# Gender and Commercial Science: Women's Patenting in the Life Sciences

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ABSTRACT. Traditional research on gender differences in productivity focuses on academic scientists, and rarely investigates outcomes other than publications. We investigate gender disparities in *commercial* outcomes, for scientists in *both* the academic and industrial sectors. Using a unique combination of career history data and patenting information across a period of two decades, we present descriptive statistics and graphical trends of male and female commercialization. Empirical evidence indicates that female scientists engage in and produce less commercial work then their male counterparts, and that the degree of disparity remains constant across time. The quality and impact of women's commercial work remains the same or better than that of men scientists, however. These results imply that a necessary focus for future work is to understand the personal, structural, and organizational reasons for the filtering process which leads to such a small proportion of female inventors.

**JEL Classification:** J16, O31, J24

## 1. Theoretical framework

The past two decades have witnessed significant changes in the organization of scientific research within universities and industrial firms. The life sciences well illustrate two increasing trends in science: women's involvement, and commercial behavior. Both have stimulated separate literatures, but are not often investigated together. In this paper, we examine the two trends simultaneously by focusing on gender differences in patenting among life scientists. Traditionally, research on gender differences in scientific productivity has investigated disparities in *publication* counts by *academic* scientists. While women have published less than their male counterparts, it remains unclear how recent emphases on patenting have affected the long-standing differences in productivity. In addition, little is known about how the gender productivity gap in academia compares with industry. Conventional measures of productivity need to be expanded to include commercial science, and to be put in organizational context.

### *Women in academic science*

The life sciences are often held up as an example of a place where women have made inroads into the natural science domain. Nearly 45% of the 2001 life science PhD recipients in the US were female, compared to less than 25% in 1977 (NSF, 2004: calculated from Appendix table 2–26). Yet there continues to be a gender gap in the pay and promotion of life scientists, to women's disadvantage (Fox and Stephan, 2001; Long, 2001; Smith-Doerr, 2004a). This gap has frequently been linked to assessments of men's and women's publishing productivity. Publications are taken as an indication of a scientist's research capabilities, and thus important determinants of career outcomes. Many studies have found female scientists to be less "productive," that is, to publish less often than their male counterparts in the academy (Cole and Cole, 1973; Fox, 1983; Zuckerman, 1987; Levin and Stephan, 1998; Long, 2001). Characterized most famously in 1984 by Cole and Zuckerman, this "productivity puzzle" has persisted despite changes in the scientific workforce. In a study of biochemists, Long (1992) found that although women publish less often, their publications had greater impact than men's across career years.

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Articles by women biochemists consistently received more citations on average than those written by their male colleagues.

A criticism of early research on the gender gap in productivity (conducted in the 1970s and 1980s, see Zuckerman, 1988 for a review), however, is its focus on individual status mobility. This individualist focus fails to consider how the organization of academic work is gendered. Grant *et al.* (22000) argue that the traditional academic imperative to pursue high productivity during prime child-raising years is not based on any rational organizational goal, but rather reflects a sexist assumption about who does science and when they should do it. In other words, productivity gaps must be viewed in a broader context of who has the opportunity to publish (Bozeman *et al.*, 2001). An adjunct professor with a heavy teaching load and small children at home inhabits a very different context than a full professor teaching only graduate students and with a spouse to manage the household. Women scientists are much more likely to have non-tenure track positions; men scientists are more likely to be full professors (Long, 2001). Indeed, much of the publishing productivity puzzle seems to be explained by organizational and family context (Xie and Shauman, 1998).

From the literature on women in science we take the following lesson: it is important to understand productivity differences by gender, to consider the quality of what is produced, and to view these in a broader context. In addition, we argue that it is important to consider scientific productivity as more than publishing—patenting is becoming an increasingly important benchmark by which scientists are being held accountable. Especially in the life sciences, productivity is beginning to include patenting as well as publishing.[1]

### *Patenting productivity*

In the past two decades, federal promotion of universities' commercial involvement and industrial firms' increased reliance on academic science have created growing similarities between the activities of firms and universities. Most prominently, the 1980 Bayh-Dole Act allowed universities to patent applications that arose from federally funded research, and the 1981 Economic Recovery Tax Act allowed for-profit firms tax credit for funding university science. Although the actual effect of the Bayh-Dole Act on patenting activity among US elite universities is less than clear, such legislative acts are now being adopted by other nations to signal governmental commitment to promoting university-industry ties (Mowery *et al.*, 2004).

