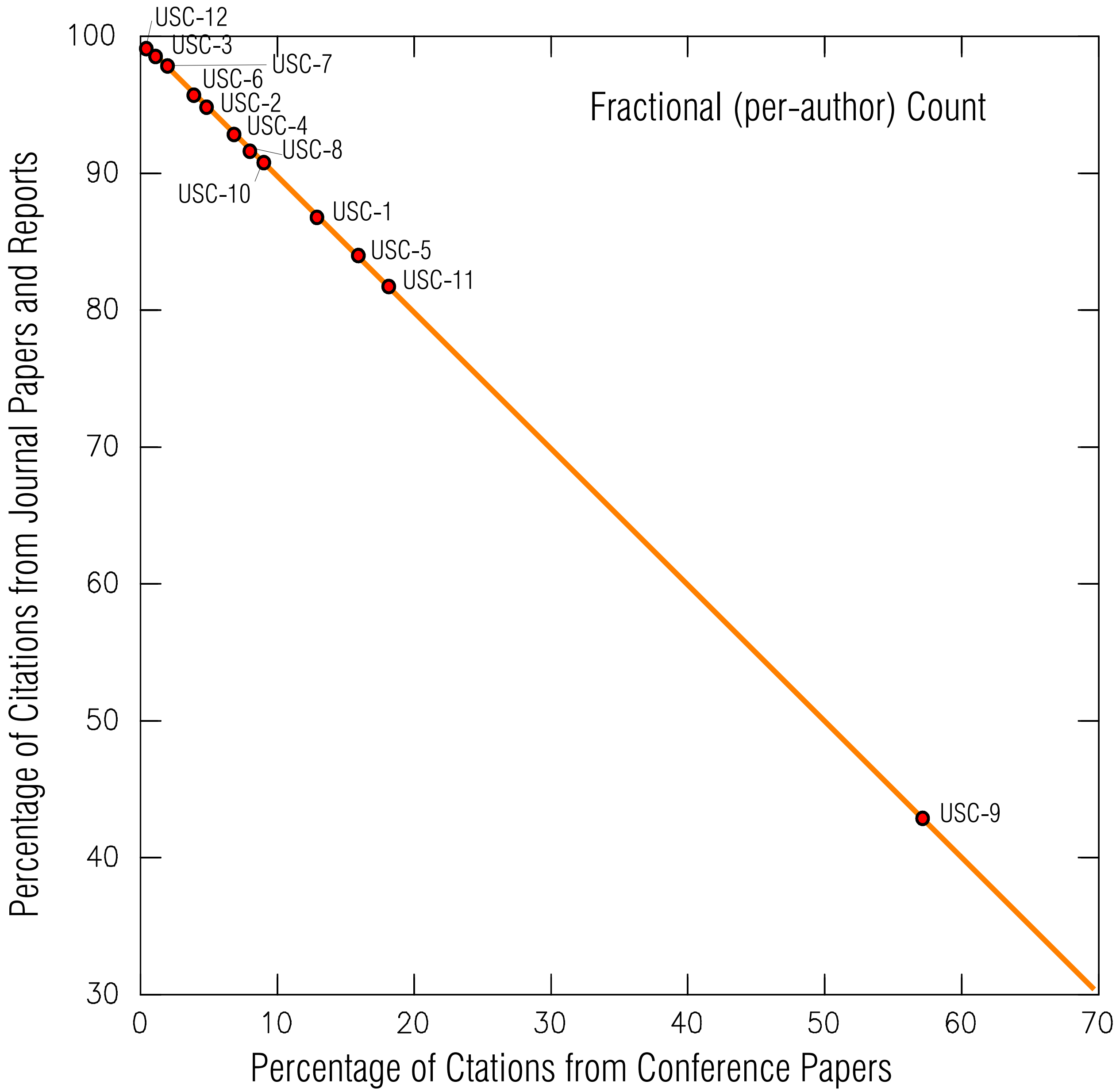

Fig. 12e: Percentage of citations from journal papers and reports versus percentage of citations from conference papers, for fractional (per-author) count.

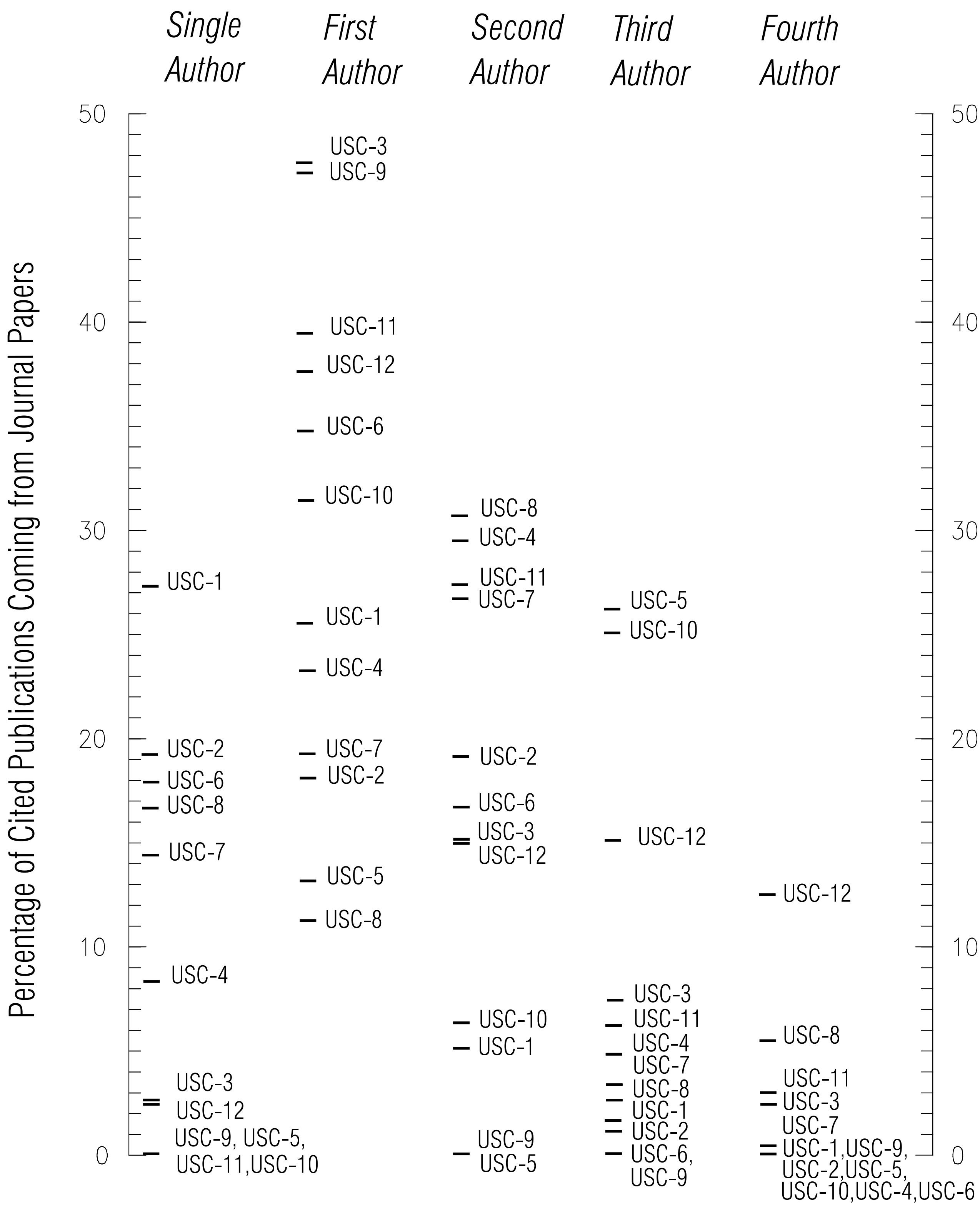

Fig. 13a: Distribution of cited papers for journals, when the writer is a single author, first author, second author, third author, and fourth author.

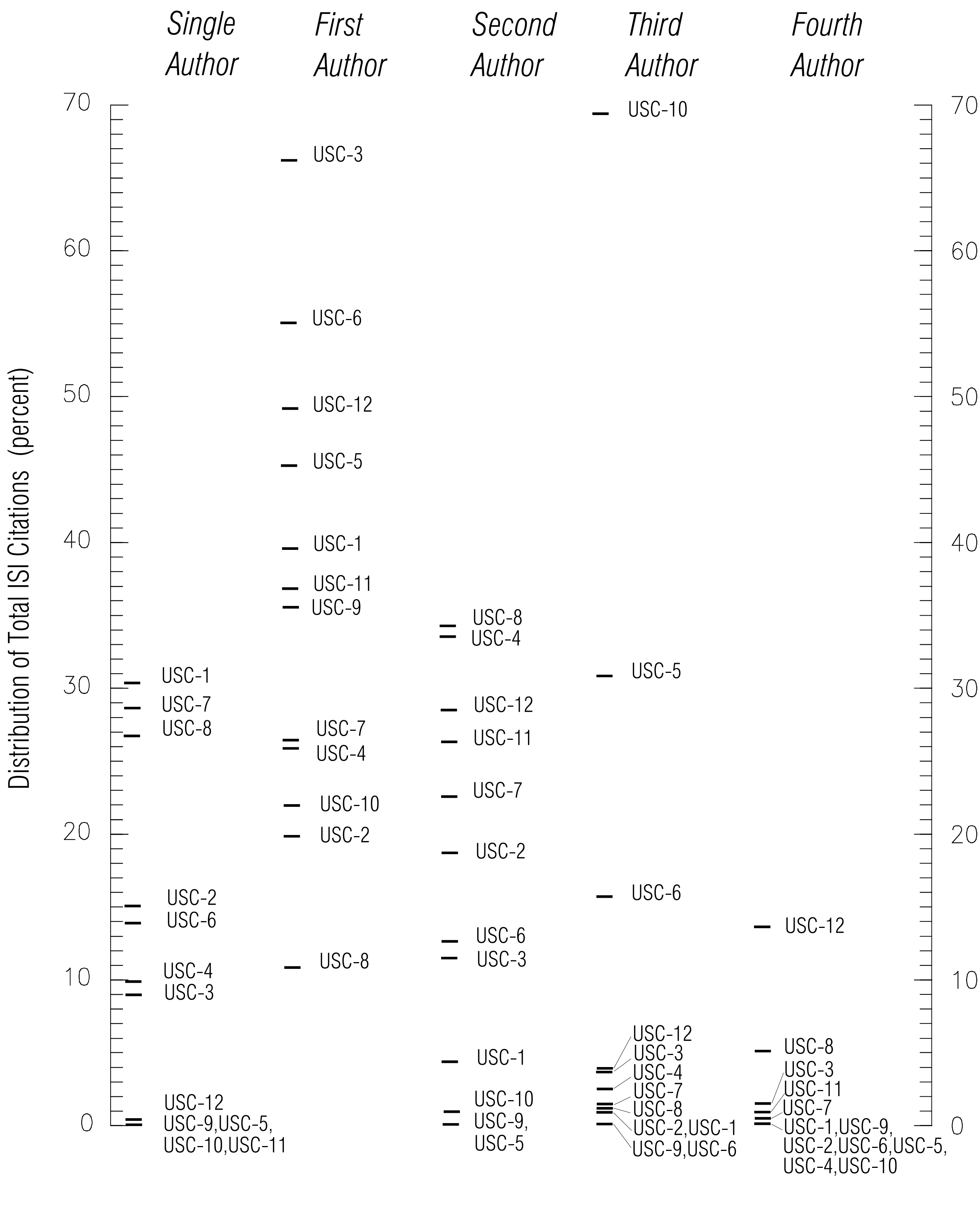

Fig. 13b: Distribution of total number of ISI citations among journals papers, when the writer is a single author, first author, second author, third author, and fourth author, for normal (total) count.

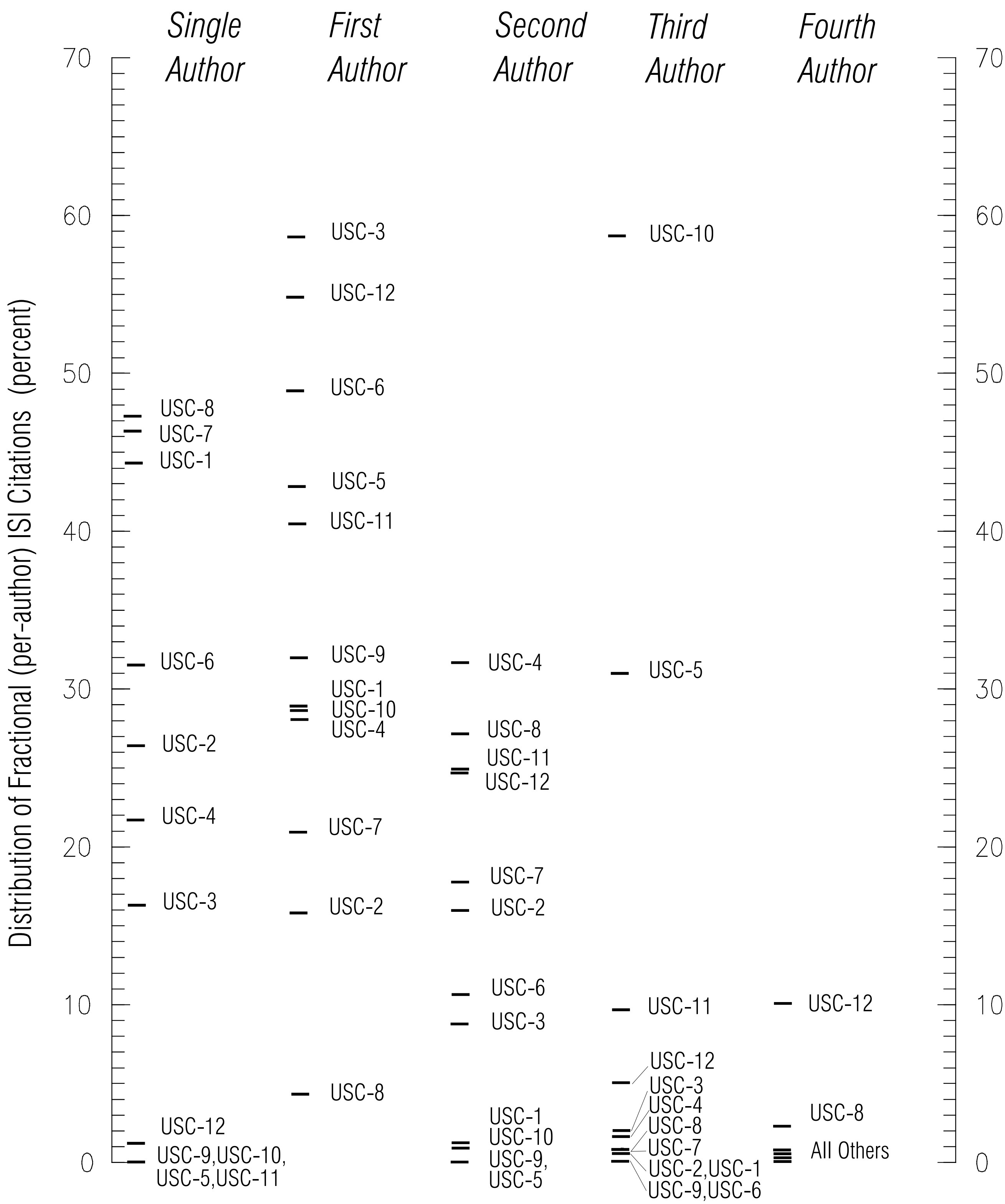

Fig. 13c: Distribution of fractional (per-author) number of citations among journals papers when the writer is a single author, first author, second author, third author, and fourth author.

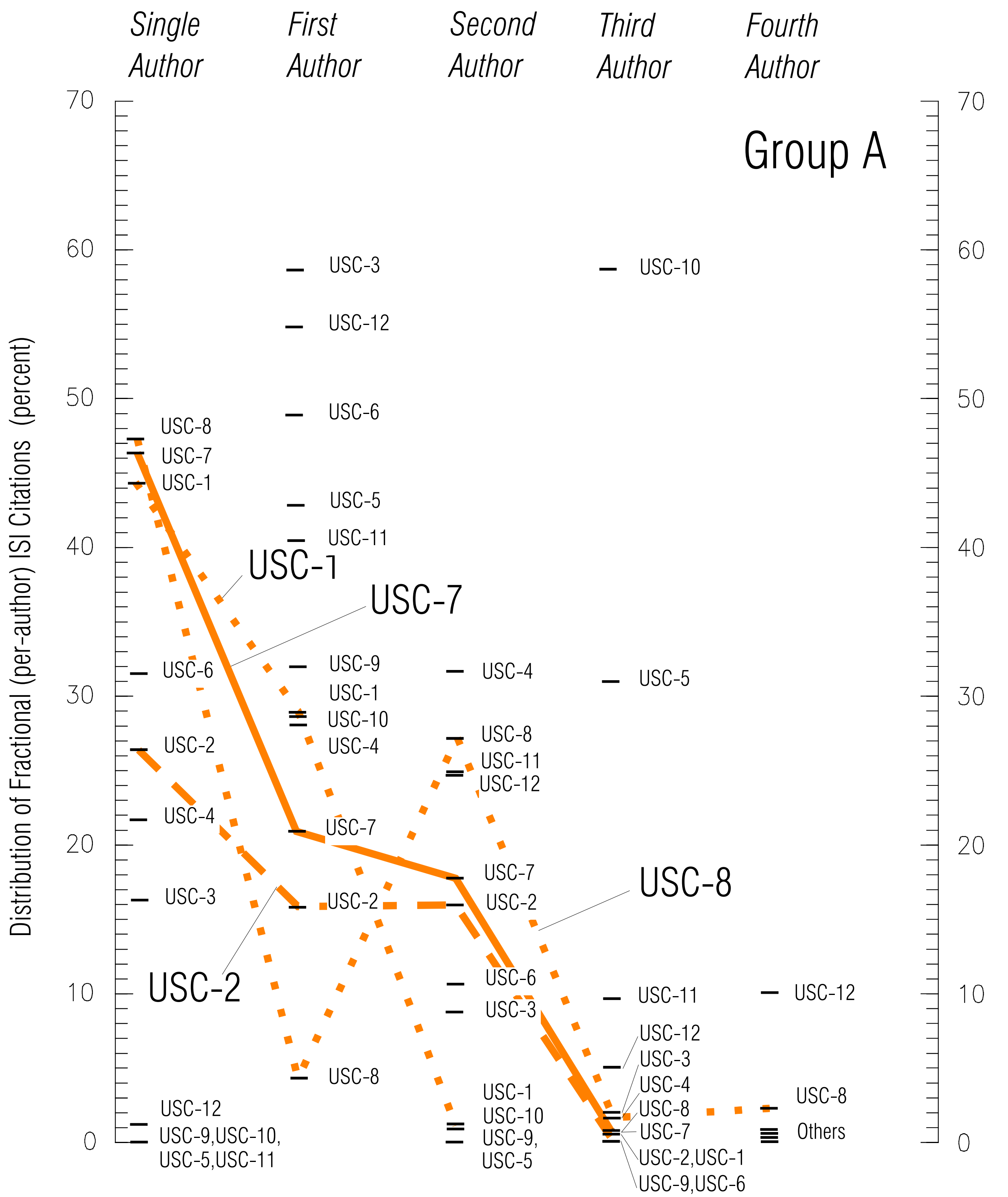

Fig. 14a: Group A (USC-1, USC-2, USC-8, and USC-7). Distribution of fractional (per-author) number of citations among journal papers when the writer is a single author, first author, second author, third author, and fourth author.

