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Women in Science. Part 1. The Productivity Puzzle—J. Scott Long on Why Women Biochemists Publish Less than Men

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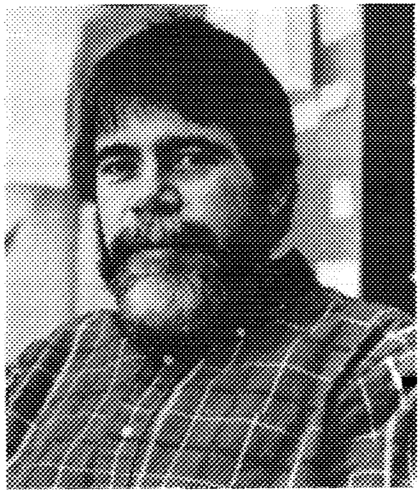
Introduction

It is not often that a long-standing controversy in science is given prominent attention in the public press. But the underrepresentation of women and minorities in science has recently become a "high profile" issue. In a rare two-part commentary on the *New York Times* Op/Ed page, Shirley M. Tilghman, a Princeton University molecular biologist, described the many cultural forces that "retard the rate at which women enter the scientific workforce."[1,2] Her solutions are to recruit more women, promote them to senior positions, and replace tenure with a system of regularly reviewed rolling appointments. She also mentioned the "firestorm" sparked by Radcliffe President Linda Wilson, who suggested that the male dominated and defined culture of science must change to accommodate more women and minorities.[3,4]

This recent publicity just shows that the scientific community is struggling with the same issues confronting society in general. In this case, the equitable participation of women, minorities, and others in the profession. It is certainly not news to researchers that women are underrepresented by almost any measure. In terms of graduate and doctoral degrees, enrollment, senior faculty or management posts, salaries, academy memberships, and other indicators, previous studies have convincingly documented that women are unequal partners in science and engineering. An excellent review of this extensive literature is provided by Harriet Zuckerman, Andrew W. Mellon Foundation, New York, in *The Outer Circle: Women in the Scientific Community*.[5]



J. Scott Long

The reasons and solutions for this are too numerous to detail here, and were briefly discussed previously.[6] But one aspect of this great debate has particularly interested me—how data on the number of papers and citations are used to examine differences between women and men in science. Studies covering various fields and different time periods have documented a clear difference—women publish fewer papers. But the reasons for this have not been conclusively established.

The Productivity Puzzle: Women Publish Less, but Why?

Many causes for the lower comparative productivity of women scientists have been suggested. An intuitively obvious reason is that women scientists must balance career demands with family obligations, especially bearing and raising children. But Zuckerman and Jonathan Cole, Columbia University, reported that marriage and parenthood do *not* affect women's publication rates.[7,8] Other reasons, ranging from subtle cultural barriers to blatant sexual discrimination, have also failed to fully account for the lower productivity of women scientists. Cole and Zuckerman have referred to this as the "productivity puzzle."[9]

As I've pointed out previously, the underrepresentation of women in science and their lower productivity do not mean they cannot produce high impact research.[6] For example, in a study of the 1,000 most-cited scientists from 1965 to 1978, 28 women scientists were identified.[10] The average number of papers per woman was indeed lower—88 versus 121 for all 1,000 authors. Also, their average citations were slightly less—3,650 versus 3,811 for the entire group. But it is interesting to note that the women's average impact (citations divided by papers) was substantially higher—41 versus 32 for all 1,000 authors. Keep in mind that the 1,000 authors represented a wide range of fields in the life, physical, and chemical sciences. Citation rates can vary significantly between different specialties.

Of course, this is by no means a random sample. Rather, the authors were among a very select group, the citation "elite" of researchers. But the lower productivity—and higher impact—of women scientists was documented in a well-designed study of biochemists by J. Scott Long, Indiana University, Bloomington.[11] It is being reprinted here in two parts.

Long's sample consisted of 556 males who earned biochemistry PhD's during 1956-1958 and 1961-1963, and 603 women who received their doctorates during 1950-1967. Over a 17-year period, he tracked 25,000 papers they published and the number of citations received. In terms of productivity, males averaged 26 percent more publications during the first three years, increasing to 66 percent between years three and four, and 91 percent by the ninth year. But the percentage differences thereafter declined to 59 percent by the 17th year. These trends result from the steady level of *non*publishing females and the increase in male nonpublishers. Also, while the average male's productivity levels off, females maintain and even increase their output over time. These data and results are discussed in detail in the first part of the reprint that follows.