The growing similarities between universities and firms are particularly visible in the life sciences. Universities are increasingly concerned with the commercial outcomes of science (e.g., the establishment of technology transfer offices), and science-based firms pay attention to markers of scientific reputation (e.g., publication in prominent journals). The blurring of the organizational boundaries between university and firm arise in part from the collaborative ties between the two sectors. These ties may take different forms—funding of research projects, collaborative R&D, exchange of graduate students, licensing of patents, informal advice networks (Slaughter and Leslie, 1997; Owen-Smith, 2003; Croissant and Smith-Doerr, forthcoming).

As the lines between university and commercial science become blurrier in the new economy, science careers also take on a composite character. In addition to seeing industrial scientists publish, increasingly we see academic scientists patenting, particularly in the life sciences (Kleinman and Vallas, 2001; Owen-Smith, 2005). A university dean interviewed by Kleinman and Vallas (2005) predicted that tenure decisions would soon ride on academic scientists' "number of patents, number of companies...and the impact on the economy." And in commercial firms, one can find "star" scientists who publish some of the most highly cited articles in the biological sciences (Powell *et al.*, 1996; Stephan, 1996; Zucker *et al.*, 1998). Research on the extent to which scientific productivity across sectors has changed, however, has typically paid little attention to the under-representation of women in positions of power in science organizations.

We view organizational context as a key feature to explore in investigating patenting productivity by gender. A descriptive study by Morgan *et al.*, (2001) notes that women who patent are more likely to be life scientists (43%) than engineers (8%), particularly among academics. Yet because women are generally more likely to be life scientists than engineers, perhaps the more interesting statistic is that in industry 32% of female engineers had patent activity, as did 28% of the female life scientists (Morgan *et al*., 2001). Bunker Whittington (2005) found that gender disparities in the involvement in publishing and patenting activities were greater among life scientists in academia than in industry. Among life scientists, Smith-Doerr (2004a) discovered that women found the most career advantages in entrepreneurial science-based firms. Women life scientists were nearly eight times more likely to move into positions of authority in biotechnology firms than in other types of work settings. Thus, based on prior research, we would expect that gender disparities in commercial behavior would be less in industry settings than in academic settings, particularly in biotechnology firms. To this end, we investigate the extent to which gender differences in commercialization behavior exist across the academic and industrial employment sectors.

### *Gender and commercial science*

While several scholars have addressed the intersection of scientific careers and commercial behavior within industry and the academy (Stephan, 1996; Kleinman and Vallas, 2001; Owen-Smith and Powell, 2001), little work addresses how commercial behavior may be gendered. Is commercialization a new arena for gender disparity in scientific productivity? If so, have male and female commercial trends increased or decreased over time? We investigate this new topic using data on male and female invention activity across two decades of life science PhD cohorts.

In the academy, patenting differs from publishing in that it is not a formal requirement of the professorial job description. Owen-Smith and Powell (2001:109) suggest that commercial involvement among academic scientists is "the appearance of a new fault line" between those involved and those who choose not to participate. An understanding of gender disparity in commercial activity thus requires first conceptualizing the multiple ways in which men and women scientists may be involved, and addressing whether a commercial "pipeline" of involvement is present for women in science. Gender differences may exist in whether scientists patent at all and the length of time it takes them to begin. Once involved, differences may exist in the *amount* of commercial productivity. Male and female scientists may also differ in their average commercial success, or patent impact. We systematically investigate each of these components of gendered commercial outcomes with particular attention to disparities that may exist across employment sectors and over time.

## 2. Data

The sample consists of life science PhDs who, as graduate or post-doctoral students, were in a university program that obtained a national research service award (commonly called a "training grant") from the National Institute of General Medical Sciences. Graduate programs that awarded training grants in Cellular and Molecular Biology provided the random sampling frame. The data include demographic, education, and career history information for all post-doctoral students and PhD graduates enrolled in the sampled programs within the 10 years previous to the application, for a total of 2820 PhD careers. A caveat of these data is that only six universities with grants provide the database foundation. Unfortunately, the Freedom of Information Act only extends to successful NIH grant applicants, not to unsuccessful programs. However, the university programs sampled vary in prestige and regional location, and the addition of the educational histories of post-doctoral students generates data for PhDs from over 100 different US universities (Smith-Doerr, 2004b).