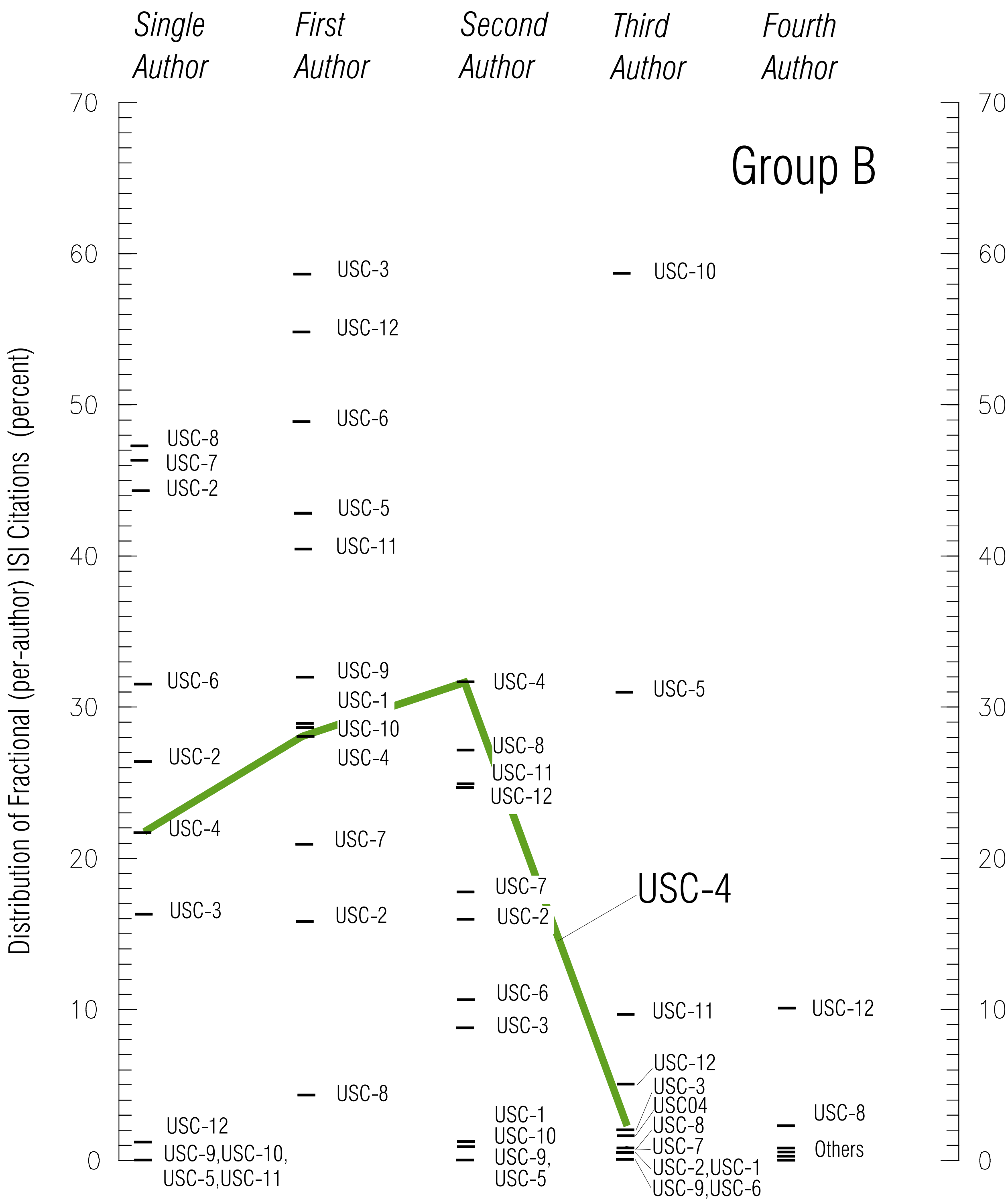

Fig. 14b: Group B (USC-4). Distribution of fractional (per-author) number of citations among journal papers when the writer is a single author, first author, second author, third author, and fourth author.

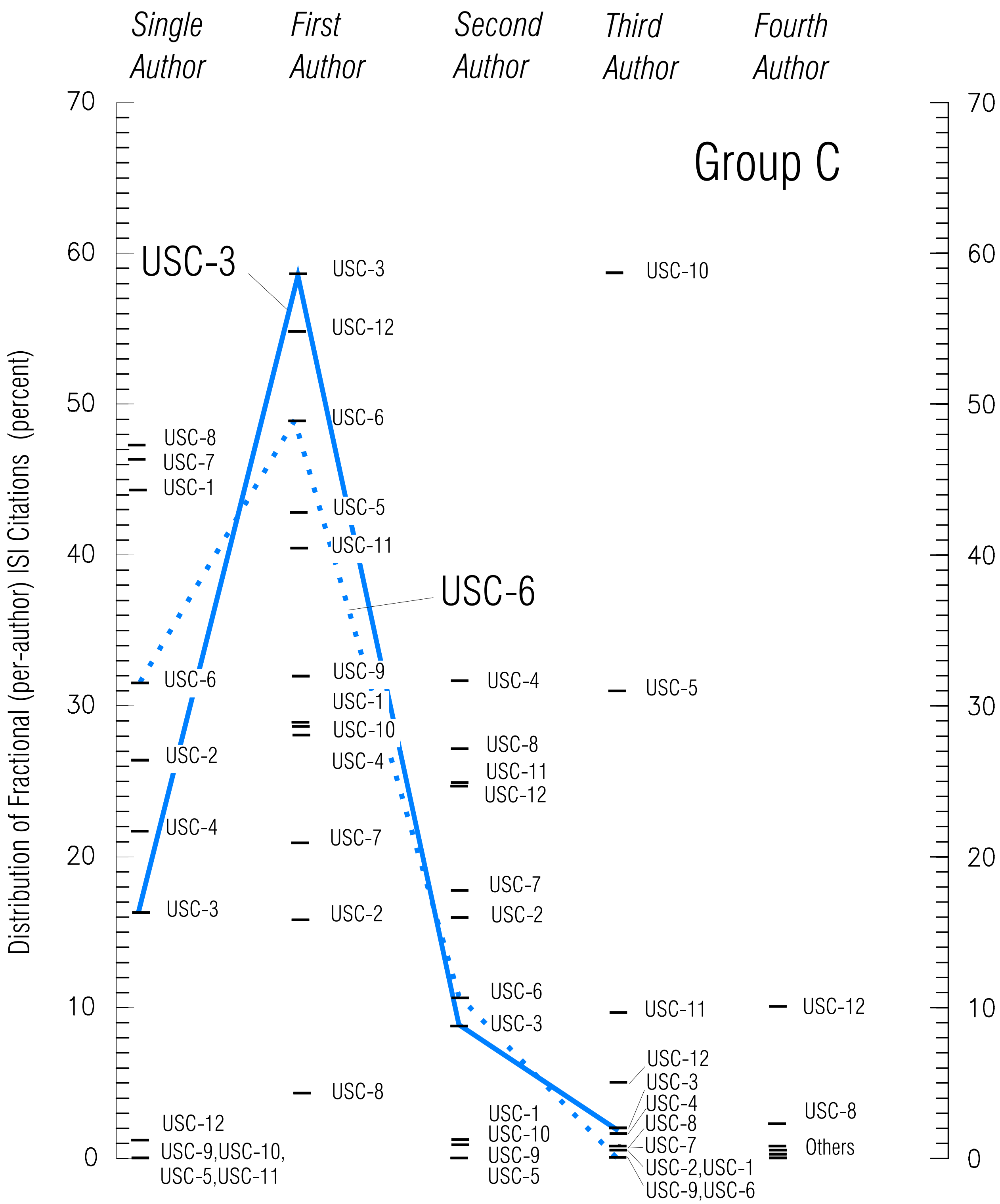

Fig. 14c: Group C (USC-6 and USC-3). Distribution of fractional (per-author) number of citations among journal papers when the writer is a single author, first author, second author, third author, and fourth author.

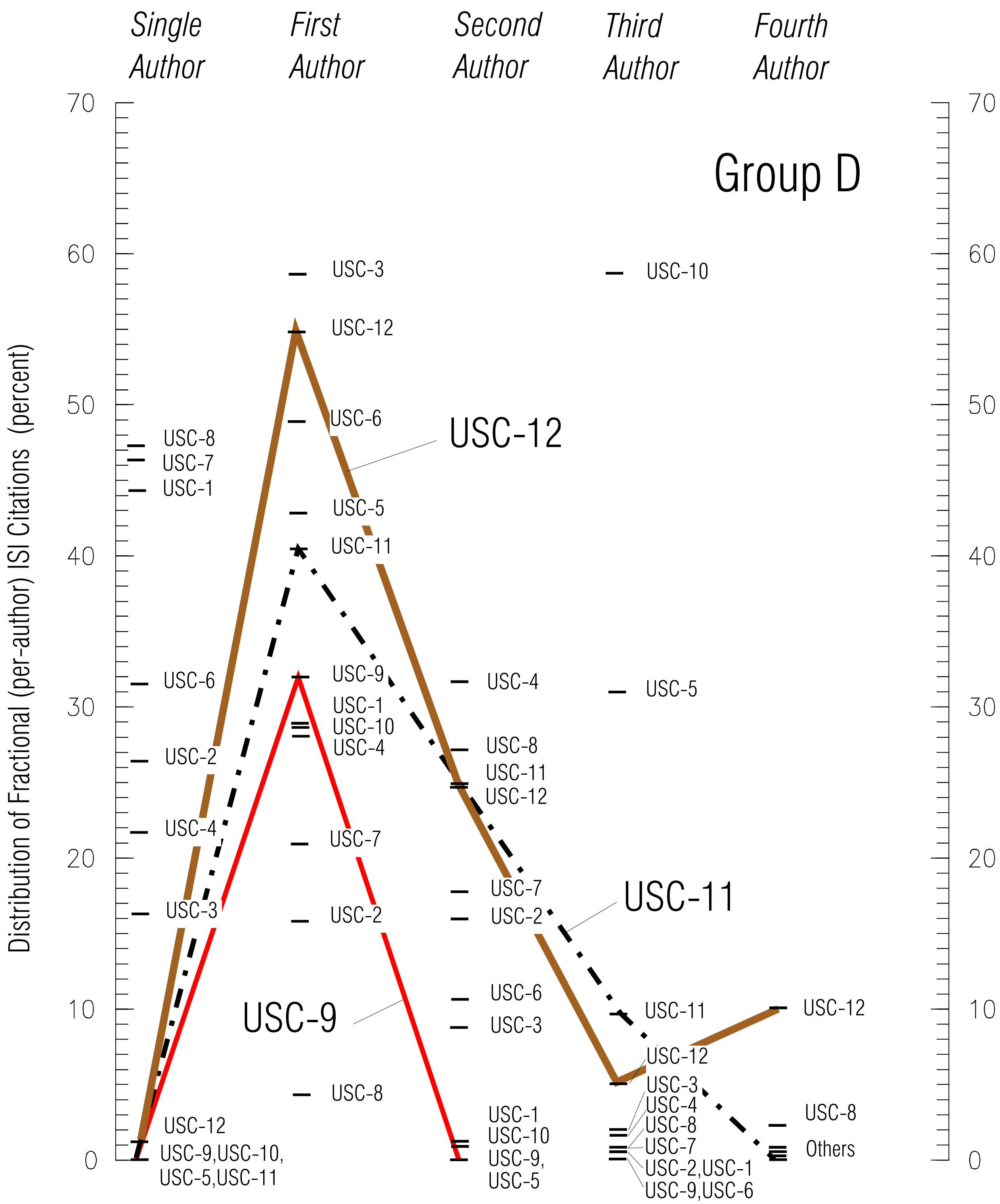

Fig. 14d: Group D (USC-9, USC-11, and USC-12). Distribution of fractional (per-author) number of citations among journal papers when the writer is a single author, first author, second author, third author, and fourth author.

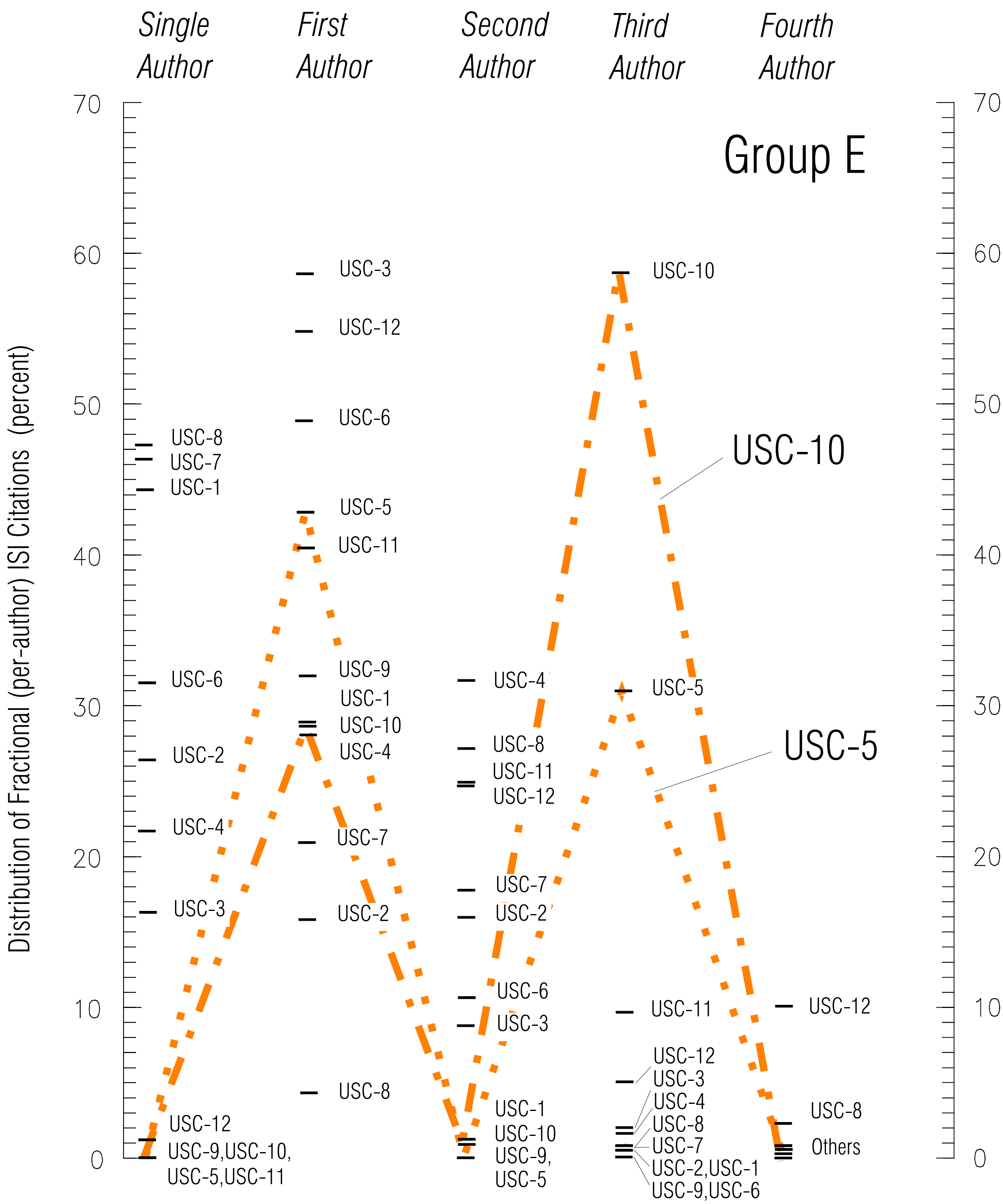

Fig. 14e: Group E (USC-5 and USC-10). Distribution of fractional (per-author) number of citations among journal papers when the writer is a single author, first author, second author, third author, and fourth author.

Based on the trends in Fig. 13c, the faculty members in our sample can be grouped into six groups, A through E, as shown in Figures 14a through 14e. The faculty in group A (Fig. 14a) receive most of their citations from their single-author journal papers. USC-1 is an example of a researcher writing alone or as a first author only, while USC-8 participates in many multi-author papers. The researchers in group B receive similar percentages of citations from the journal papers they wrote as a single author, first author, and second author, and the faculty in group C receive most of their citations from journal papers of which they are the first authors. Further perusal of the curricula vitae of the faculty in group C shows a prevalence of two-author papers, often with the same, usually more senior co-author. The faculty in group D also receive most citations from first authorship, but they have essentially no single-author cited papers. The characteristics of this group can be viewed as transitional, from strong dependence on a senior co-author (USC-9), to cooperative effort with a group of independent investigators (USC-12 and USC-11). Group E (Fig. 14e) is characterized by no citations from single-author papers, a moderate number of citations from first authorship, and large number of citations from third authorship. This suggests strong dependence upon the first two co-authors and a minor role in the formulation of the research ideas, their execution, and final writing.

Figure 15 shows the number of conference papers per year for the sample of twelve faculty. USC-9, with 85 percent of his publications being published in conference proceedings, writes about 10 conference papers per year. He is followed by USC-10 with 6^+ and by USC-6 with 4^+ conference papers per year.