The Impact Enigma: Women Have Higher Impact, but Why?

As will be seen in part 2, similar trends were found in terms of average citations per *author*. No significant differences were observed in the first three career years. Beginning in year four, mean citations for females drop substantially while increasing for males. But at the 10th year, average citations for males level off and increase for females. By year 17, averages for males and females are nearly identical. Long concludes, not surprisingly, that these differences "are *totally* the result of differences in the numbers of articles."[11] This confirms Zuckerman's earlier finding that "aggregate differences between men and women in numbers of publications account for their differences in citations."[5] (p. 46)

Most interesting, in terms of average citations per *paper* (impact), women fare better than men. Papers by males averaged seven to nine citations over the 17-year period and remained fairly stable. But females averaged between 9 and 13 citations per paper, and their impact steadily increased from years 10 to 17. By the 17th year, the average female's paper was cited 1.5 times more frequently than the average male's paper.

Long speculates on the reasons for this but concludes that more detailed analyses are needed to account for the higher impact of women biochemists. This "impact enigma," to coin a phrase, is as intriguing as the productivity paradox and deserves as much attention by sociologists of science.

About the Author

J. Scott Long received a bachelor's degree from Juniata College, Huntingdon, Pennsylvania, in 1973. He earned both a master's and doctoral degree in sociology from Cornell University, Ithaca, New York, in 1975 and 1977, respectively. He has been a faculty member of Washington State University, Pullman, and currently is professor of sociology at Indiana University.

The author of more than 30 papers and books, Long is editor of *Sociological Methods and Research* and has served on the editorial board of *Science and Technology Studies*. He is a member of the American Sociological Association, American Association for the Advancement of Science, Society for the Social Studies of Science, Social Research Association, American Statistical Society, and Psychometric Society. His primary research interests currently focus on sex differences in scientific careers as well as quantitative analyses and models in sociology research.

Conclusion

The second part of Long's study will be presented in the March 15 issue of *Current Contents*®. It examines the effects of collaboration—with mentors, colleagues, and spouses—on differences in productivity between female and male biochemists. Differences in author's position on the paper's byline are also discussed. In addition, part 2 presents detailed longitudinal trends in both author and paper impact for women and men.

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My thanks to Al Welljams-Dorof for his help in the preparation of this essay.

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Measures of Sex Differences in Scientific Productivity*

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Abstract

Satisfactory and robust explanations of sex differences in scientific productivity remain elusive. This article provides a multidimensional, longitudinal description of the productivity of male and female biochemists. Several findings have implications for explaining differences in productivity. Sex differences in the numbers of publications and citations increase during the first decade of the career but are reversed later in the career. The lower productivity of females results from their overrepresentation among nonpublishers and their underrepresentation among the extremely productive. Among biochemists who publish, differences cannot be explained by patterns of collaboration, which are nearly identical for males and females, with one exception: females are much more likely to collaborate with a spouse. The smaller number of citations received by females results from their fewer publications, not from the quality of their publications. Papers by females on average receive more citations than those by males. These and other findings suggest future directions for research to understand sex differences in scientific productivity.

Explaining the immense variation in the productivity of scientists is a major research objective in the sociology of science. The sex of a scientist is an important source of variation in scientific productivity. The lesser productivity of females has been established in dozens of studies covering diverse fields, spanning decades, and using a myriad of measures (see Cole & Zuckerman 1984; Fox 1983; Hornig 1987; Long 1987; and Zuckerman 1987 for reviews of this literature). Many explanations for sex differences in productivity have been proposed. Differences may exist in personal characteristics such as ability, motivation, and dedication, or in educational background. Obligations of family and children may differentially affect the careers of males and females. Discrimination may make resources more difficult for females to obtain, which in turn can limit their ability to publish. A fifth explanation magnifies the effects of other processes. The importance of even small differences in levels of causal variables and subtle forms of discrimination may be enhanced by processes of cumulative advantage and disadvantage (Merton [1968] 1973). Unfortunately, none of these explanations has been very successful in accounting for sex differences in productivity. Indeed, Cole and Zuckerman (1984) aptly label these sex differences "the productivity puzzle."