Patenting information for the sample was collected from the National Bureau of Economic Research (NBER) Patent Citations Data File (Hall *et al*., 2001). These data comprise detailed information on all US patents granted between January 1963 and December 1999, and all citations made to these patents between 1975 and 1999.[2] We obtain patenting counts and citation information for the PhD sample through a name-matching algorithm, which matches respondents on first, middle, and last name.[3] Name-matches were accepted on a stringent basis, and only those matched by name as well as at least one other piece of identifying information—matching affiliation (assignee name), hometown, or patent technological class and subclass—were accepted. Because many departments listed only first initials for their students, roughly half (49%) of the sample was unmatchable and therefore excluded from this analysis.[4]

Scientists' gender is coded from their first names. Common male and female name lists and background searching were used for those with ambiguous names.[5] The gender ratio in this sample is proportionate to other national samples of PhDs in the biological sciences (NSF SESTAT, 1995; Davis *et al*., 1996; Fox, 1996; NRC, 1998). Nationally, women make up 28.6% of life science PhDs (NSF, 2002), likewise they constitute 31.2% of this sample.

Scientists are classified as working in "industry", "academia", or "other organization" (e.g., government, non-profit institute or hospital).[6] Much like the aggregate life science doctorate population, the distribution of scientists across sectors is heavily weighted towards academic workers. Sixty-six percent of the sample is located in a university, and 16% are employed in industry (compared with 63% and 20% nationally, respectively (NSF SESTAT, 1995). We exclude from this analysis workers employed in non-science occupations ($N = 23$), and scientists with missing or incomplete affiliation information (~4% of the sample). We also classify the sample by PhD cohort, defined by the year each received his/her doctorate. Graduation dates in this sample range from 1963–1995, however, the majority received a PhD between 1980–1990 (64.6%). Nine percent of the sample had missing data on year of graduation.

Taking into account available data on all variables, there are 1084 scientists included in the final sample. Unless otherwise noted, all comparisons reported in this research are significant at the $p < 0.05$ level or below, and all significant differences between men and women are noted as such in the "Male" column of each table presented in the paper. We now turn to the results of our investigation of the three ways commercial activity may be gendered: (1) the extent to which male and female scientists *engage* in any patenting activity, (2) gender differences in the *quantity* of commercialization, and (3) gender differences in commercial *quality or impact*. We address each in turn in the sections that follow.

## 3. Gender and commercial involvement

We first investigate whether male and female scientists differ in having any involvement in commercial activity. Involvement is an indicator variable where a value of 1 means a scientist has patented at least once in the period between receiving their doctorate and the end of 1999.[7] Table 1 presents statistics on the degree to which life scientists engage in patent activity, disaggregated by gender and sector. Those who are involved in commercial activity are still a minority in the aggregate population. Roughly 25% of scientists in the sample patented at least once by December 1999 ($N = 273$). Our data confirm that female scientists are less likely to patent than male scientists (Morgan *et al*., 2001). In the sample as a whole, 30% of male compared with 14% of female scientists have ever patented.

This disparity holds true across generational cohorts. Figure 1 shows involvement in patenting activity across cohorts of male and female scientists, defined by the year of granted doctorate degree. We present five year moving averages that show the percent of men and women involved in patenting activity by year. The decreasing trend in the tail end of the graph is almost surely an artifact of timing: these later cohorts have just received their degrees and thus have had less time to apply and receive a granted patent for their research before the boundary of the available patent data. This graph is useful, however, because it shows differences in involvement among men and women who have had similar time to patent. Figure 1 suggests that across all years, women have been significantly less likely to be commercially involved than their male counterparts, with the possible exception of the late-70s, in which there is almost parity among cohort members. What is striking about the figure is the consistency of the disparity. Despite yearly increases in the numbers of female life scientists, the growing popularity of the field (particularly biotechnology), and the increasing prevalence of commercial patenting (both in industry, and markedly so, in academia), female scientists remain less involved than male scientists for most years. Steadily across time and cohort,