We have already shown that, for the faculty in our sample, the number of citations from conference papers is small relative to those from journal papers and reports (see Fig. 3). Figure 16 shows a plot of the percentage of cited conference papers versus the percentage of publications that are conference papers (see Table 2a) for each faculty. It can be seen that for those who write more conference papers than journal papers and reports, the probability of a conference paper being cited at all is only 0 to 20%. USC-10 has less than 4% of his conference papers cited, while USC-12 has no such citations (note that USC-12 has only 13 of his 96 publications (14%) as conference papers, while USC-10 has 76 of his 139 publication (55 percent) as conference papers). USC-1, with 46% of his publications being conference papers, has a relatively high citation rate from conference papers—about 36%.

The above suggests that the time and effort taken by writing too many conference papers (say, more than two to three per year, see Fig. 15) is counter-productive, especially for younger researchers (USC-9, USC-10). As shown in Figures 3 and 17, the percentage of cited contributions increases, and is well correlated with, the production of journal papers and reports. The citations of journal papers in the ISI database come from carefully selected leading journals in their respective disciplines. Papers in these journals are systematically reviewed before being accepted for publication. Good research reports frequently include complete Ph.D. dissertations and

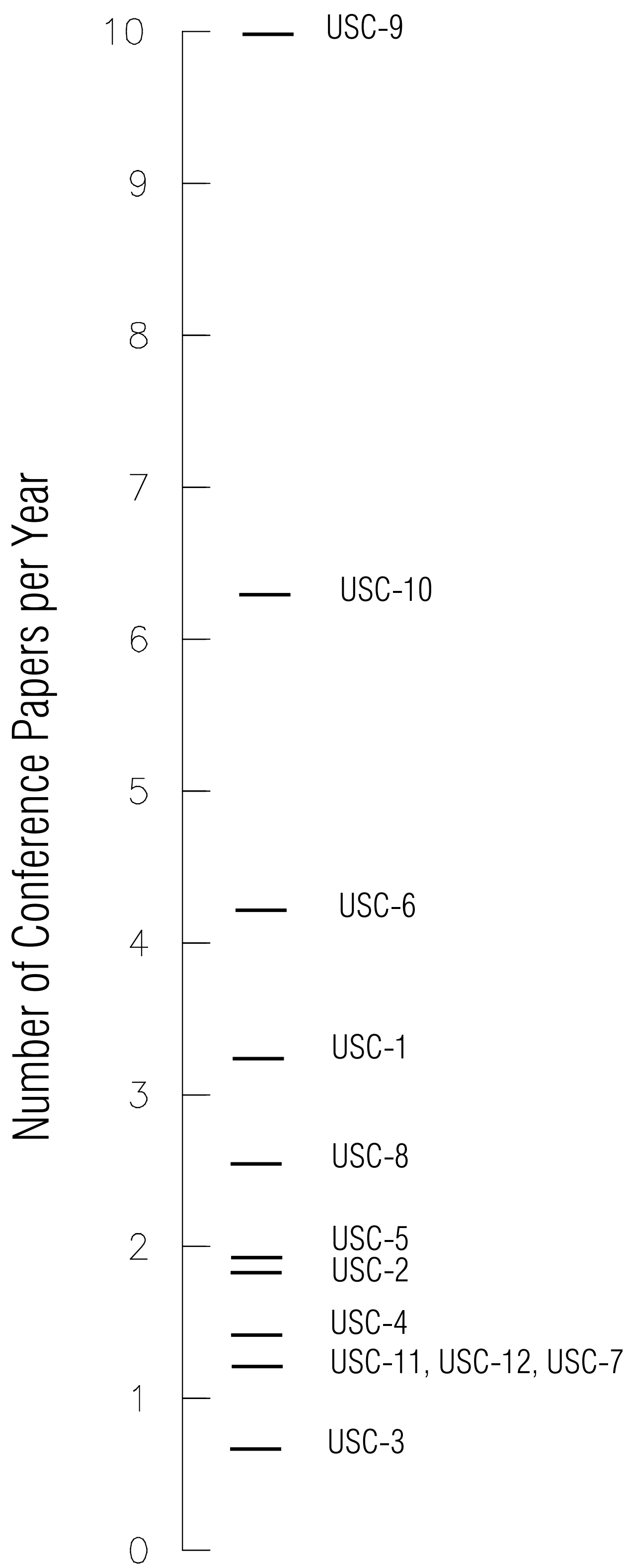

Fig. 15: Average number of conference papers per year for the sample of twelve USC faculty members.

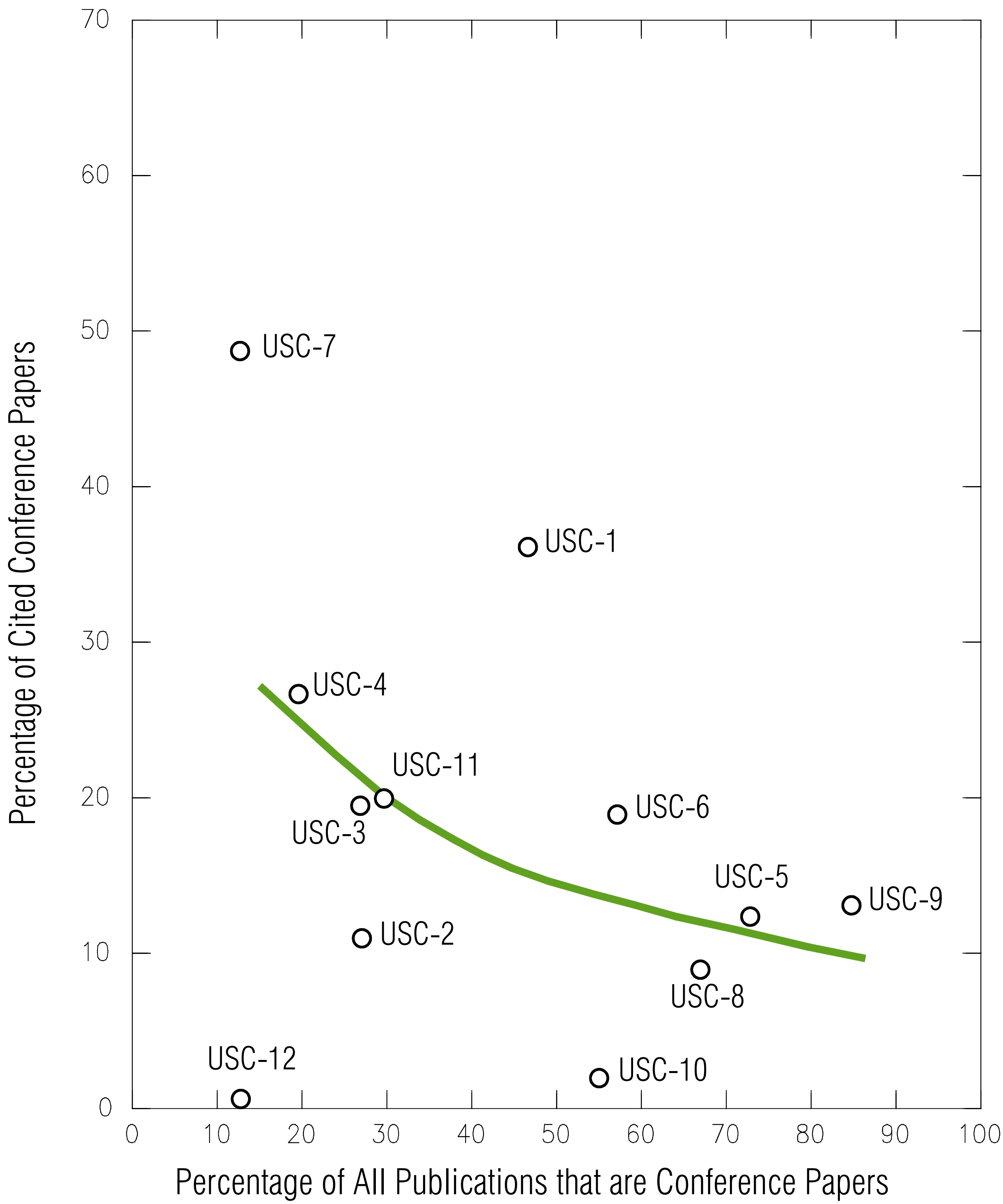

Fig. 16: Percentage of cited conference papers versus the percentage of all publications that are conference papers.

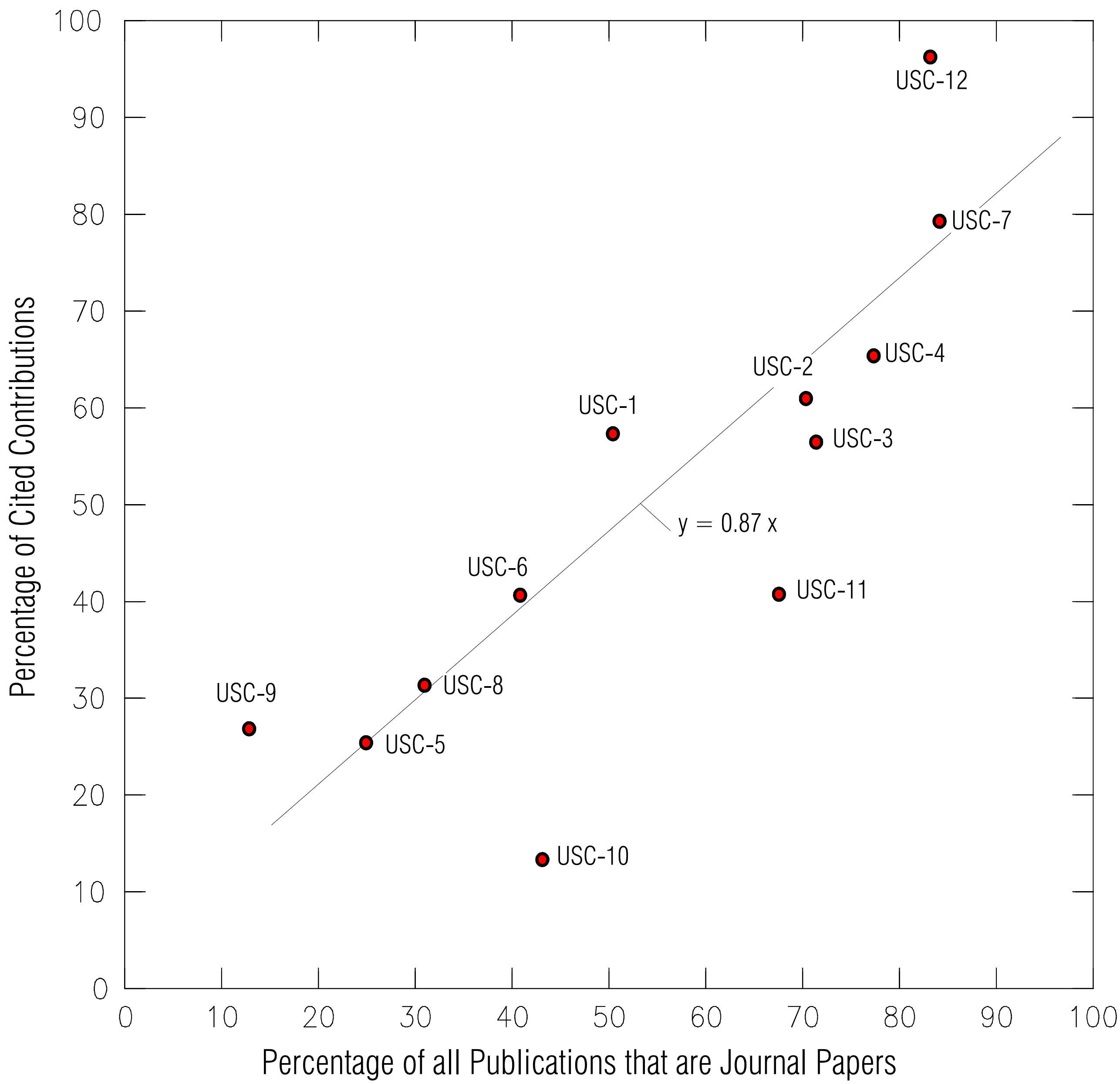

Fig. 17: Percentage of all cited contributions versus percentage of all publications that are journal papers.

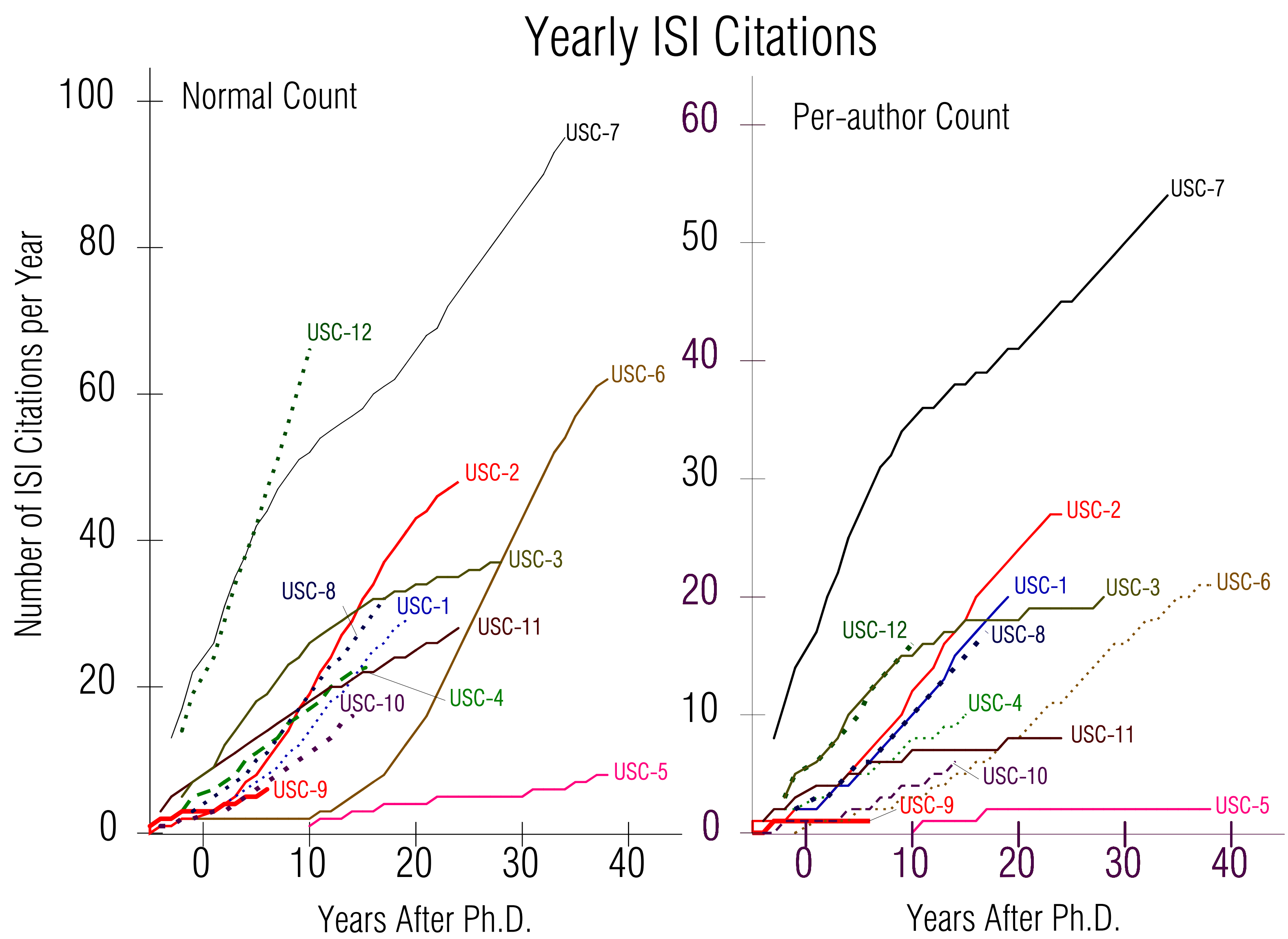

Fig. 18: (left) Normal (total) count and (right) fractional (per-author) count of the number of ISI citations per year plotted versus years after Ph.D. degree.

monographs, often hundreds of pages in length, with detailed theoretical studies and with comprehensive data analyses. In contrast, most conference papers are less than 20 pages long, are not carefully reviewed (if reviewed at all) before publication, and, when published, may not be widely distributed to the leading libraries worldwide.

Figure 18 compares the normal and per-author counts of the number of ISI citations per year plotted versus years after Ph.D. degree. With few exceptions, the number of citations received increases with time.

5. COMPARISON WITH SELECTED EARTHQUAKE ENGINEERING FACULTY

Ten of the twelve USC faculty in our sample (USC-1 through USC-10) are engaged full time or part time in research related to earthquake engineering. To enable comparison of their citation indicators with their peers (mostly in the U.S.) in the following we will adopt two approximations.

The first approximation is that the number of publications for each author can be approximated by the number of their contributions in the earthquake engineering abstracts database of NISEE, which, at present, contains more than 100,000 records and is the most comprehensive and complete database on the subject of earthquake engineering and the related fields, in the world. It includes all *significant* journal papers, reports, conference papers, and workshop contributions. To demonstrate that this is a reasonable approximation, we first show a correlation for ten of the faculty in our sample (excluding USC-11 and USC-12, whose research is in environmental engineering), for which we have the curricula vitae. Table 4 shows the total number of published journal papers (y_1), reports (y_2), conference papers (y_3), and abstracts in the NISEE database (x), up to and including December 2003. Figures 19a, b, and c show y_1 versus x, $y_1 + y_2$ versus x, and $y_1 + y_2 + y_3$ versus x, respectively.

Table 5 shows the best estimates for coefficients a and b of the regression lines $y = a+bx$ plus/minus their standard deviations, and the correlation coefficients, r. It can be seen that the NISEE database (x) can be used to predict both y_1 and $y_1 + y_2$ well.

The second approximation is that we will use the “raw” total number of ISI citations (i.e., without any corrections)—e.g., to exclude self-citations or the articles published in *Nature* and *Science*. These corrections are complex and labor intensive and require in-depth analyses of the curricula vitae (as in Appendix F), which are not available to us at present for earthquake engineers who are not at USC. Figure 20 shows an example of correlating the total number of citations (normal count) after detailed corrections (y), versus the “raw” total number of ISI citations (x), for four faculty members in our sample. The y/x ratios range from 0.46 (USC-4) and 0.63 (USC-8), through 0.77 (USC-6), to 0.85 (USC-7). Figure 20 implies that the total number of *corrected* ISI citations can be predicted within a factor of about two, or better, from the raw total number of ISI citations. In the following we will assume that $y \sim x$.