The premise of this article is that the failure to explain sex differences in productivity is partially the result of incomplete descriptions of what it is that needs to be explained. Too often studies of sex differences in productivity are based on the differences in means of a few indicators of productivity measured at a single time.[1] The resulting evidence is limited in three important ways. First, comparisons of means mask differences in the distributions of productivity. For example, knowing that the average male publishes twice as much as the average female provides no insights on whether these differences are due to a disproportionate number of females having low productivity, a disproportionate number of males having extremely high productivity, or some combination of these. A given difference in means can be generated by a variety of distributions generated by substantively different processes. Second, there is no single measure of produc-

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tivity that is adequate or universally accepted (Fox 1983; Edge 1979). While number of publications and citations are the most commonly used measures, other factors such as the number of coauthors and author position need to be considered. And finally, it is important to understand how differences change over time. Processes of cumulative advantage are fundamental to the scientific career (Merton [1968] 1973), and such processes operate over time.

This article provides a multidimensional, longitudinal *description* of how male and female biochemists differ in scientific productivity. The questions of interest are, What is the degree of difference in productivity? Does it vary over time? Is it uniform across measures of productivity? Without more complete answers to these questions, attempts to model the processes generating sex differences in productivity are necessarily limited.

Data and Sample

The population is defined as all males who received Ph.D.'s in biochemistry during the periods 1956-1958 and 1961-1963 (N=556) and all females who received Ph.D.'s in biochemistry from 1950 to 1967 (N=603). The larger range of years for females is necessary due to the smaller number of females receiving Ph.D.'s in biochemistry. The roster of sample members was obtained from inquiries to departments of biochemistry and university registrars, checks of dissertation abstracting services, examination of the American Chemical Society's *Directory of Graduate Research* (*DGR*), and a search of commencement rosters. Complete biographic and bibliographic information was coded for approximately 80% of both males and females (556 males, 603 females). A significant number of those for whom complete information was unavailable appear to be either non-U.S. citizens who returned to their home country or persons who left the field of biochemistry. The sample may be thought of as the most visible 80% of the Ph.D.'s graduating during the years sampled.

The name of the mentor or dissertation supervisor was found for 98% of the sample, using the *DGR*, dissertation abstracting services, inquiries to the department and institution of the degree, and mailings to cohort members. Information on collaboration with a mentor was obtained by searching for the mentor's name on the list of authors for each student's papers.

Information on 25,000 articles published in refereed journals was coded from *Chemical Abstracts*. Citations were coded from *Science Citation Index*® for each of the three years following a paper's publication. Since there may be sex differences in rates of being the first author, both first- and junior-authored papers were coded. To smooth out yearly variations, productivity measures for a given year were averaged over three years, including the year before and the year after the given year. For females particular attention was paid to name changes resulting from marriage and divorce. If a name change is not known, a female's publishing may appear to halt when in fact the publications were missed due to name changes.[2]

Given the possibility of cohort effects due to changes in the scientific labor market, the legal and social environment of science resulting from the passage of Title VII in 1964, or the nature of research within biochemistry, comparisons of males and females could be misleading if controls are not introduced for the different years during which degrees were obtained. For this reason the female sample was split into three cohorts: the cohort receiving degrees between 1950 and 1955, hereafter the 1950 female cohort (N=153); the cohort receiving degrees between 1956 and 1963, hereafter the 1956 female cohort (N=230); and the cohort with degrees obtained after 1963, hereafter the 1964 female cohort (N=220). The males who received their degrees between 1956 and 1963 are referred to as the 1956 male cohort (N=556). Analyses focus on the 1956 cohorts of males and females, since these allow comparisons that are not contaminated by different Ph.D. years. For example, it is impossible to determine whether differences between the 1956 cohort of males and the 1950 cohort of females are sex differences or cohort differences. Comparisons among the three female cohorts are given when significant differences are found.