Table I
Means of commercial involvement by gender

| | Male total $N = 745$ | Female total $N = 339$ | Gender ratio (M/F) | Total $N = 1084$ |
|---|---|---|---|---|
| *Involved in commercial activity (0–1)* | | | | |
| Academia | 0.23*** (112)[a] | 0.10 (23) | 2.3 | 0.18 (135) |
| Industry | 0.52* (67) | 0.36 (17) | 1.4 | 0.48 (84) |
| Other | 0.33 (46) | 0.13 (8) | 2.5 | 0.27 (54) |
| Total | 0.30*** (225) | 0.14 (48) | 2.1 | 0.25 (273) |
| *Time to first patent (years since PhD)* | | | | |
| Academia | 8.5 | 8.2 | 1.04 | 8.4 |
| Industry | 6.7 | 7.9 | 0.85 | 6.9 |
| Other | 6.6 | 6.7 | 0.99 | 6.6 |
| Total | 7.5 | 7.9 | 0.95 | 7.6 |
| Change over time | | | | |
| 1970 cohort | 11.9 | Not available | – | 11.9 |
| 1980 cohort | 8.5 | 10.9 | 0.78 | 9.1 |
| 1990 cohort | 4.5 | 4.4 | 1.02 | 4.5 |
| *Inventor sequence (average author order on patent)* | | | | |
| First inventor on all patents (0–1) | 0.19 | 0.23 | 0.83 | 0.20 |
| Average inventor position | 2.2 | 2.5 | 0.88 | 2.3 |
| Academia | 2.1 | 2.6 | 0.81 | 2.2 |
| Industry | 2.2 | 2.4 | 0.92 | 2.3 |
| Other | 2.3 | 2.5 | 0.92 | 2.4 |
| Total | 2.2 | 2.5 | 0.88 | 2.3 |

[a]Numbers in parentheses indicate sample cell sizes for commercial involvement = 1, and the Time to First Patent and Inventor Sequence Measures.

*** $p < 0.01$ **$p < 0.05$ *$p < 0.1$ (two tailed).

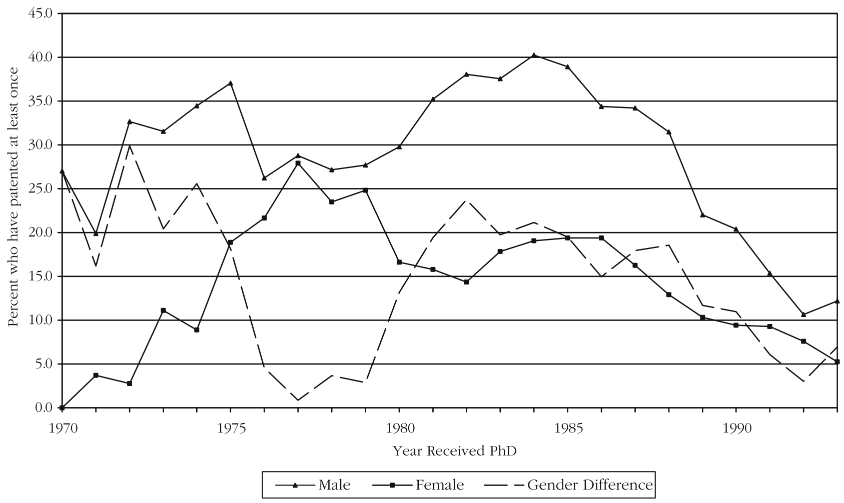


Figure 1. Percent involvement in patent acitivity by cohort and gender (five year moving average). Positive values indicate that more men than women patent at the indicated patenting rate.

women engage less in commercial science than men do.

*Employment sector differences*

We also explore the extent to which these trends hold across employment sectors. Employment sectors differ in the degree to which scientists are commercially involved. Academic science has been built on the traditional principle of pursuing "knowledge for knowledge's sake", and until recently, many scientists have avoided commercial activities where the proprietary benefits have been thought to violate the norms of "open science". By definition, industrial life scientists are much more likely to be involved in commercial endeavors than their academic counterparts. In industry, the bulk of corporate scientific activity depends heavily on exclusivity. We see this trend in our data. Across all cohorts, roughly half (48%) of industry scientists have patented at least once, compared with approximately one-fifth (18%) of academic scientists.

Across sectors, the gender difference in commercial involvement is greatest in academia, where the percentage of men more than doubles the percentage of women involved in commercialization (23% as compared with 10%, respectively). The percentage of men and women also differs when looking at industry, although to a lesser degree—52% as compared with 36%, respectively. Male scientists in industry patent 1.4 times as much as female scientists, whereas in academia the male to female ratio is 2.3.