5.1 Input

As for the twelve USC faculty, in order to maintain confidentiality we have replaced individual names with abbreviated codes representing the institution, followed by a randomly chosen number. Table 6 lists the adopted abbreviations and lists, for each institution, the number of their faculty we included in this study. Note that for USC, we considered additional six faculty members, who work on a part-time or full-time basis in earthquake engineering but who were not

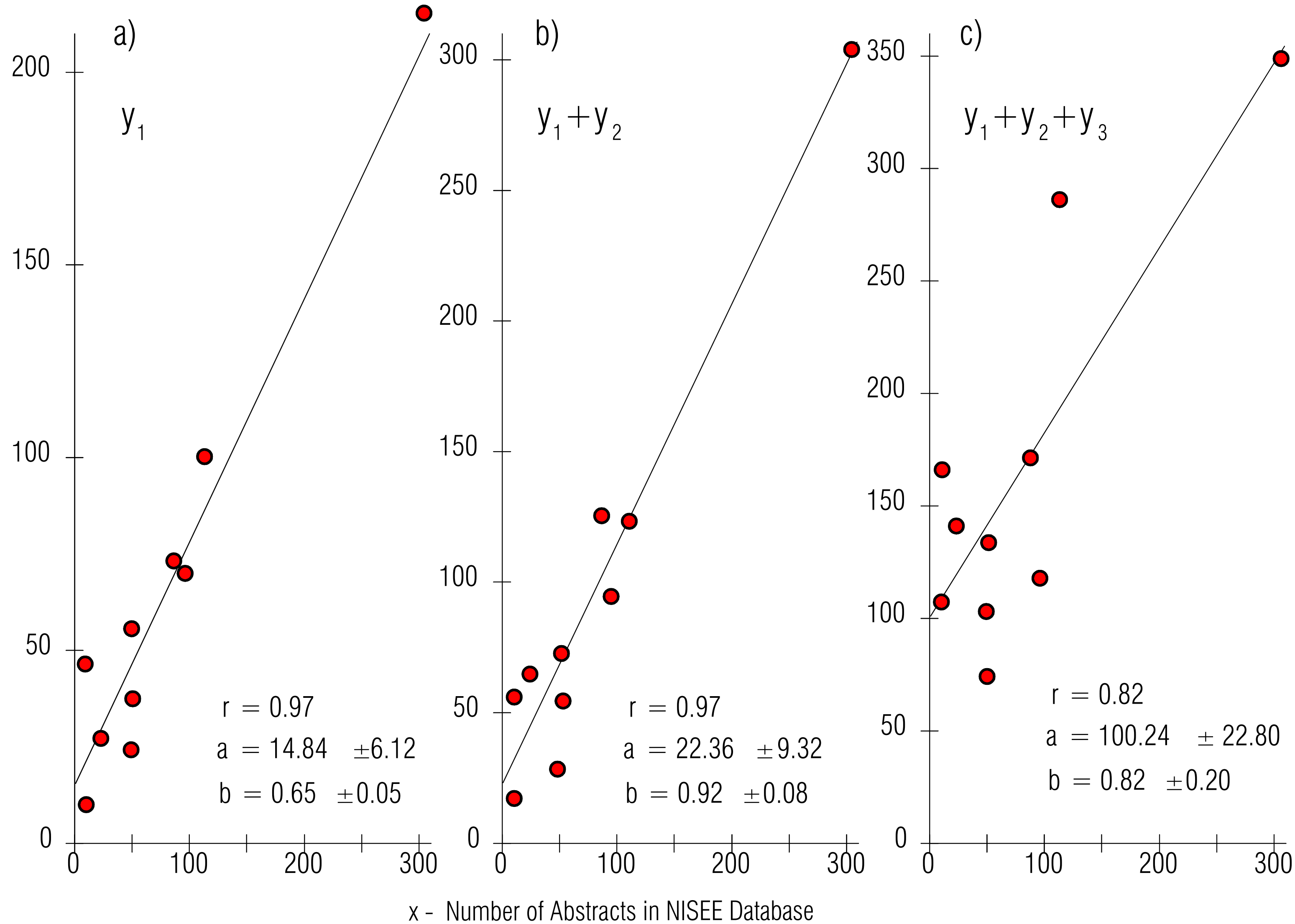

Fig. 19(a): Number of published journal papers, y_1; (b) number of published journal papers and reports, $y_1 + y_2$; and (c) number of published journal papers, reports, and conference papers, $y_1 + y_2 + y_3$. All are plotted versus the number of abstracts in the NISEE database as of December 2003. Listed in each plot are the corresponding correlation coefficient, r, and the coefficients a and b in the straight line fit of form $y = a + bx$.

Table 4. Distributions Among Publication Categories and Number of Abstract in the NISEE Database

Name	Journal y_1	Report y_2	$y_1 + y_2$	Conference y_3	Total $y_1 + y_2 + y_3$	NISEE Total* x
USC-1	54	17	71	61	132	48
USC-9	9	7	16	89	105	7
USC-2	72	52	124	45	169	84
USC-5	23	4	27	74	101	46
USC-6	99	23	122	162	284	110
USC-8	45	9	54	111	165	7
USC-4	69	24	93	23	116	92
USC-7	209	94	303	44	347	301
USC-3	36	17	53	19	72	48
USC-10	26	37	63	76	139	20

* As of December, 2003.

Table 5. Coefficients in the Straight-Line Regressions $y = a + bx$ for y_1, y_2, y_3, and x in Table 4

Function	a	b	r
$y = y_1$	14.84 ± 6.12	0.65 ± 0.05	0.97
$y = y_1 + y_2$	22.36 ± 9.32	0.92 ± 0.08	0.97
$y = y_1 + y_2 + y_3$	100.24 ± 22.80	0.82 ± 0.20	0.82

included in our initial sample of twelve. Finally, we made one exception to the above rule. We chose to show the name of Maurice A. Biot (see Appendix E). We felt that his singular position in the plots can serve as a benchmark of excellence and that, by showing his name, the true meaning of the comparison with all other data points can thus be better understood and evaluated.

In Figures 21 through 23, we present sets of cumulative numbers of abstracts in the NISEE database versus time, measured in years since the publication of the first abstract (approximately equal to years since Ph.D.). Figures 21a, b and c present the cumulative *input*, respectively, of 18, 14, and 13 (total of 45) leading earthquake engineers, mainly in the U.S., and Figure 21d presents the same for 11 “younger” earthquake engineers. Figure 22 shows the same for 10 of the 12 faculty in our sample, together with 4 other USC faculty who work full-time or part-time in

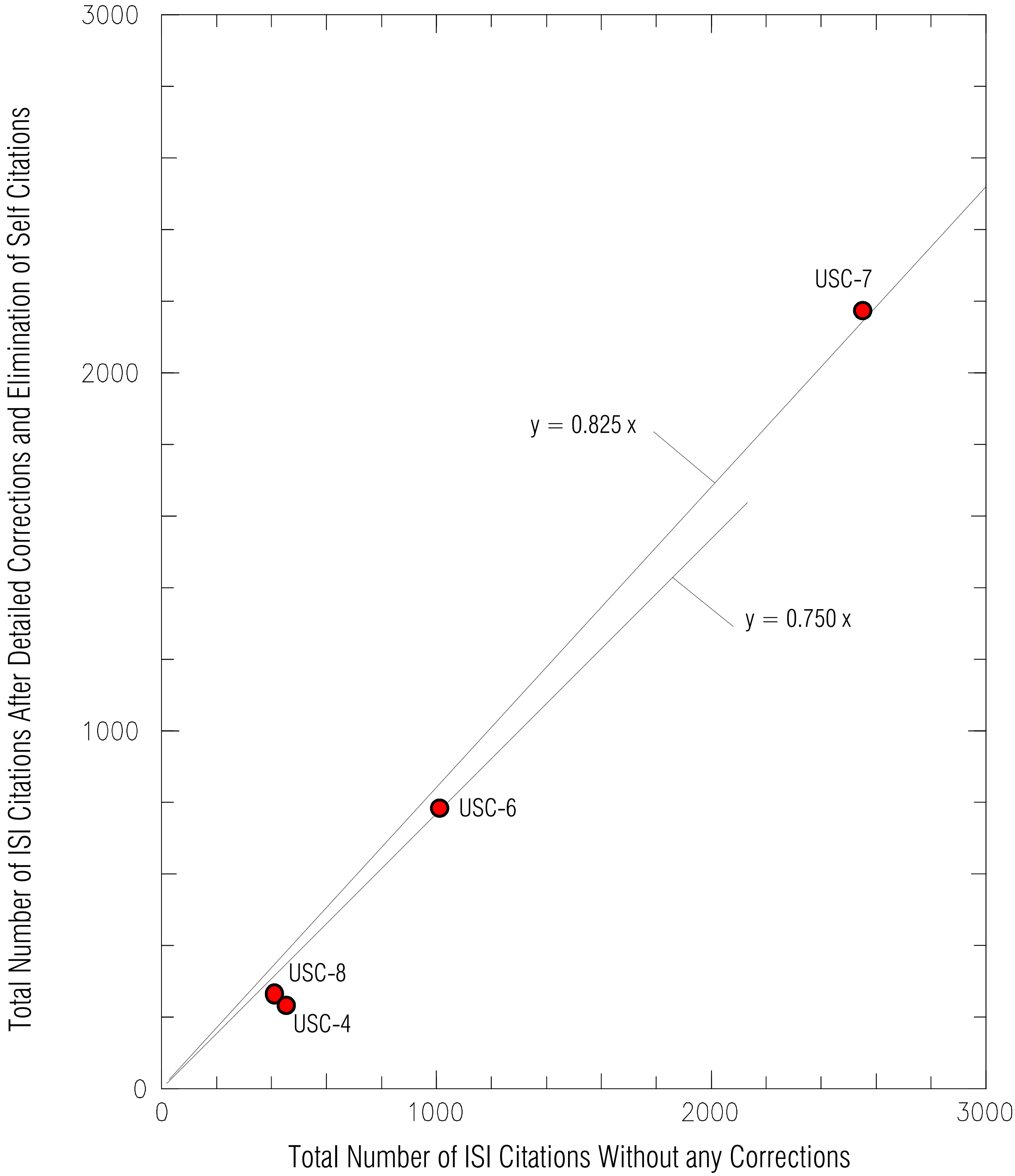

Fig. 20: Total number of ISI citations after detailed corrections and elimination of self-citations, versus total number of ISI citations without any corrections.

earthquake engineering. Figure 23 shows the same for 9 female faculty members (see Appendix D).

All of the ISI citation and NISEE abstract data presented here can be considered to be complete up to and including December 2003. In Figures 21a through 23, the ordinate of the last point (e.g., 301 for USC-7, 277 for UCB-6, 267 for UCSD-1, etc., in Fig. 21a) represents the total number of articles recorded in the NISEE database (see also x in Table 4).

5.2 Output

The distribution of total ISI citations per year for 54 faculty and researchers in earthquake engineering is shown in Fig. 24. The left part of this figure shows citation rates *per year*, while the right-hand side shows the corresponding histogram and the cumulative distribution function. With respect to this sample, it can be seen that Biot, UCB-1, UCI-1, and USC-7 are in the top 5 percent. UCB-2 and UCSD-2 are in the top 10 percent, UCB-12, USC-12, UCSD-1, MIT-1, TUA-1, CIT-2, and USC-4 in the top 20 percent, and so on. USC-9, CU-2, UCB-11, USC-5, and USC-14 are in the bottom 10 percent.

In Figure 25, we show the total number of ISI citations (y) versus the total number of NISEE abstracts (or equivalent) (x), both plotted on a logarithmic scale. With few exceptions, most data points fall between 1 and 50 citations per NISEE abstract. For Biot (see Appendix E) and USC-8, the NISEE abstracts database is incomplete, and therefore we used instead the total number of papers in their curricula vitae.

Figure 26 shows the corresponding rates. The y axis shows the number of ISI citations per year since the publication of the first abstract in the NISEE database, while the x axis shows the number of NISEE abstracts per year since the publication of the first abstract, both plotted on logarithmic scale. It can be seen that, for this sample, the publication rates range from 0.7 to more than 8 per year, while the citation rates range from less than 1 (FEF-18, FEF-2) to 173 (Biot) per year.

In Figures 24 through 26, we include both USC-12 and USC-11 for completeness of the presentation of the analysis of our sample of 12 USC faculty, even though they both work in environmental engineering and thus cannot be compared with earthquake engineering researchers.

Table 6. Institution Codes and the Number of Male Faculty for Each Institution Considered in This Study

American Institutions	**Code**	**No. of Faculty Considered in this Study**
University of Southern California	USC	USC-1 through USC-18
University of California, Berkeley	UCB	UCB-1 through UCB-12
California Institute of Technology	CIT	CIT-1 through CIT-5
University of California, San Diego	UCSD	UCSD-1 through UCSD-4
Stanford University	SU	SU-1 through SU-3
University of California, Irvine	UCI	UCI-1 through UCI-3
University of Texas	UT	UT-1 through UT-2
University of Washington	UW	UW-1 through UW-2
University of California, Los Angeles	UCLA	UCLA-1 through UCLA-2
Columbia University	CU	CU-1 through CU-2
State University of New York, Buffalo	SUNYB	SUNYA-1 through SUNYB-2
Rice University	RU	RU-1 through RU-2
University of Illinois, Urbana	UIU	UIU-1 through UIU-2
University of California, Davis	UCD	UCD-1
Johns Hopkins University	JH	JH-1
Massachusetts Institute of Technology	MIT	MIT-1
Renselear P. Institute	RPI	RPI-1
Carnegie-Mellon	CM	CM-1
European Institutions	**Code**	**No. of Faculty Considered in this Study**
Imperial College; London, England	IC	IC-1
Tech. University of Athens, Greece	TUA	TUA-1
University of Ljubljana, Slovenia	ULJ	ULJ-1

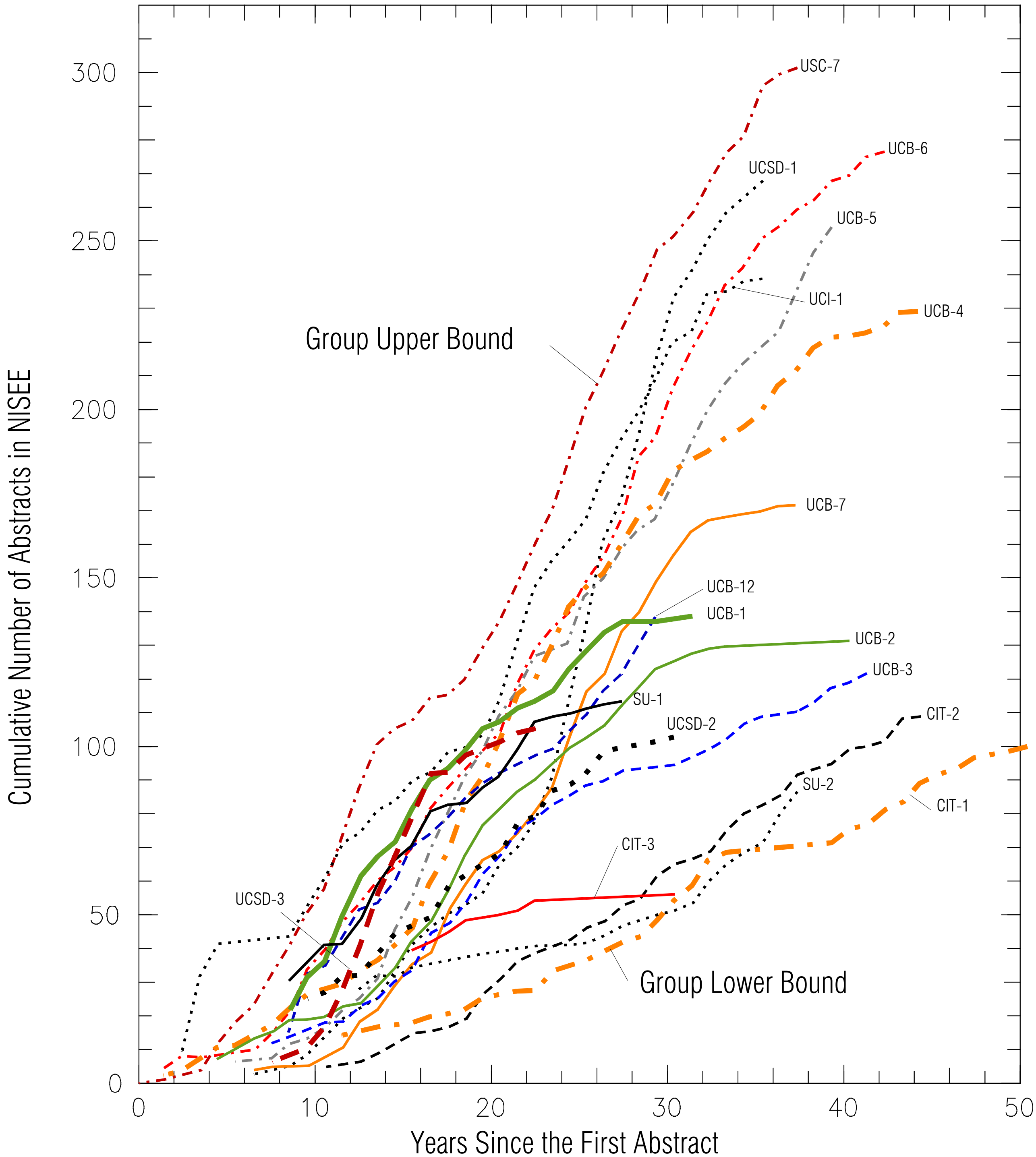

Fig. 21a: Cumulative number of abstracts (journal papers, reports, and conference papers) versus number of years since publication of the first reported abstract, for 18 faculty in earthquake engineering. The upper bound (USC-7) and the lower bound (CIT-1) will be used as reference lines in the following plots.