Results

Three dimensions of productivity are used: frequency, collaboration, and utilization. While frequency of publication is the most fundamental dimension, it has been criticized for failing to account for collaboration or to standardize for quality (Lindsey 1978; Nudelman & Landers 1972; Porter 1977). Collaboration is examined by considering the number of authors of a paper and the existence of certain types of collaboration, for example, collaboration with a mentor. Quality of work is notoriously difficult to operationalize and has generated substantial debate (cf. Cole & Cole 1973; Edge 1979). In this article the dimension of quality is thought of in terms of the impact and utilization of articles. Two indicators are used: number of citations and the impact of the journal publishing the article. Finally, these measures are combined in various ways, such as weighting each article by the inverse of the number of authors.

FREQUENCY OF PUBLICATION

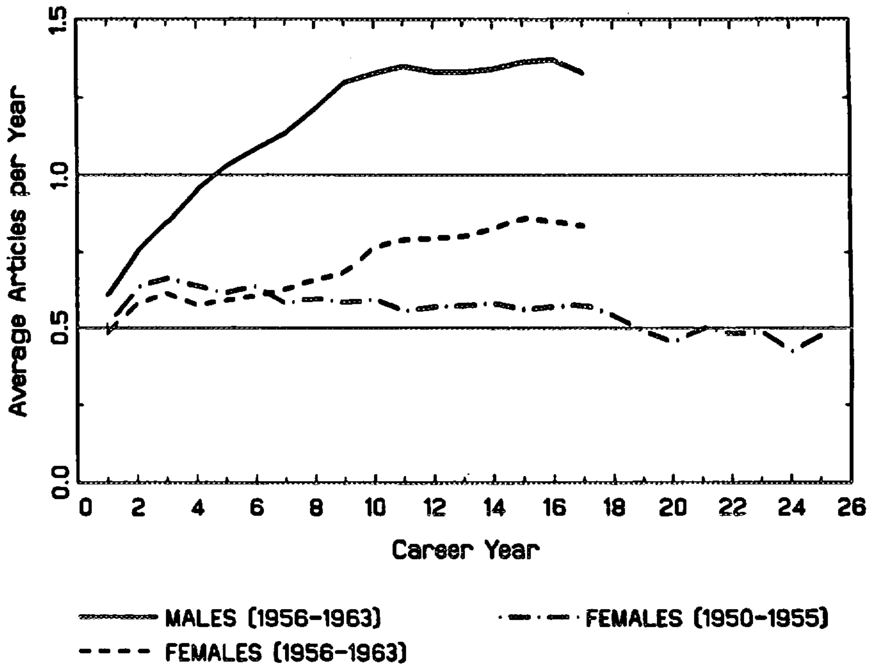
My strategy for describing sex differences in frequency of publication is to begin with the mean number of publications and to elaborate this description by taking closer looks at the shape of the distribution. Sex differences in publications begin during graduate school, increase over the first decade of the career, and then slowly decline. This information is shown in Figure 1, which plots the average yearly number of articles for the 1956 cohorts of males and females and the 1950 cohort of females.

First, consider males and females from the 1956 cohorts. Differences in publication are slight during the first three years, with males starting with 26% more publications. The percent difference jumps to 66% between years three and four, a period roughly corresponding to the end of postdoctoral positions and the start of permanent employment. This result suggests that females are less successful in translating their postdoctoral investment into increased productivity by means of secure employment. Percent differences steadily build, until males average 91% more publications by the ninth year. At this point the productivity of males levels off, while that of females continues to increase. As a consequence, the percent differences steadily decline, to 59% by year seventeen.

Figure 1 is significant in two major respects. First, while cumulative advantage may explain the increasing differences in publications during the first decade, it cannot account for the reversal in the second decade. Second, the steady increase in the average number of publications for females indicates that a substantial proportion of females maintain and enhance their productivity despite difficulties they may encounter. The erosion in percent differences is all the more significant because it is based on the entire cohort of females, not just on those who remain active in science. If females are more likely to drop out of science, sex differences in levels of publication for active scientists would be even smaller. Female scientists in the 1956 cohort and in the 1964 cohort (data not shown) do not appear to be marginalized to the extent that they abandon their research careers.

Publication levels for the 1950 cohort of females are consistent, with a pattern of steady decay in scientific activity. This is shown by the long dashed line in Figure 1. The early cohort of females begins with a rise in productivity until the third year, followed by a steady decline through the twenty-fifth year. By the sixteenth year, the last year for which we have data for males, males are nearly three times more productive. Differences between the 1950 cohort and later cohorts are also found in many of

FIGURE 1: Average Number of Articles by Career Year



the analyses below. Explanations are considered in the conclusion.