*Time to first patent*

During the time period we are examining, rates of patenting in the general population increased dramatically (Hall *et al.*, 2001). Our sample shows a similar dramatic increase in the total number of patents applied for per year. There are few gender differences in the extent to which male and female scientists, as a group, increased their patenting activity over time, although the highest peak of female activity in our sample comes approximately one year later than that of male activity.[8] This difference may stem from the more recent increase in female involvement in the life sciences, or it may indicate the women receive slightly delayed access to, or impetus for, commercial involvement. Are the fewer numbers of women who participate in commercial activities also slower to enter the commercial realm than men? If academic (and industrial) scientists are increasingly operating in a world where measurements of productivity include commercial activity, it is important to discern if women begin commercializing at a later stage in their careers than men. Knowing how gender disparities in involvement overlay with gender differences in timing can help specify the process by which male and female scientists come to participate differently in commercial activities.

We examine how men and women differ in the average number of years from graduation to filing their first patent. The data suggest that men and women who become involved with patenting activity tend to do so at the same time. Table 1 shows that in the aggregate population, both sexes take approximately eight years to file their first granted patent. This equity is true *within* cohorts as well as across them. In plots of scientists' number of years since graduation until filing for first patent, by gender and cohort, men and women follow a similar time trajectory across all cohort years.[9] Table 1 also shows that the average length of time scientists take to file a first patent changes dramatically across time. In 1970, scientists became involved about 12 years out of graduate school; this number has decreased dramatically to about 5 years in the early 1990s. This might be attributed to the recent increase in commercializable life science applications in the past two decades, and the increasingly blurry boundary between public science and private research. While not the immediate focus of this research, this qualitative change demonstrates the changing influence of commercial practices on scientific work across time. The data suggest that commercial work is increasingly an activity in which scientists become involved early on, and hints at its growing importance in scientific careers.

We also investigate gender differences in time to first patent by work setting. Table 1 shows that industrial scientists start commercializing after graduation approximately 1 1/2 years earlier than academic scientists. Across sectors, male and female scientists take a similar amount of time to apply for their first patent upon receipt of their PhD. While graphs across time by employment sector are not possible for this measure (and all subsequent measures) due to the small numbers of women in each work setting and cohort, our inspection of the trends suggests that gender differences, or lack thereof, appear to remain static across time.

*Inventor sequence*

It is debatable whether the position of "first inventor" on a patent holds the same status as first (or last) author on a scientific publication. Contrary to publications, in which authorship is based primarily on social norms in science, US patent law dictates that only inventors who have made documentable and significant contributions to an invention be included on a patent. Ducor's (2000) research on patent-paper pairs shows that, on average, the number of inventors on a patent is significantly lower than on the corresponding publication. Additionally, not all first (and last) publication authors are listed as inventors on the corresponding patent. Despite the formal guidelines of the United States Patent and Trademark Office (USPTO), recent discourse in the scientific community suggests that the listing and inclusion of inventors is still largely based on the personal decisions of the scientists and the patent examiners involved (Ducor, 2000; Marshall, 2000). Little research has investigated whether or not inventors lobby or attempt to dictate their position on the granted patent, or whether or not employers and others place a value in the role of first inventor when evaluating scientists' contributions. In as much as the order of publication authorship matters to individual scientists, it is likely that inventor sequence matters on a commercial patent.

Regardless of how inventors are named, commercial work plays an increasingly influential role for academics, and continues to be important for industrial researchers. Patents represent value and productivity to potential employers of scientists. Thus, despite some confusion over the meaning of scientist authorship positions, we consider it important to investigate whether male and female scientists hold similar inventor orders on their patents. We consider inventor position among our sample scientists by calculating the average position held across all patents assigned to the scientists. Across all sectors, approximately 20% of scientists were "first inventor" on all of their patents. The *typical* inventor is listed as second inventor on their commercial work. There is little variation across employment sectors.

There is remarkable similarity between men and women in average inventor sequence. As Table 1 shows, there is no significant difference between the average inventor sequence of female and male scientists. The average male and female scientist in this sample is at the 2.2 and 2.5 position in the inventor sequence, respectively. There are no gender differences across employment sectors, and no clear increasing or decreasing trends among the sexes over time. On this measure, men and women who are already involved in patenting remain remarkably similar.