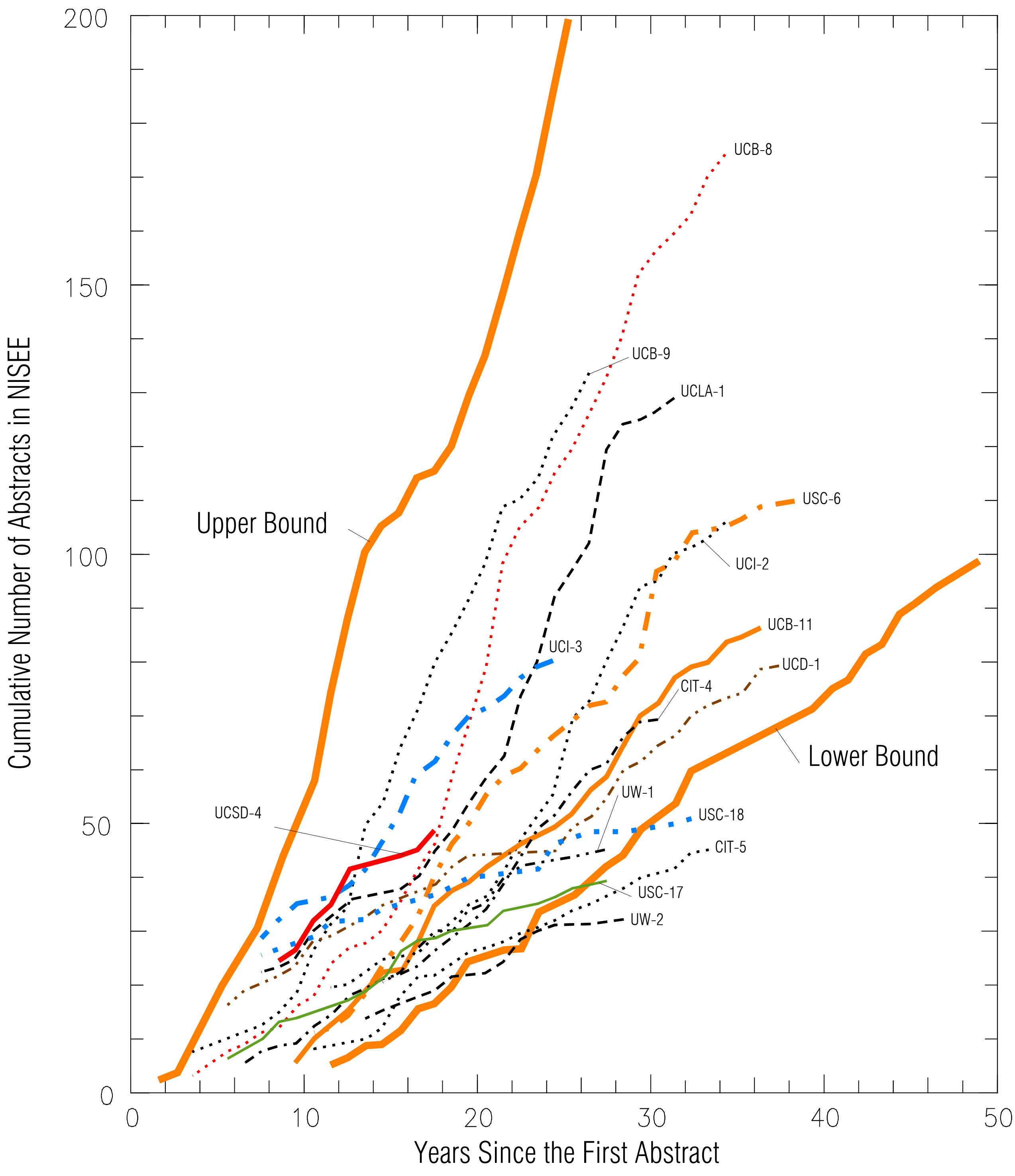

Fig. 21b: Cumulative number of abstracts (journal papers, reports, and conference papers) in NISEE database versus number of years since publication of the first reported abstract for 14 faculty in earthquake engineering. The upper and lower bounds from Fig. 21a are shown with wide lines.

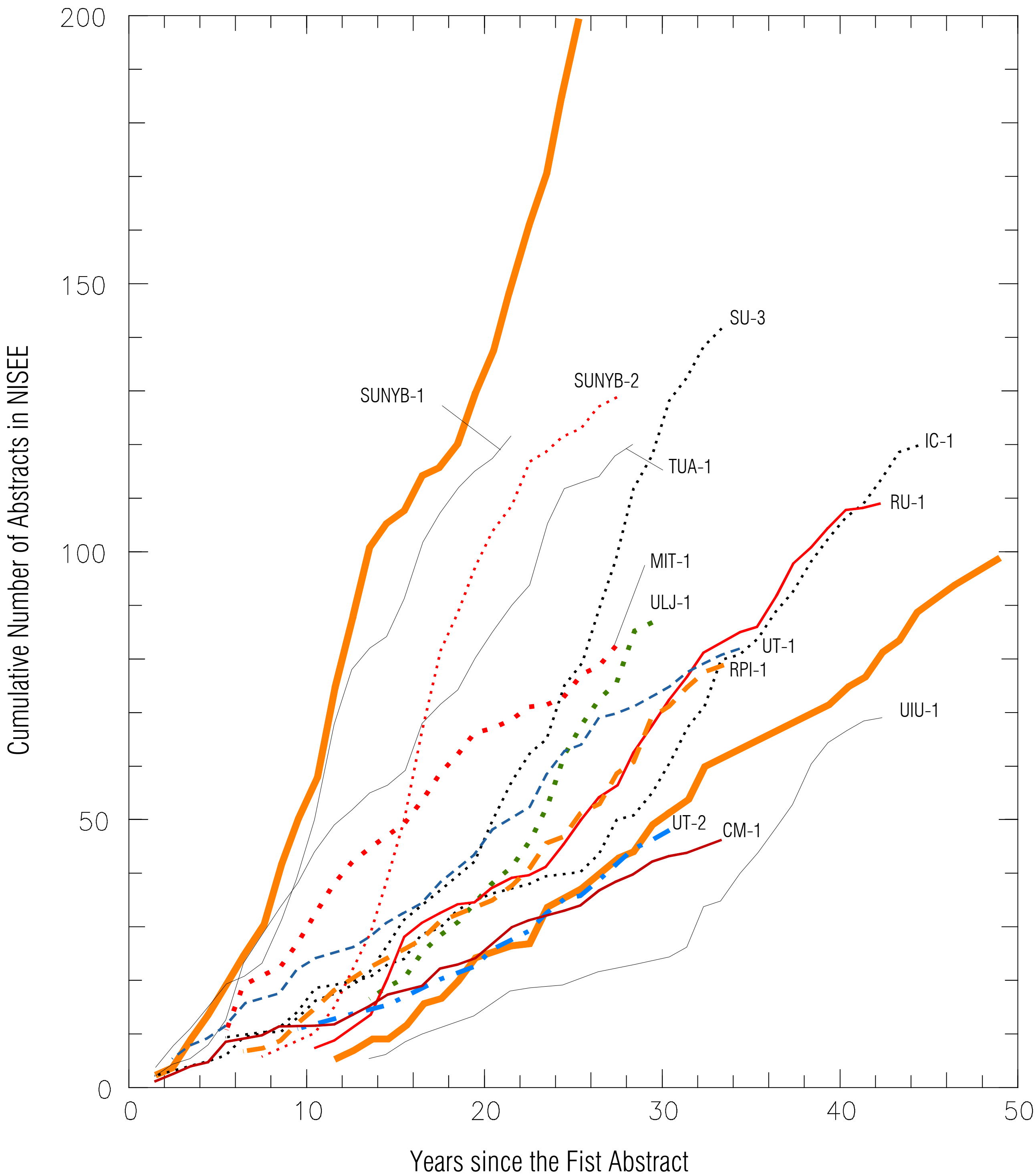

Fig. 21c: Cumulative number of abstracts (journal papers, reports and conference papers) in NISEE database versus number of years since publication of the first reported abstract for 13 faculty in earthquake engineering. The upper and lower bounds from Fig. 21a are shown with wide lines.

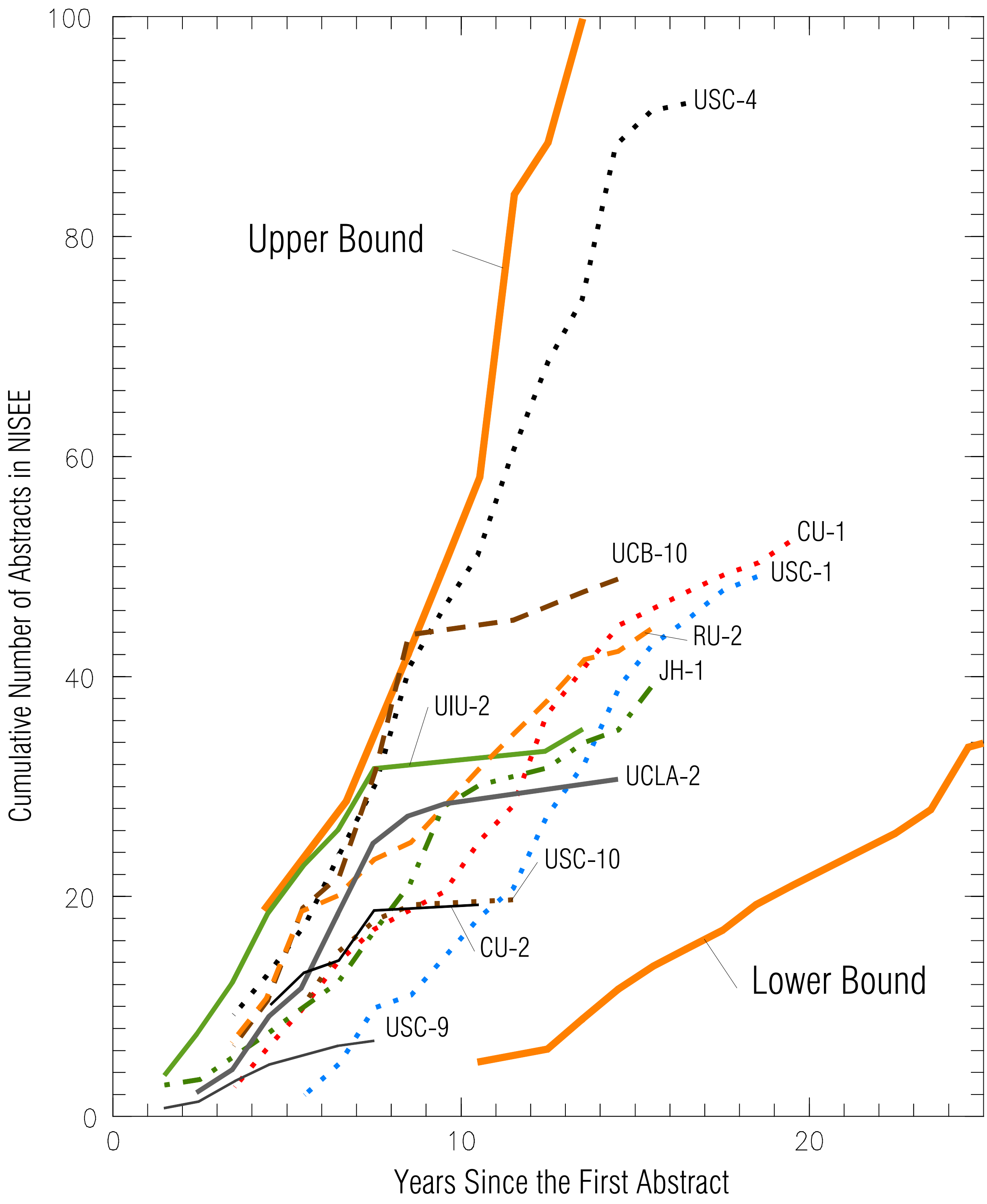

Fig 21d: Cumulative number of abstracts (journal papers, reports, and conference papers) in NISEE database, versus number of years since publication of the first reported abstract for 11 "younger" faculty in earthquake engineering. The upper and lower bounds from Fig. 21a are shown with wide lines.

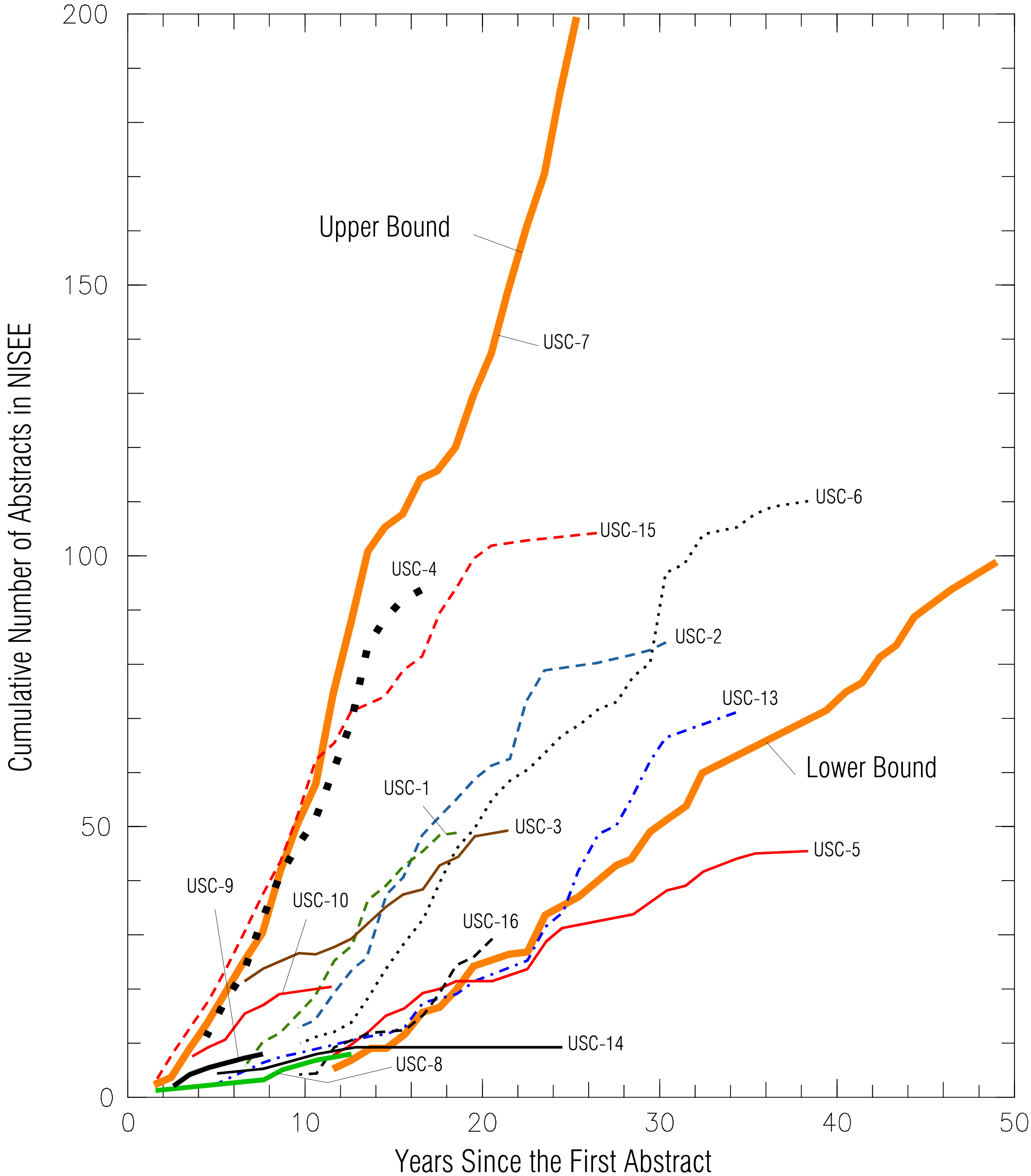

Fig. 22: Cumulative number of abstracts (journal papers, reports, and conference papers) in NISEE database versus number of years since publication of the first reported abstract for 14 faculty in civil engineering at USC. The upper and lower bounds from Fig. 21a are shown with wide lines.

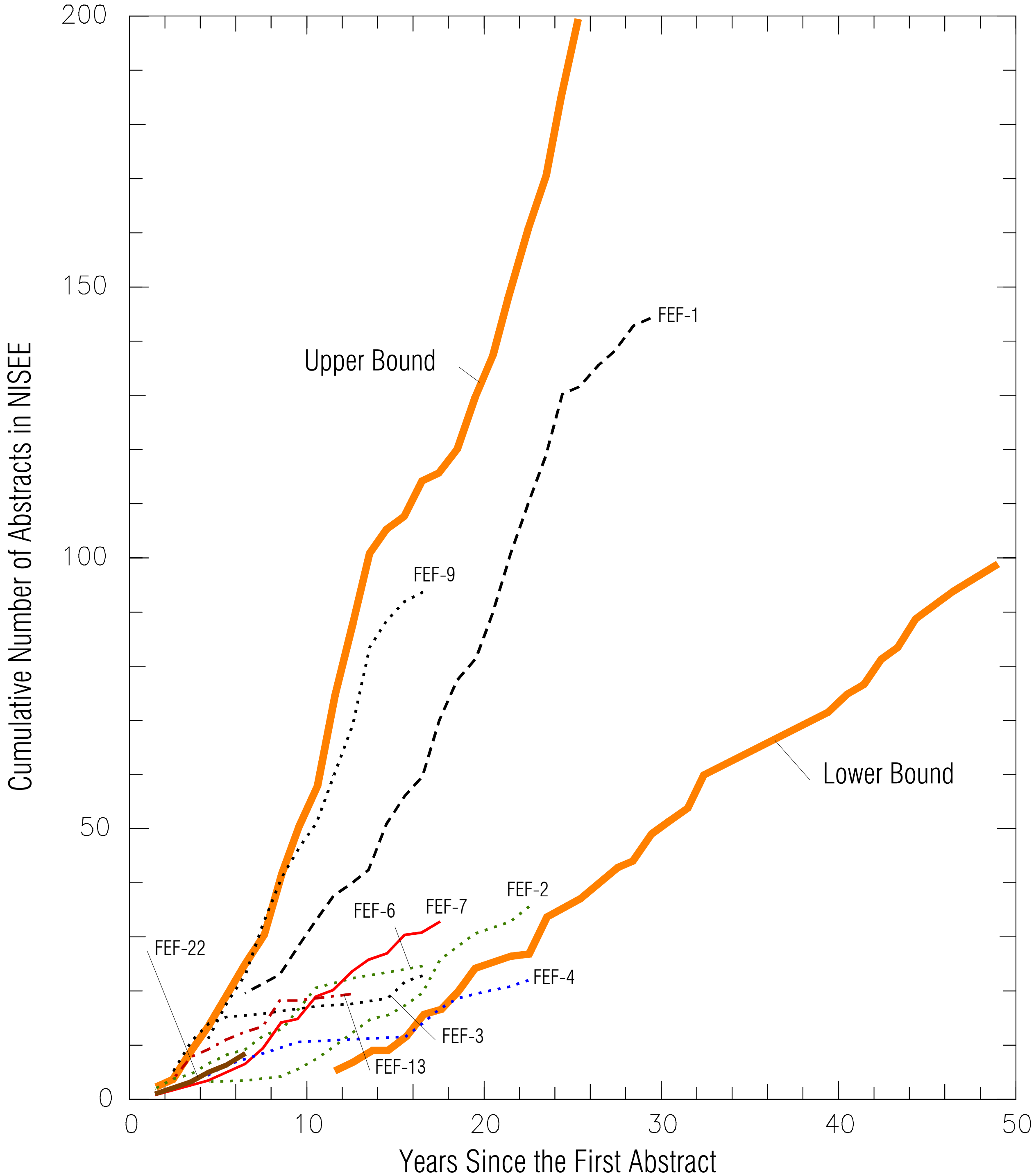

Fig. 23: Cumulative number of abstracts (journal papers, reports, and conference papers) in NISEE database versus number of years since publication of the first reported abstract for 9 female faculty in earthquake engineering (see also Appendix D). The upper and lower bounds from Fig. 21a are shown with wide lines.