Cole and Zuckerman (1984) present twelve years of bibliographic data for a sample of 263 pairs of male and female Ph.D.'s in astronomy, biochemistry, chemistry, earth sciences, mathematics, and physics. They found increasing differences with time but did not uncover a reversal of the trend toward increasing differences in publications, perhaps due to their shorter time series. The new evidence on the reversal of differences in productivity suggests the need to examine sex differences over more than the first decade of the career.

STABILITY OF PRODUCTIVITY

In addition to having fewer publications than males, the publication rates for females are less stable, a result consistent with findings from Zuckerman and Cole (1975). Table 1 presents the correlations over time among article counts for males and females from the 1956 cohorts. The hypothesis that the correlation matrices are equal can be rejected (χ^2=38.70, df=15, p=.001), with correlations for males being on average .11 larger. The correlations among measures at adjacent times are the most informative. They are smallest between years one and four, reflecting the substantial changes that can occur as a scientist leaves graduate school and enters the job market. The correlations between adjacent years for males increase until year ten and then gradually decline. This period of decline corresponds to the leveling off in the mean number of publications starting at year ten. For females, the correlations start much lower than for males and increase steadily, until the correlation between years thirteen and seventeen is slightly higher than that for males. The steady increase in the stability of publication corresponds to the steady rise in the average number of publications for females as seen in Figure 1. Both increases

TABLE 1: Correlations among Article Counts over Time for 1956 Cohort[a]

	Year 1	Year 4	Year 7	Year 10	Year 13	Year 17
Year 1		.412	.386	.381	.313	.316
Year 4	*.296*		.650	.599	.528	.487
Year 7	*.338*	*.469*		.765	.617	.576
Year 10	*.210*	*.351*	*.577*		.709	.651
Year 13	*.173*	*.273*	*.521*	*.649*		.674
Year 17	*.185*	*.261*	*.440*	*.601*	*.690*	

[a] Males (*N*=556) above diagonal; females (*N*=230) below diagonal, in italics

may be the result of females attaining more stable and adequate working conditions.

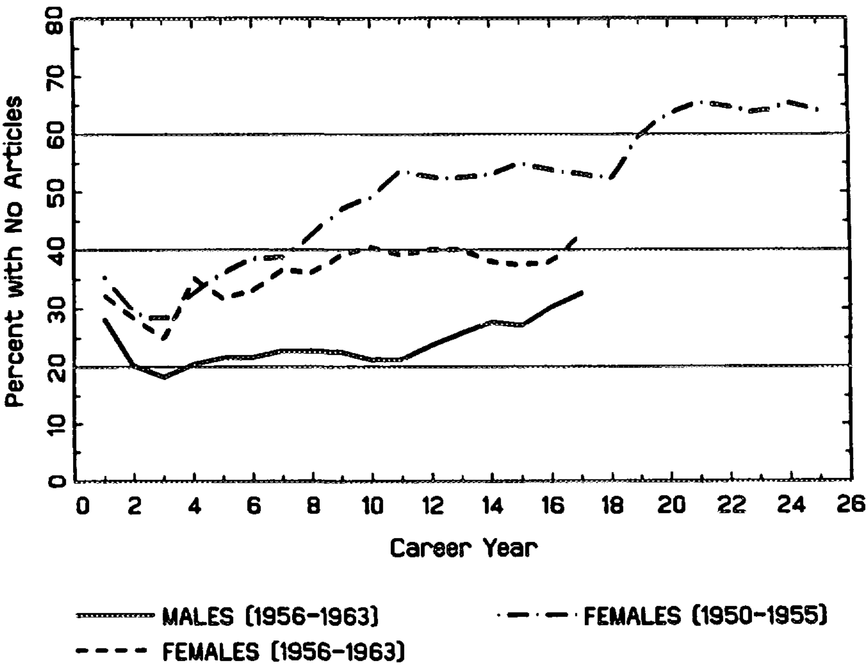
THE DISTRIBUTION OF PUBLICATIONS

The distribution of publications is highly skewed. The lower extreme of productivity is represented by those who do not publish. Lack of publication may represent at least three types of activity: a scientist who normally publishes may have a period during which no papers are submitted or accepted for publication; a scientist may be actively involved in research but may not be in a position where publication is allowed or required; or a Ph.D. in science may no longer be active in science, for example, when raising a family or pursuing other types of work. Since the measure of nonpublishers is based on counts over a three-year period, the definition of nonpublishers is more likely to reflect a long-term lack of research activity than a momentary fluctuation in a steady flow of publications.