In sum, when evaluating gender disparities in overall involvement, we see areas of both similarity and difference. Women participate less than men in commercial science, although the gender disparity among scientists is less in industry than it is in academia. This trend is remarkably consistent across cohorts and time. Among those who patent, however, gender differences in time to first patent look relatively similar across sectors. Lastly, few differences exist between men's and women's average inventor-authorship position.

We have not yet, however, accounted for gender differences in the *amount* of commercial activity. Given their involvement, the next section compares gender differences in the *rate* at which male and female scientists patent.

## 4. Gender and commercial productivity

We operationalize male and female commercial *productivity* as the sum total of patents assigned to a scientist. Patent quantity is coded as the number of patents granted to each scientist between year of graduation and 1999. Because older scientists have more opportunity to patent than younger ones, counts of patents are conditioned on the number of years since receipt of the PhD. As such, this analysis uses "patents per year" as a measure of commercial quantity.[10]

Table 2 presents statistics on the productivity levels of male and female scientists. Life scientists in this sample have an average patenting rate of 1.1 patents across all years, or 0.07 per year. As is common with productivity counts, this average is heavily skewed towards the 75% who have

Table II
Means of commercial productivity by gender

| | Male | Female | Gender ratio (M/F) | Total |
|---|---|---|---|---|
| *Patents per year since PhD, non-inventors incl. (count of patents/years since PhD)* | | | | |
| Academia | 0.06*** (479)[a] | 0.02 (232) | 3.0 | 0.04 (711) |
| Industry | 0.22*** (128) | 0.07 (47) | 3.1 | 0.18 (175) |
| Other | 0.10*** (138) | 0.02 (60) | 5.0 | 0.07 (198) |
| Total | 0.10*** (745) | 0.02 (339) | 5.0 | 0.07 (1,084) |
| *Total patents since PhD, non-inventors incl. (count of patents)* | | | | |
| Academia | 0.92*** | 0.21 | 4.4 | 0.68 |
| Industry | 3.5*** | 1.1 | 3.2 | 2.9 |
| Other | 1.4*** | 0.38 | 3.8 | 1.1 |
| Total | 4.9*** | 2.6 | 1.9 | 4.6 |
| *Patents per year since PhD, non-inventors excl. (count of patents/years since PhD)* | | | | |
| Academia | 0.25*** (112)[b] | 0.15 (23) | 1.7 | 0.24 (135) |
| Industry | 0.43*** (67) | 0.19 (17) | 2.3 | 0.38 (84) |
| Other | 0.29 (46) | 0.18 (8) | 1.6 | 0.27 (54) |
| Total | 0.31*** (225) | 0.17 (48) | 1.8 | 0.14 (273) |
| *Total patents since PhD, non-inventors excl. (count of patents)* | | | | |
| Academia | 3.9** | 2.1 | 1.9 | 3.6 |
| Industry | 6.8*** | 3.1 | 2.2 | 6.0 |
| Other | 4.3 | 2.9 | 1.5 | 4.1 |
| Total | 4.9** | 2.6 | 1.9 | 4.5 |

[a] Numbers in parentheses indicate sample cell sizes for patent measures with non-inventors included.
[b] Numbers in parentheses indicate sample cell sizes for patent measures with non-inventors excluded.
***$p < 0.01$ **$p < 0.05$ *$p < 0.1$ (two tailed).

*no* involvement. Excluding those who have never patented brings the average patenting rate up to 4.7 patents across all years, or 0.31 per year. Mean statistics of this measure are also somewhat difficult because of the over-dispersion in the count data, where the majority patent a little, and only a handful of "star" scientists patent a lot. The median level of productivity is 2 patents across all time (or 0.2 patents per year since graduation) and the mode is 1 patent (or 0.1 patents per year).[11]

On average, male life scientists produce significantly more commercial work throughout their careers than female life scientists. Male scientists in the sample hold an average of 1.5 patents, and patent at a rate of 0.1 patents per year. In contrast, female scientists hold an average of .4 patents, and patent at a rate of 0.03 patents per year. Gender disparities decrease when excluding those who do not patent from the statistics. When looking at only those who patent to any degree, men hold an average of 4.9 patents (0.3 patents per year) as compared with the female average of 2.6 patents (0.2 patents per year).[12] Although still significant, the gender gap narrows dramatically when looking at differences that exist among those who patent at all.