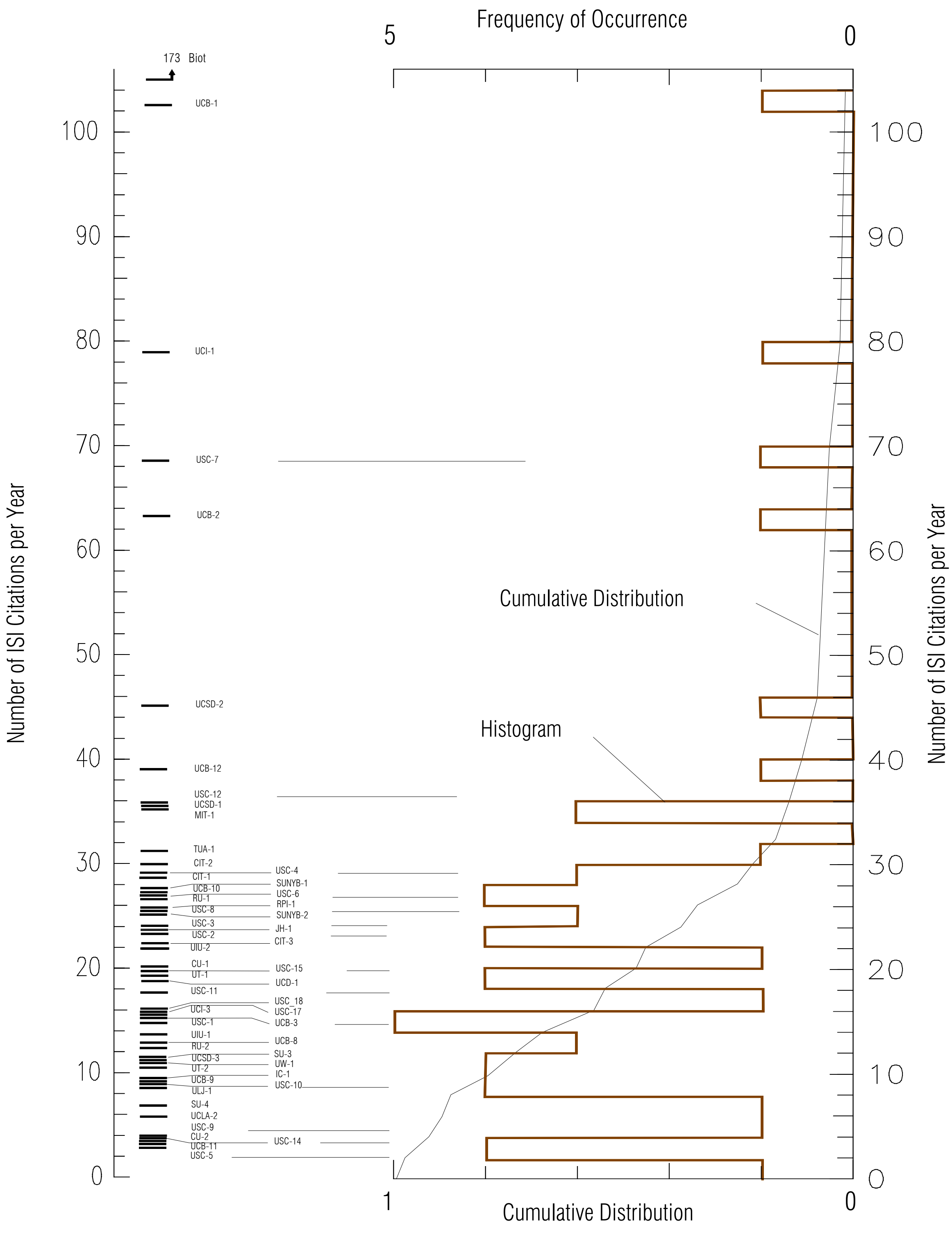

Fig. 24 (left): Average citations per year for 54 faculty in earthquake engineering; (right) histogram and cumulative distribution of average citations per year. The 14 faculty of the USC Civil Engineering Department are highlighted by drawing horizontal lines from the left towards the histogram on the right.

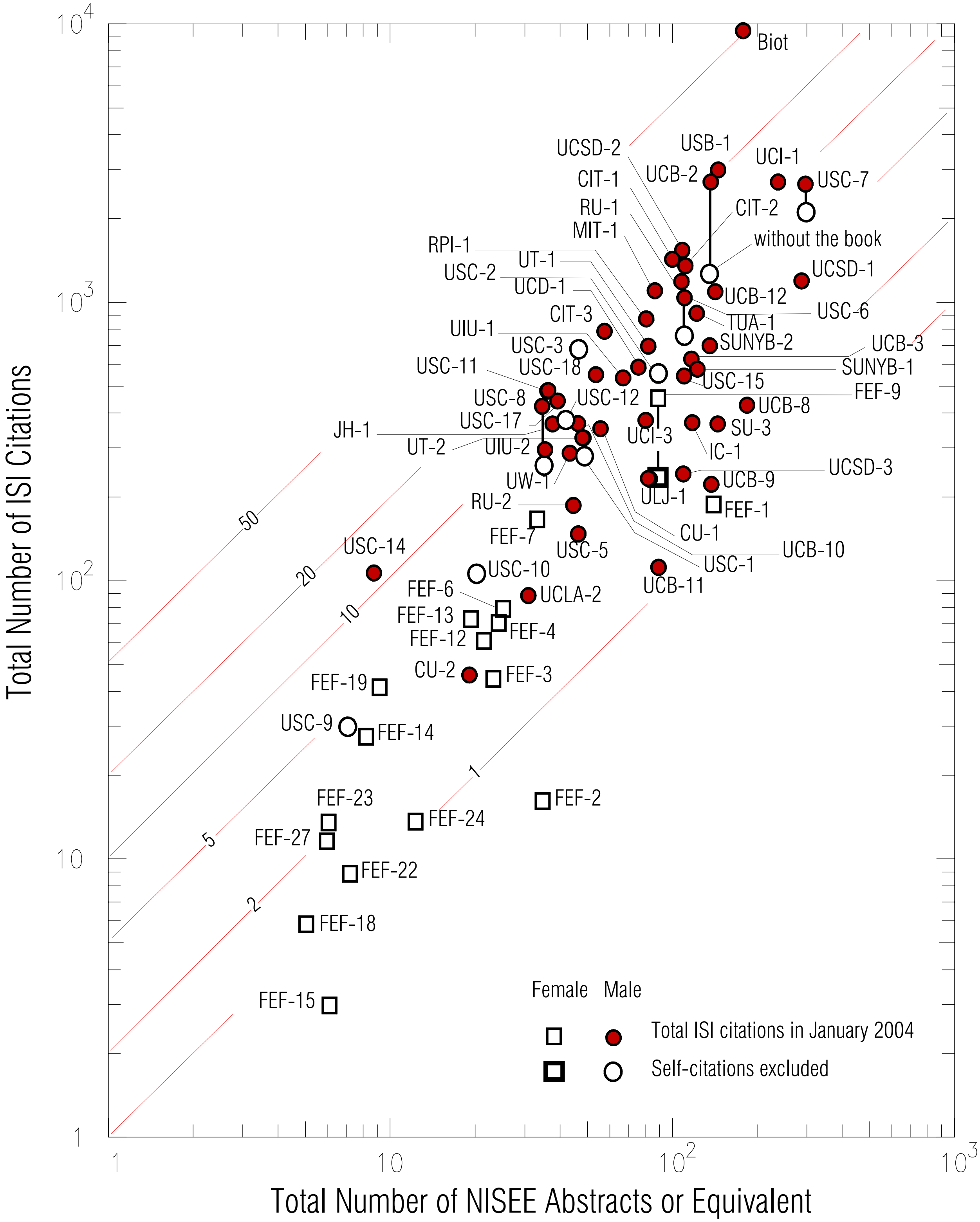

Fig. 25: Total number of ISI citations versus the total number of NISEE abstracts or equivalent.

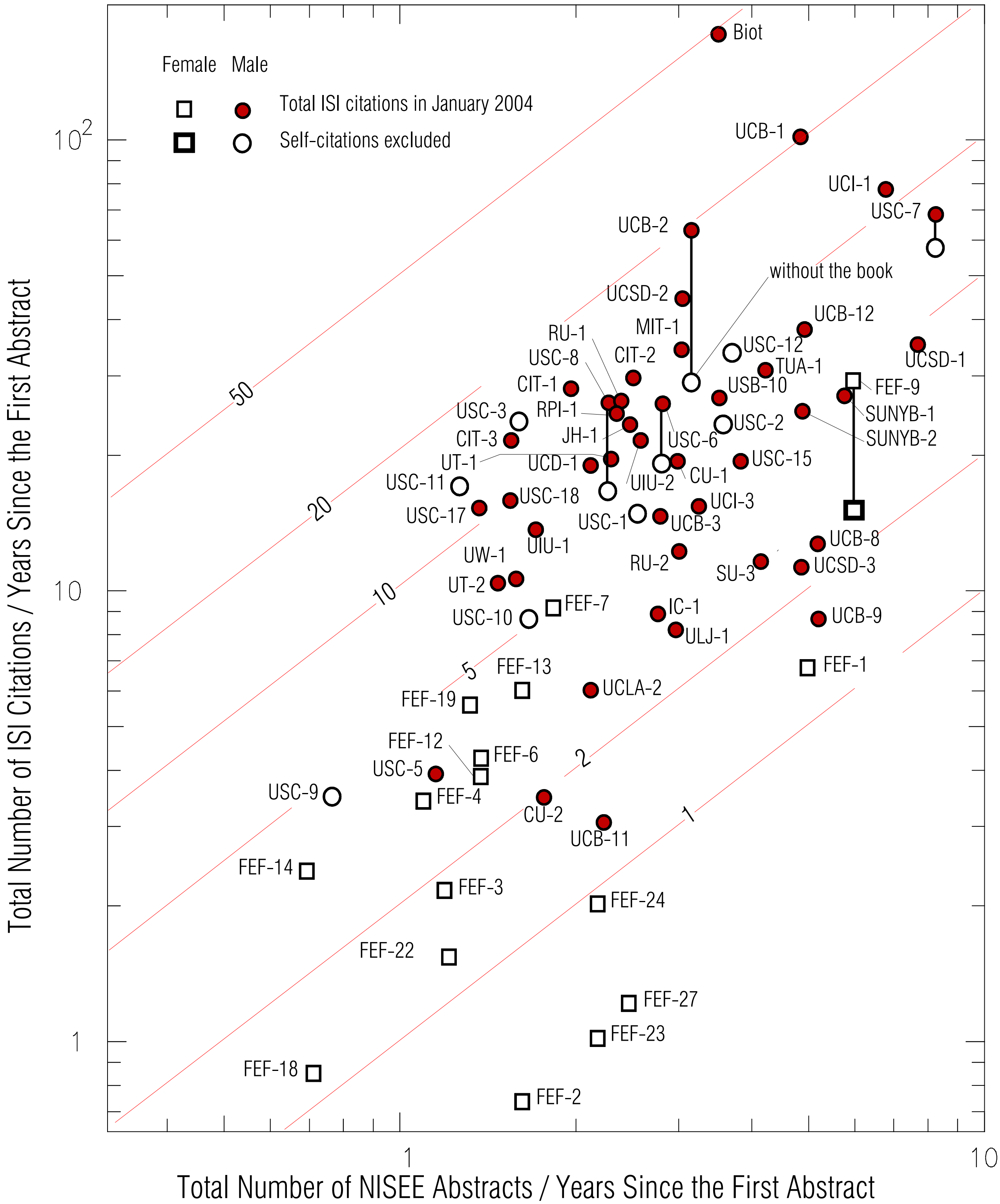

Fig. 26: Total number of ISI citations versus the total number of NISEE abstracts per year.

6. DISCUSSION AND CONCLUSIONS

Because a consensus on what constitutes adequate and meaningful measures of academic productivity may not exist at present, in this work we have taken a simplified, management-type approach to the relationships between "input" and "output." Needless to say, we still face the difficulty of identifying all of the relevant input and output factors, and we cannot identify all of the causal relationships between the two. Even after focusing on only one component of productivity related to published work, we still lack criteria on (1) how to weigh the quality of publications (should an article in a journal with high JIF receive the same credit as an article in a journal with low or nonexisting JIF?), (2) how to categorize books and chapters in books, relative to journal papers, and (3) how to distribute the credit among multiple authors.

Productivity could be measured by the average publication rate (total number of publications divided by number of years since the first publication), or by per-author publication rate (the sum of $1/a_i$ for all publications divided by the number of years since the first publication). In this work, we chose to consider those only as measures of the *input* productivity—i.e., of the input into the pool of scientific and engineering literature. Using the ISI databases, we then considered only those inputs that have been cited as a measure of *recognized* productivity. The fact that a journal paper is cited does not necessarily mean that the paper is of high quality, that it is relevant, or that it contributes to the overall knowledge and understanding in the respective discipline. It is a statistical data point contributing to the author's cumulative sums of such points, and when these sums become large enough we can consider accepting them as measures of *recognized* productivity, or simply as *output*. In our sample of 12 USC faculty, the percentage of cited contributions ranges from 12% (USC-10) to 95% (USC-12) when we consider all publications collectively (journal papers, reports, conference papers, books, book chapters, etc.; see Fig. 3).

Wanner et al. (1981) argued that the important research results in the sciences are reported in refereed journals and that other journal articles, books, and other publications are less used by researchers to advance the science. Thus, weighing the publications becomes an important bibliometric issue, which is possible only within the study of the same disciplines (e.g., see fig. A.2 in Appendix A).

Another important issue is how to distribute credit among the authors of a paper. Cole and Cole (1972) proposed the use of *straight count*, which allocates all credit only to the first author. This method assumes that the order of authors listed on the paper reflects the level of their contributions. The problem with this count is that it discriminates against those researchers whose name appears late in the alphabetic listing (Rudd, 1977).

The second method is *adjusted count* (or *fractional count*, or *per-author count*), which gives each author credit equal to $1/a_i$, where a_i is the number of authors. The advantage of the adjusted count is that it eliminates the bias in overestimating production when the value of a co-authored paper is distributed among all contributors (Lindsey, 1980).

The third method is the *normal count*, which gives full credit to all contributors regardless of the order of the listed authors. The problem with this count is that it is not reasonable to expect that all co-authors contributed equally, especially when some publications list authors for social reasons (Hagstrom, 1965). Also, in some circles the practice of making colleagues "honorary co-author" is common (LaFollette, 1992).

In this work, we used both the *normal* and *fractional* counts. Inadvertently, in a few cases, for the more senior researchers in our sample (USC-6, USC-5, USC-7), some of their citations for publications before 1975 may be incomplete due to the use of *straight count* in the old *Science Citation Index*.

6.1 Age

Studies by Lehman (1953) showed that major contributions for scientists occur in their 30s and early 40s, and that the production peak occurs earlier for researchers in the abstract and theoretical disciplines and later for those in the more empirical fields. Pelz and Andrews (1976) found similar trends, but they also observed a second peak, ten to fifteen years later, at age 50. And Bayer and Dutton (1971) identified two peaks in the productivity curve, with the first peak occurring at about ten years into the career and second near the retirement age.

Pelz and Andrews (1976) considered four hypotheses to describe the decline of productivity with age: (1) atrophy of intellectual functioning with age, (2) migration into administration of mature researchers, (3) decrease of zeal and motivation with age, and (4) loss of breadth in knowledge through over-specialization, which is needed for new results. They found support only for the third and fourth hypotheses. Hammel (1980) presented different results showing that the productivity increases with age, but with gradually decelerating increase.