Figure 2 plots the percent of nonpublishing Ph.D.'s over a three-year period, centered in the given year. This figure clarifies the findings from Figure 1. First, the lower productivity of the 1950 cohort results from a greater proportion of nonpublishers. Among those who publish, the level of productivity closely matches that of the 1956 female cohort. Second, the sharp divergence in mean publications between years three and four for the 1956 cohorts results from the jump in female nonpublishers in year four. This jump would be expected if the 53% of the females in the 1956 cohort who began their careers with postdoctoral fellowships had difficulty obtaining adequate employment at the end of the postdoctoral period. This timing is consistent with the 2.6 years mean duration of postdoctoral fellowship for this cohort. Third, the leveling of mean publications for males is due to an increase in the percent not publishing beginning in the eleventh year. Among those who continue to publish, the mean productivity steadily increases. And finally, the convergence in mean publications for males and females results from the increase in nonpublishers among males and the steady level of nonpublishers among females. Overall, differences in publication levels are reduced if only scientists who are actively publishing are examined. This finding may explain inconsistencies in the literature, since some studies are based on all scientists and others are based only on active scientists.

The mean is also sensitive to extremely productive scientists. Thus, to understand the changing relative productivity of males and females, it is useful to consider the entire distribution of productivity. Figure 3 compares the distributions of publications over the first seventeen years of the career, using box plots (Cleveland 1985). Box plots consist of a box in the center with whiskers (i.e., vertical lines with small horizontal lines at the end) at each end. Consider the first solid box plot in Figure 3. The horizontal line at the end of the top whisker corresponds to the 95th percentile of the

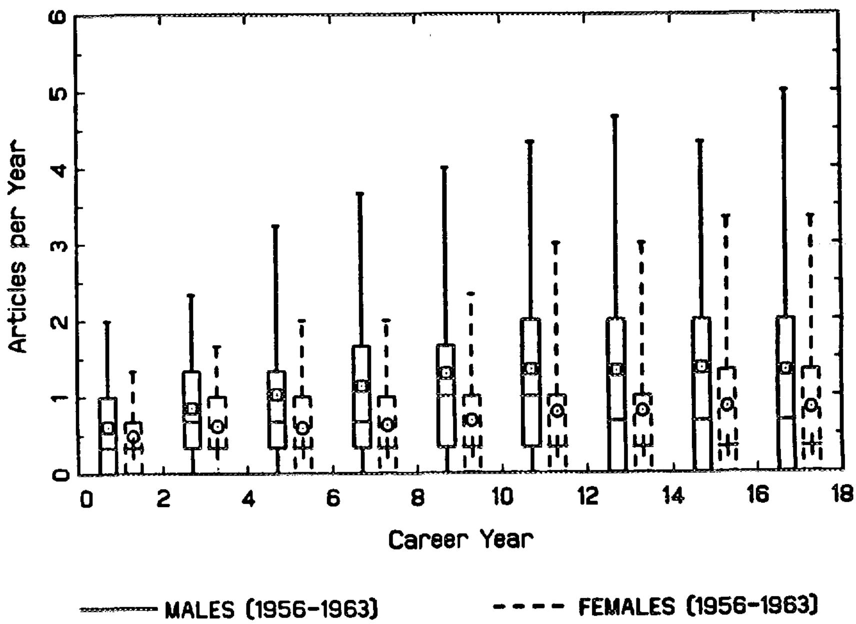
FIGURE 2: Percent of Cohort Members with No Articles by Career Year



distribution.[3] Thus, 95% of males average 2.0 or less articles per year. The horizontal line at the top of the box, located at 1.0, marks the 75th percentile. The horizontal line in the middle of the box is the median, or 50th percentile. To help distinguish the medians for males and females, the medians for females have a small vertical line in the center. The bottom of the box locates the 25th percentile. The median and 25th percentile are usually distinct, although in some cases (e.g., females in the third year) the median and the 25th percentile have the same value and the lines coincide. There is no whisker at the bottom of the box since the 25th and 5th percentiles coincide.