Figure 27, redrawn from Fig. 2, now with different *x*-coordinates, shows the number of journal publications per year (top for normal count and bottom for per-author count) versus the age of the researcher. The national average rate (Appendix C) is plotted assuming the average age of receiving the Ph.D. to be 28.83 (Table 7). It can be seen that the variation in productivity with time of USC-6, USC-11, USC-5, and USC-3 can be described by a single peak in the late thirties and early forties. USC-12 and USC-4 are experiencing increasing productivity (Hammel, 1980), while USC-2, USC-1, and USC-7 had a peak in their late thirties and another gradual increase

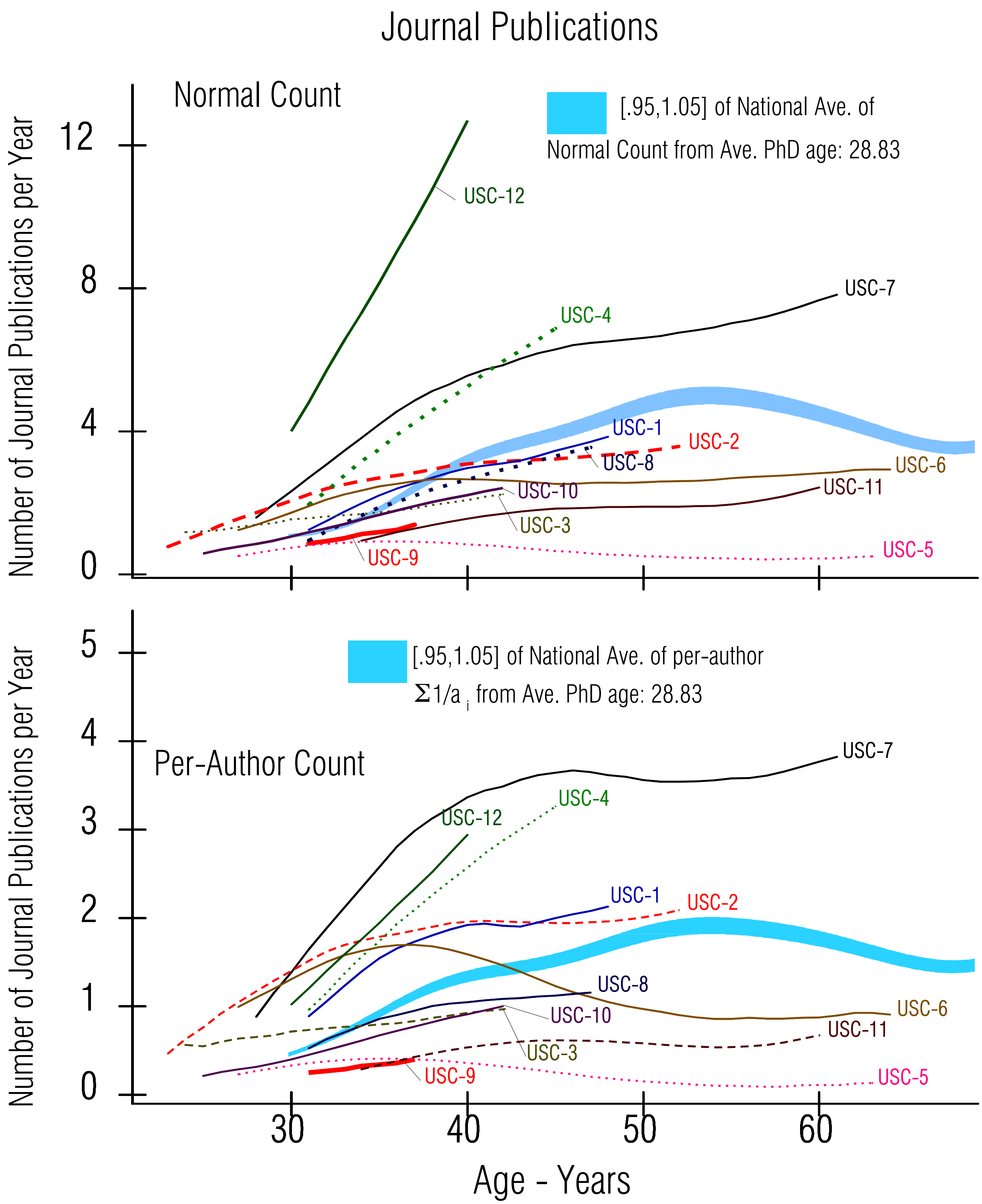

Fig. 27: Number of journal publications per year (top: normal count; bottom: per-author count) plotted versus the age of the faculty.

after the age of about 50 (Bayer and Dutton, 1977). Figure 27 shows that 7 of the 12 faculty in our sample, or about 60%, have productivity below the national average (Appendix C).

Figures 28 and 29 are redrawn from Fig. 1 and 5, but now the data is plotted versus the ages of the faculty. These figures confirm the trends shown in Fig. 27, but now in terms of cumulative indicators and as *input* (Fig. 28) and *output* (Fig. 29).

To identify the years during which significant work was carried out, we use the results from the tables in Appendix F and summarize those for all 12 faculty in Fig. 30. This figure shows year-by-year sums of all currently received citations (through December 2003) using the right-hand side columns in Table F.1, in Appendix F for both normal (total) and fractional (per-author) counts. The last column in Table 7 identifies more than average productive years. Citations for USC-2, USC-6, USC-11, and USC-4 have no "peaks" yet, and all of their cited papers attract a similar number of citations throughout their careers. In the last column of Table 7, their productive age has been characterized as "continuous." USC-1, USC-5, USC-8, USC-7, and USC-3 have had periods in their careers during which they produced publications that now receive more than the average number of citations. Whether there will be other such periods later on in their careers, or some of their already-published work will become more recognized with time, producing new citation peaks, will be brought out by citation data for the next 10 to 20 years. USC-9, USC-12, and USC-10 are young, and therefore for them no characterization in the last column in Table 7 was made.

Table 7. Biographical Information and Productive Age for the 12 USC Faculty in the Sample

Name	Ph.D. Education		Productive age
	Age	School	
USC-1	29	Caltech	35-40
USC-9	31	U. Illinois	---
USC-2	28	USC	Continuous
USC-5	26	U.C. Berkeley	35-37
USC-6	26	Caltech	Continuous
USC-11	36	U. Michigan	Continuous
USC-12	30	Harvard	---
USC-8	30	Caltech	30-40
USC-4	30	USC	Continuous
USC-7	26	Caltech	27-38
USC-3	25	Caltech	25-30
USC-10	28	Kyushu U.	---

*Average age at Ph.D. = 28.833

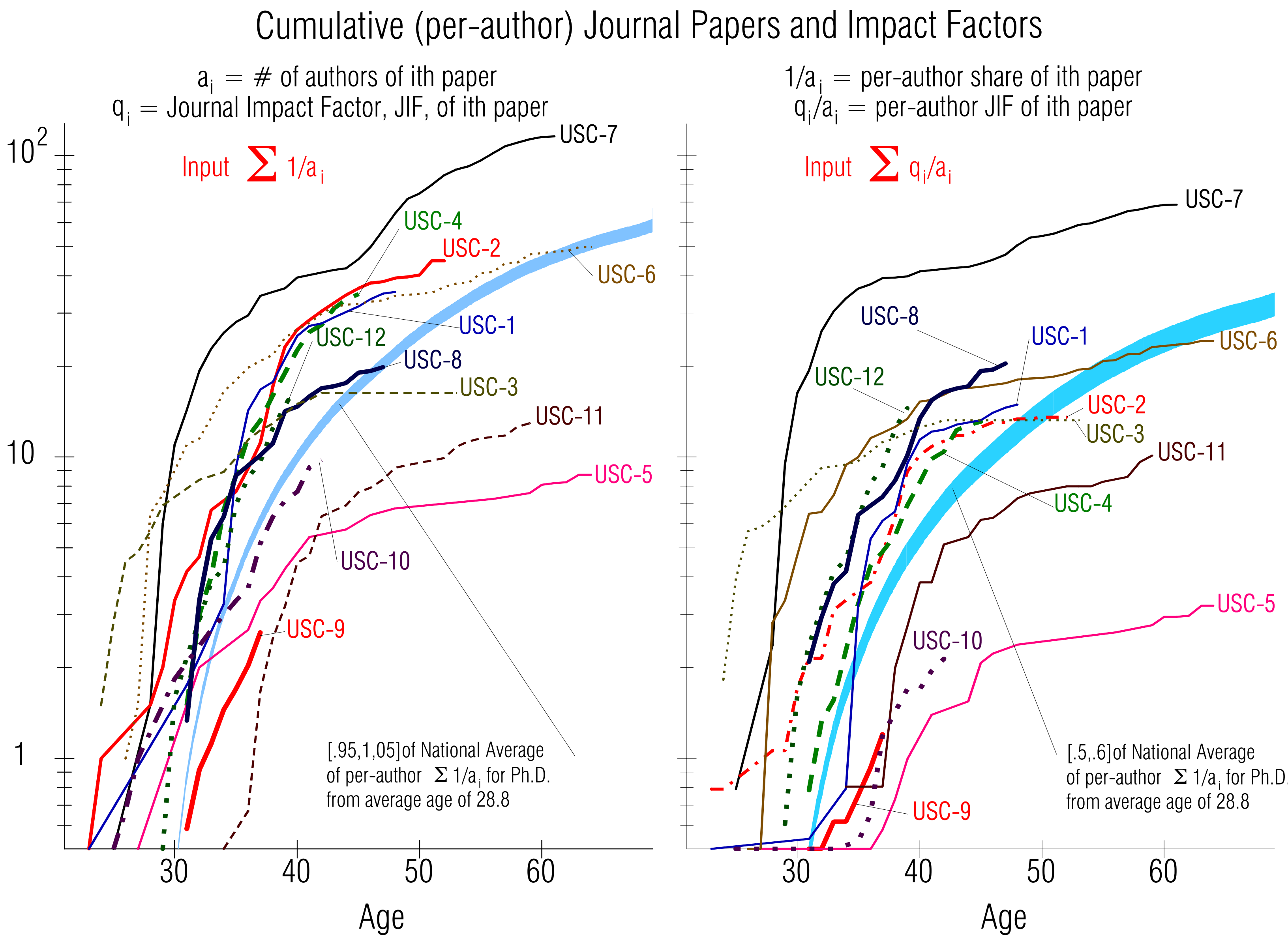

Fig. 28 : (left) Cumulative (per-author) number of journal papers, and (right) cumulative (per-author) impact factors, for 12 faculty members in civil engineering at USC, both plotted versus the age of the faculty.

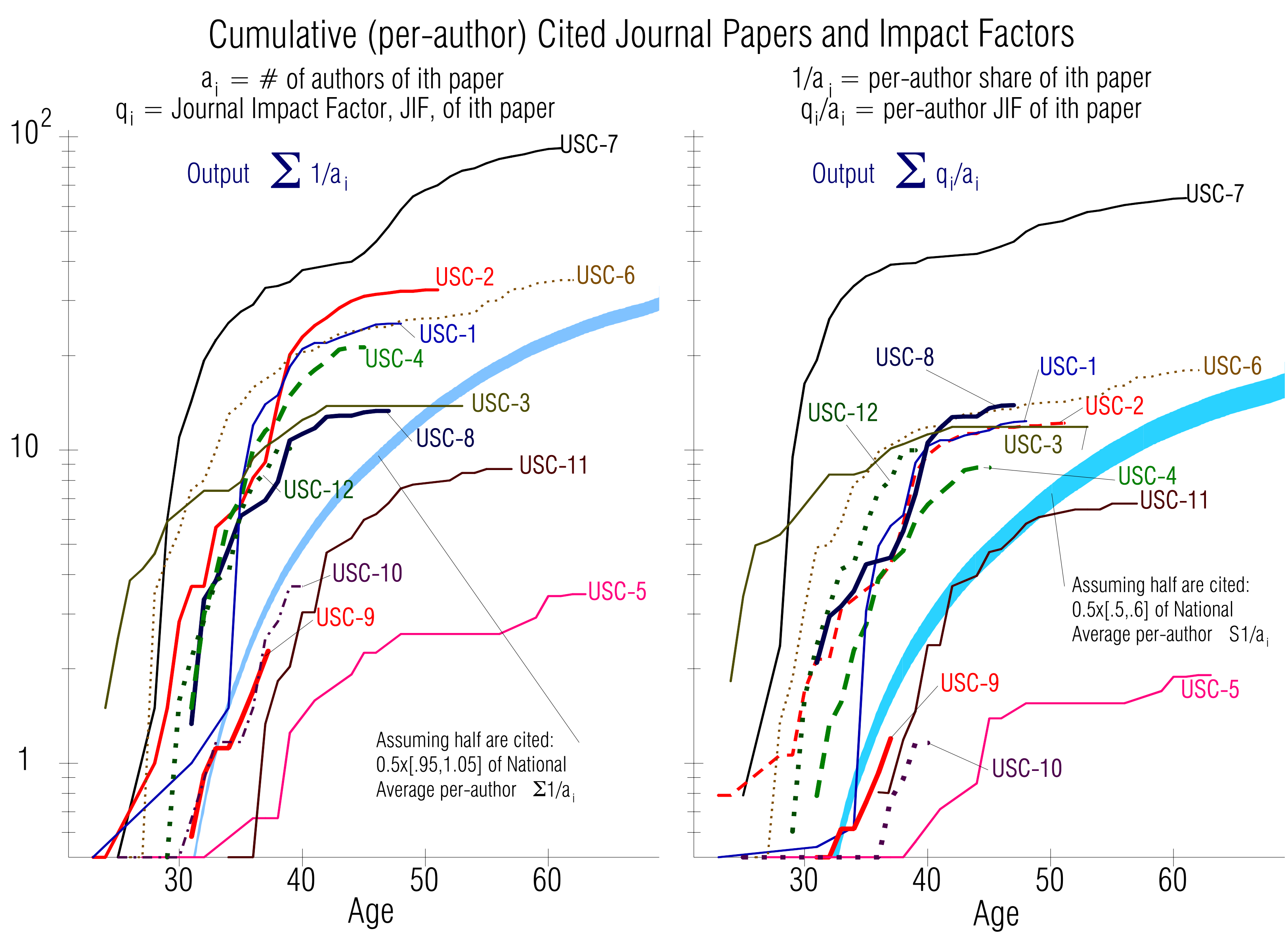

Fig. 29: (left) Cumulative (per-author) number of cited journal papers, and (right) cumulative (per-author) impact factors of cited papers for the sample of 12 USC faculty members, both plotted versus the age of the faculty.

The above trends are consistent with what other investigators have found, which is that the most productive period, from the point of view of publications that receive more than the average number of citations, appears to be the first ten to fifteen years after award of the Ph.D. M.A. Biot (see Appendix E), the most cited member of the sample of faculty and researchers we selected for this study (see Figs. 24, 25, and 26), does not fit into this pattern. Figure 31 shows his citations (as of January 2004) plotted versus his age at the time the cited work was published. Assuming linear growth of citations, from the publication date to January 2004, this figure also shows a lower bound of the citations he would have received at his age of 40, 50, 60, 70, and 80. It can be seen that he has been very productive during all of his life and has had especially productive periods at ages 36, 51, 57, and 60.

6.2 Collaboration

A study of Nobel laureates showed strong correlation between collaboration and productivity (Zuckerman, 1967). Nobel laureates published more and were more collaborative than a matched sample of other scientists. High-profile authors seem to collaborate most frequently, and authors of all levels tend to collaborate more with highly productive than with less-productive authors (Bozeman and Lee, 2003).

In an early research project about motives for collaboration, Beaver and Rosen (1978) identified 18 motives: access to special equipment and facilities, access to special skills, access to unique materials, access to visibility, access to recognition, efficiency in use of time, efficiency in use of labor, gaining of experience, training of researchers, sponsoring of a protégé, increasing productivity, multiplying proficiencies, avoiding competition, surmounting intellectual isolation, the need for additional confirmation or evaluation of a problem, the need for stimulation and cross-fertilization, spatial propinquity, and accident or serendipity. They found that about half of the motives were related to the desire to enhance productivity.

Similarly, Fox and Faver (1984) found that division of labor is one of the main motivations of collaboration. As in business management, division of labor is expected to give mutual benefits to participants by increasing efficiency. In a recent in-depth review of research collaboration, Katz and Martin (1997) articulated the following reasons why the level of research collaboration has been growing over the last 30 years: the escalating instrumentation costs of conducting fundamental science at the research frontier, the substantial fall in the cost of travel and communication, the growing importance of networking and interaction, the complexity of instrumentation, the need for interdisciplinary research, and the political factors encouraging collaboration.

Melin (2000) surveyed 195 university professors about the major reasons for collaboration and the chief benefits of collaboration. The respondents' most-often-reported (41%) motive for collaboration was that the "co-author had special competence." Other common motives included "co-author has special data or equipment (20%)," "social reasons: old friends, past collaboration (16%)," "supervisor-student relationship (14%)," and "development and testing of new methods (9%)." With respect to the benefits of collaboration, the respondents pointed to increased knowledge (38%)," "higher scientific quality (30%)," "contact and connections for future work (25%)," and "generation of new ideas (17%)." Based on this data, Melin concluded that scientists collaborate for strongly pragmatic reasons. These "pragmatic reasons" are largely consistent with the concept of productivity-oriented collaboration.

For the 12 USC faculty members in our sample, the average number of authors per paper is in the range from 1.39 (USC-1) to 4.15 (USC-12) (see also Table A.1 and Fig. A.3 in Appendix A). One of the benefits of cooperation with other researchers, then, can be viewed in terms of the distribution of received citations among single-author papers, first-author papers, second-author papers, etc. (see Fig. 14a through e), and it can also be viewed in the five groups A through E. We found that those who received the most citations had a significant number of single-author papers (USC-1, USC-2, USC-7, and USC-8—Group A, see Fig. 14a), while those with the smallest number of citations received more than half of all journal citations as third authors (USC-10, USC-5—Group E, see Fig. 14e). Two faculty in our study group with successful cooperation record (USC-8 and USC-12) have very different primary sources of citations. While USC-12 receives more than half of his citations as a first author, USC-8 gets almost half of his citations as a single author. Even though Bozzeman and Lee (2003) state that in “the Big Science era, the lonely genius working alone in the laboratory is still lonelier,” and that at present working with others has become the norm, our sample of 12 faculty shows that, at least in the Civil Engineering Department at USC, most significant citations still come mainly from single-author papers. Our finding is emphasized by the fact that we chose to work with fractional (per-author) count, but it holds true even when we use the normal count.