The small squares and circles indicate the means for males and females, respectively. This information corresponds exactly to that in Figure 1. By considering the change in the quartiles of the distribution, additional information on how the means change can be obtained. Consider males first. In year one, the 25th percentile is 0; it increases to .33 for years three through nine and then returns to 0. This corresponds to the drop in the percentage of nonpublishers after obtaining a Ph.D. and the subsequent rise in the percent that was shown in Figure 2. The median rises from .33 in year one to .66 in years three through seven and to 1.0 from years nine through eleven, with a drop to .66 for years thirteen through seventeen. The leveling off of the mean observed in Figure 1 reflects the increasing proportion of scientists averaging less than one article per year. At the same time, the spread between the median and the 95th percentile and from the 75th to the 95th percentile increases with time, with a small reversal in year fifteen. Changes in mean publication result from a dual process in which the most productive scientists increase their productivity relative to other scientists, and the proportion of scientists with very low productivity increases.

FIGURE 3: Box Plots of Articles by Career Year



For females the 25th percentile in year one is 0; it increases to .33 in year three and then drops to 0 for the remaining years. The median is .33 for all years, indicating that at least half of the cohort averages .33 or less articles per year throughout the first seventeen years of the career, compared to .66 and 1.0 for males. The median is lower for females than for males, but unlike the median for males, it does not drop later in the career. The failure of the medians to show the steady increase of the mean reflects the influence of high publishers on the means. More females than males are low publishers, but their proportion does not increase over time. While the median is constant, the 75th percentile steadily increases, from .66 in year one to 1.0 in years three through thirteen and to 1.33 for years fifteen through seventeen. As with the males, the spread from the median to the 95th percentile increases over time. While the 95th percentile increases steadily for females, the difference between the 95th percentile for males and the 95th percentile for females stays nearly constant for years five through seventeen.

The following conclusions can be drawn about the changing ratio of publications for males and females. First, the male-to-female ratio of medians is larger than the ratio of means, reflecting the lesser productivity of the least productive half of the female cohort compared to the least productive half of the male cohort. Second, while the female lower half is less productive than the male lower half, the productivity of the least productive half remains constant for females but decreases for males. The male lower half is responsible for the leveling off of the means observed in Figure 1. Third, the most productive scientists increase their lead over the least productive through time. If one considers the mean publications of the most productive 25% of scientists in each year (figure not shown), their average number of publications increases more rapidly and steadily than the average for all cohorts. Finally, differences in means are determined by both extremes of productivity. A greater proportion of females have very few publications, and the most productive males exceed the productivity of the most productive females by a factor that is generally larger than the difference among all cohorts. In short, both tails of the distribution are important for understanding sex differences in the publication of papers. While Zuckerman (1987) suggests that sex differences in productivity are largely the result of differences in the upper extremes of productivity, the current results suggest that differences in the least productive scientists may be even more important.

[**Editor's Note**: In part 2, to be published in the March 15 issue of *Current Contents®*, Long discusses the effects of collaboration on sex differences in productivity, author position in paper bylines, and sex differences in citations per author and paper.]

Notes

1. Cole and Zuckerman's (1984) "The Productivity Puzzle" is an important exception to this statement. Indeed, the current article can be viewed as an extension of their article.

2. Several methods were employed to track name changes. The request for a vita asked scientists to list names used for professional work. Articles on the vita were checked for name change. For those not providing such information, the names of all female biochemists listed in biographical sources were recorded. *First* names were matched against those of sample members. Matches were compared to determine if it was the same person using a new last name. Finally, for females whose flow of papers suddenly ceased, *Science Citation Index®* was used to find papers that cited the scientist's earlier work. In some cases the citing papers were written by the same scientist using a new last name. One indication of the impact of name changes is that 11.7% of the female scientists who published at least one article used two or more last names for their papers. A larger percentage used variations in how their first, middle, and maiden names were indicated.

3. The top whisker in a box plot normally ends at either the 90th percentile or 1.5 times the distance from the median to the 75th percentile. Given the highly skewed nature of the publication distribution, using the 95th percentile was more informative.

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