6.3 Gender

Many studies have found somewhat lower production rates for women than for men (Cole and Zuckerman, 1984; Fox 1983; Long, 1987; see also Table C.4 in Appendix C) and have noted that obligations to family and children and sex discrimination may make it more difficult for females to compete for resources (Wenneras and Wold, 1997) and that this in turn may limit their ability to publish. In contrast to this stereotype that women are less productive, Clement (1973) and Wanner et. al. (1981) found that gender does not affect productivity in terms of articles published. Long (1992) and Bozeman and Lee (2003) (see Appendix C) found that the differences in the number of publications and citations increase during the first decade of the career but are reversed later in the

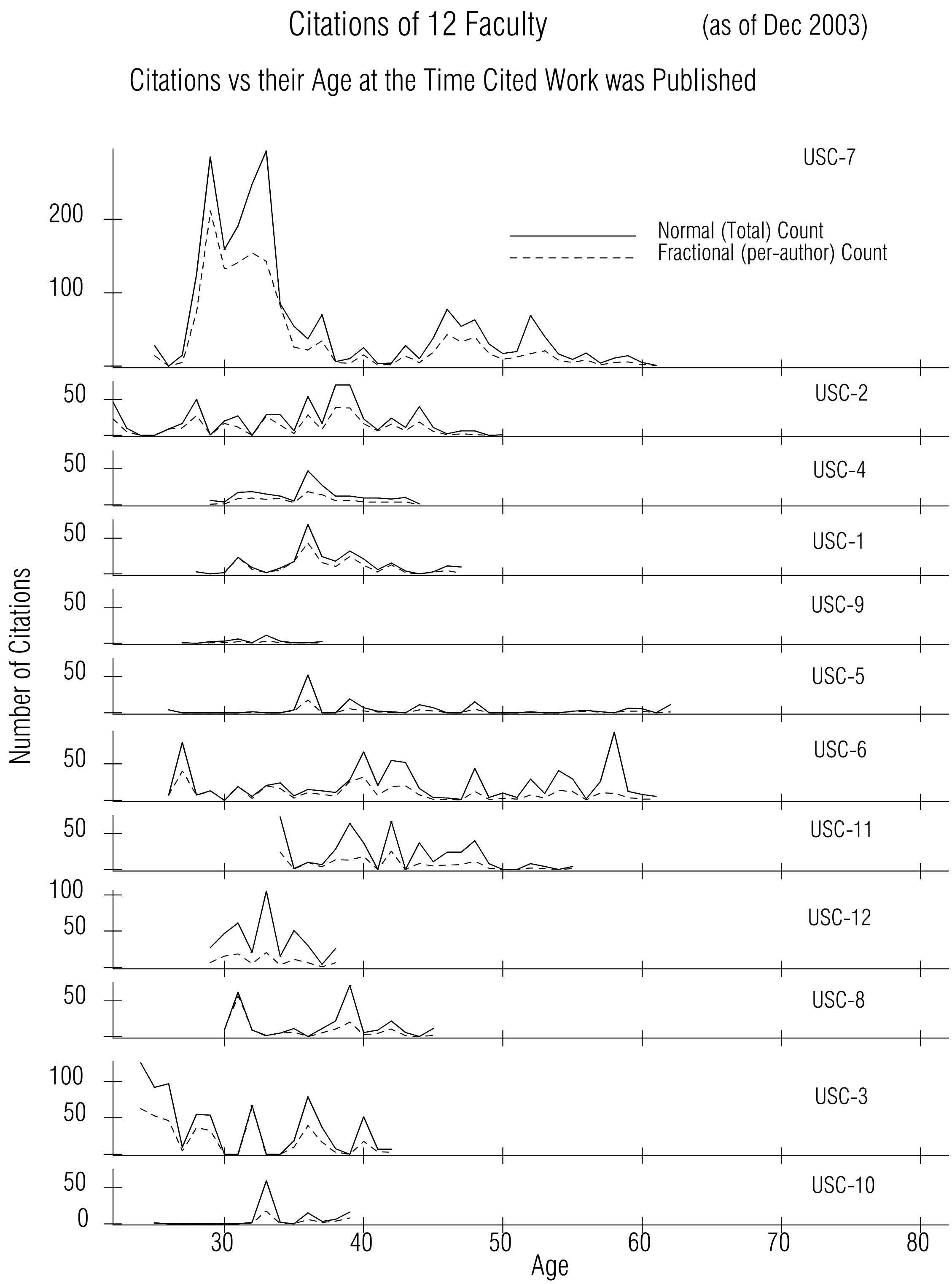

Fig. 30: Current (December 2003) number of citations, using normal (total) and fractional (per-author) counts, plotted versus the faculty age at the time the cited work was published.

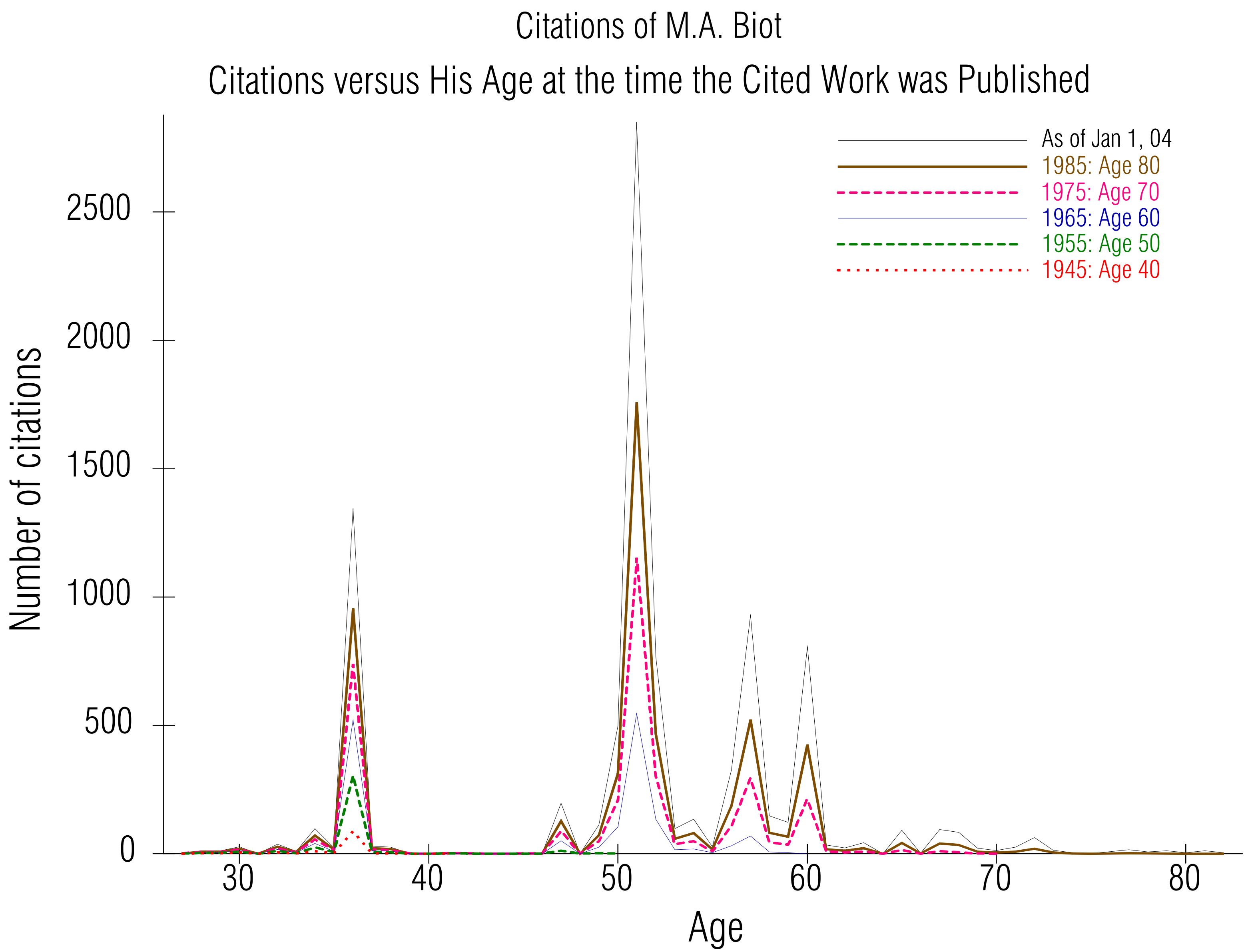

Fig. 31: Current total number of citations (as of January 2004) of M.A. Biot, and estimates of his total number of citations at age 40, 50, 60, 70, and 80, all plotted versus his age at the time the cited work was published.

career, so that the differences in lifetime productivity may be negligible. A decline in the effects of gender on scientific productivity may also be due to the increasing participation of females in scientific jobs (Xie and Shauman, 1998; see also top of Fig. D.1 in Appendix D).

In our sample of 12 USC faculty, there is only one female researcher, who is on the research track, and so we cannot make any general conclusions. Insofar as this analysis can show, her publication productivity is well above the average national trends and is certainly better than the publication productivity of many full-time faculty in our sample. Going beyond the Civil Engineering Department at USC, the data further show that her productivity and recognition are comparable to that of the best male researchers in earthquake engineering.

6.4 Citizenship

With an increasing number of foreign nationals in U.S. research and educational institutions, it may be expected that different cultures and languages may influence productivity. As reported by Bozeman and Lee (2003) the productivity of foreign-born researchers is somewhat higher than that of native Americans (see Table C.3 in Appendix C). In our sample of 12 USC faculty, only one was born in the U.S., but our sample is too small to study the effects of citizenship on productivity.

6.5 Education

Five of the 12 USC faculty in our sample (USC-1, USC-6, USC-8, USC-7, and USC-3) have Ph.Ds. from Caltech (Table 7). USC-2 earned his B.S. and M.S. degrees at Caltech and his Ph.D. at USC under the direction of USC-7. USC-4 earned the Ph.D. at USC under the direction of USC-2, and so it could be argued that USC-2 is the "first generation," and USC-4 is the "second generation" offspring of the Caltech "family." USC-12 earned his Ph.D. degree at Harvard, where, it could be argued, similar emphasis as that at Caltech was placed on the fundamentals. Thus, eight faculty from our sample of 12, or two thirds, come from similar educational backgrounds. In terms of most indicators of productivity considered in this work, this group is performing well and, in most cases, above the national average.

6.6 Some General Observations

One of the key observations of this and probably of other similar studies is that there is no short and direct path to glory. As the ancient Romans used to say, *per aspera ad astra* (through difficulties to the stars) is as true today as it was 2,000 years ago. Original and hard work and its systematic documentation in recognized journals (*per aspera*) may lead to recognition and respect. But whether some of these published ideas will ever evolve into the professional milestones and vehicles for the new ways of doing things (*astra*) depends upon persistence and luck.

Figure 31 shows citations (normal count) of M.A. Biot, the father of modern earthquake engineering (see Appendix E), plotted versus his age, at the time the cited work was published. From 1975 to January 2004, Biot received 9,214 citations, mainly derived from four groups of his contributions that were published in: (1) 1941, (2) 1956, (3) 1962, and (4) 1965, when he was 36, 52, 57, and 60 years old, respectively. The first group includes his papers 40 and 41 (see Fig. E.1 and Table E.1 in Appendix E); the second group includes papers 55, 57, 60, 61, 62, 63, 68, and 71; the third group includes papers 90, 97, and 99; and the fourth derives citations from his book *Mechanics of Incremental Deformations*. So far, Biot's paper that received the largest number of citations (1,447) is paper no. 60, published in 1956, which deals with the theory of propagation of elastic waves in a fluid saturated porous solid (see Table E.1 in Appendix E). During all other years, Biot's papers received on the average about 50 citations (Fig. 31 and E.1). A remarkable characteristic of all these highly cited papers is that Biot wrote them alone.

In Fig. 30, we showed citations for the 12 USC faculty in our sample, plotted versus their age at the time the cited work was published. In this figure, we use both normal (total) and fractional (per-author) counts. The vertical scale in this figure is similar to the vertical scale in Fig. 31, to enable comparison. It can be seen that emerging small "peaks" in Fig. 30 might be present but that none of these peaks so far has the growth rate of Biot's four major citation peaks. In Fig. 32, we show the number of cumulative citations versus years after publication for eight of the most cited papers by our sample of 12 faculty. The most cited papers of USC-1, USC-11, USC-6, USC-2, and USC-5 have citation rates of 0.5 to 1.5 citations per year. The most cited papers of USC-8, USC-7, and USC-3 have citation rates of about 3 per year, or about 15 times smaller than the rates of Biot's most-cited papers (Nos. 40 and 60, see Table E.1 in appendix E).

A positive consequence of the increasing use and interpretation of the ISI database is not only that it will help weed out the culture of appearances but also that it will help quantify the realities. For example, our analysis of 12 faculty in civil engineering has shown examples of excessive emphasis on conference papers (and, presumably, conference participation) (USC-9, USC-6, USC-10, see Fig. 12a and 15), and the consequences of such a strategy, which results in fewer journal papers and fewer subsequent citations. Active participation in conferences is useful and educational for almost every academic researcher, but it should not be done at the expense of writing journal papers, reports, and monographs.

To the extent that it contributes to the scientific growth and productivity of the faculty, we found that active collaboration (USC-12) can be rewarding and beneficial (Bozeman and Lee, 2003). Passive collaboration (USC-10, USC-5), in which the researcher plays a minor or only a supporting role, should be avoided.

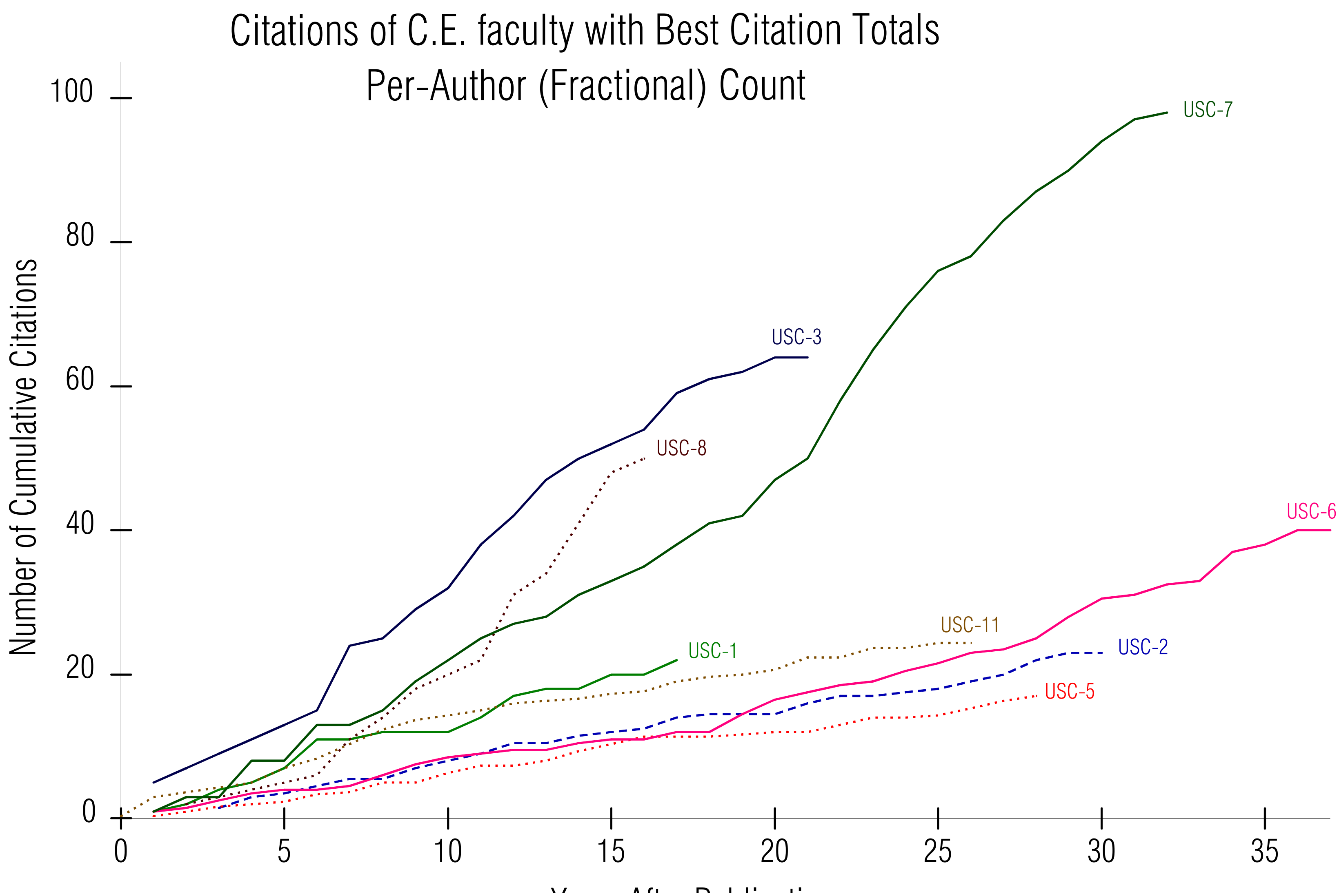

Fig. 32: Number (per-author) of cumulative citations versus years after publication for most cited papers of 8 USC faculty.

Analyses of the trends examined in this work (e.g., publications per year, citations per year, etc.) suggests that the “initial conditions” are stable in the sense that initially small publication rates and citation rates stay small (see, for example, Fig. 27 and 29). These performance characteristics can be helpful for future deliberations of appointment, promotion, and tenure committees.

7 RECOMMENDATIONS

In the following, we give examples of several "problems" and their "solutions" that follow from the above examples and discussion.

Problem 1. The current procedures for Faculty Merit Evaluation (FME) in the USC School of Engineering do not measure publication productivity adequately, in that they assign equal weight to all publications regardless of the number of co-authors. This leads to giving proportionally larger credit to authors who engage more co-authors, which gives rise to biased estimates.

Solution 1: In the FME, the total number of publications should be replaced by $\sum_i 1/a_i$ and $\sum_i q_i/a_i$, discussed previously in this report, in which a_i is the number of co-authors, and q_i is the current Journal Impact Factor (JIF) for the respective journal.

Problem 2. At present, in FME all published papers are given full credit, regardless of their relevance (i.e., whether they have ever been cited). The aim should be to reward quality, not just quantity.

Solution 2. The total (per-author) citations, with self-citations excluded, compiled from the ISI database and received during the previous calendar year should become a separate new item in the merit evaluation forms. In this process, the differences in citing rates (cultures) among different fields of sciences and engineering can and should be accounted for.

Problem 3. In the present system, faculty can be appointed (and promoted) without having published one single-author paper in a reputable journal. Independence and early demonstration of the ability to create original ideas are indicators of scientific productivity later in the academic and research career. Within the scope of this report, appointment and promotion of faculty with performance characteristics similar to those in Groups A, B, and C (see Figures 14a,b,c) should be encouraged. Faculty with characteristics analogous to those illustrated here by Group E should neither be appointed nor promoted, unless they have some other outstanding and demonstrable academic qualities.

Solution 3. An analysis of the distribution of the publications contributing to the existing citations in the ISI database, and solicitation of opinions of former advisors and teachers, can help identify and quantify this problem, when present.

What should be done? To implement the above recommendations, it is necessary to prepare a "matrix" (see Tables 1 in Appendix F) maintained and updated once a year by all faculty. This matrix should become an integral part of the file prepared by faculty for the yearly merit evaluation process. For verification of accuracy and authenticity of the data summarized in the matrix, each faculty member should maintain the list of actual citations, extracted from the ISI database, which will be used to prepare the matrix.

Benefits. We are convinced that the principal benefit of the proposed introduction of the "matrix" into the yearly faculty merit evaluations is that this will lead to positive feedback and self-improvement. As faculty members prepare the data for the "matrix," they will learn about their own strengths and weaknesses and will use this information to develop individual strategies for self-improvement. We are also convinced that, having seen and analyzed their own data, faculty will develop new ideas and ways to interpret this data, which will improve and elevate this type of analysis and help us to make new and innovative qualitative jumps in our academic performance.

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