The male to female productivity difference is constant across time, neither increasing nor decreasing in disparity. Figure 2 plots five-year moving averages of the ratio of male to female productivity across cohort averages, and includes a trend line for involvement as well. Controlling for cohort, this graph shows that differences between men and women are the greatest for patenting averages across the population as a whole. When removing those who are not involved at all, we see that productivity differences look remarkably like differences in patenting involvement. Thus, female life scientists must overcome two levels of gender disparity in commercial activity—both in involvement and in productivity. Across all cohorts, male life scientists are involved, and subsequently produce patents, at rates that are approximately double that of female scientists.[13]


Figure 2. Ratio of male to female involvement in patenting acitivity by cohort (five year moving average). Values greater than 1 indicate greater involvement by male scientist.

### *Employment sector differences*

We also examine differences in patenting rates for scientific employment sectors. Table 2 includes descriptive statistics on the quantity of patenting across sectors and gender. In addition to *participating* less, we find that academic scientists who are involved with commercial work also patent at a lower rate than industry scientists. Academic scientists who commercialize produce an average of 1 patent every 4 years, as compared with approximately 1 every 3 years for industry scientists. When all scientists are considered (i.e. those that patent and those that do not), a similar and significant gender difference between academic and industrial scientists is present. Men patent at a rate that is approximately 3 times that of women. This ratio declines significantly when looking at only those that patent, and only small employment sector differentials appear. Among those who patent, academic life scientists experience a slightly smaller gender difference in patenting rate per year than industrial scientists. Whereas the difference between male and female academic scientists is 0.11 patents per year (with the male to female ratio at 1.7), the industrial difference is 0.24 patents per year (with the male to female ratio at 2.3).

In sum, female scientists produce commercial work at a lower rate than male scientists, independent of employment sector. This trend is consistent across cohorts and time. Across two decades of PhD cohorts, male scientists produce approximately double the number of patents that female scientists do. Although patenting gender disparities are less in industry than academia in the percentage of scientists involved, there are no employment sector differences when looking at commercial quantity. This suggests that sector-level employment factors may influence who *engages* in patent activity but not the *amount* of output.

Although female scientists may be less engaged in commercial activity, do those who patent generate qualitatively different work in composition or influence than their male colleagues? The next section investigates a third dimension of how commercial work may be gendered—its average originality, generality, and influence.

## 5. Gender and commercial impact

One of the major drawbacks of using simple patent counts as a measure of innovative output is that not all patents are of a similar quality and importance. Patents, like publications, can vary greatly in their commercial impact and technological influence. The United States patent application requires inventors and patent examiners to cite all "prior art" upon which an invention is built, including prior granted patents as well as

Table III
Means of commercial impact by gender

| | Male $N = 225$ | Female $N = 48$ | Gender ratio (M/F) | Total $N = 273$ |
|---|---|---|---|---|
| *At least one citation (0–1)* | | | | |
| Academia | 0.70 (78)[a] | 0.57 (13) | 1.2 | 0.67 (91) |
| Industry | 0.81 (54) | 0.47 (8) | 1.7 | 0.74 (62) |
| Other | 0.80 (37) | 0.63 (4) | 1.3 | 0.78 (41) |
| Total | 0.75*** (168) | 0.54 (25) | 1.4 | 0.71 (193) |
| *Avg. citations per year across all patents (all inventors incl.)* | | | | |
| Academia | 0.43 (112)[b] | 0.69 (23) | 0.63 | 0.48 (135) |
| Industry | 0.68 (67) | 0.43 (17) | 1.6 | 0.63 (84) |
| Other | 0.55 (46) | 0.42 (8) | 1.3 | 0.54 (54) |
| Total | 0.54 (225) | 0.56 (48) | 0.96 | 0.54 (273) |
| *Generality—Avg. generality across all patents (all inventors incl.)* | | | | |
| Academia | 0.23** | 0.39 | 0.59 | 0.26 |
| Industry | 0.29 | 0.33 | 0.88 | 0.29 |
| Other | 0.31 | 0.26 | 1.2 | 0.30 |
| Total | 0.27* | 0.35 | 0.77 | 0.28 |
| *Originality—Avg. originality across all patents (all inventors incl.)* | | | | |
| Academia | 0.35 | 0.44 | 0.80 | 0.37 |
| Industry | 0.39 | 0.36 | 1.1 | 0.38 |
| Other | 0.41 | 0.37 | 1.1 | 0.41 |
| Total | 0.38 | 0.40 | 0.95 | 0.38 |

[a] Numbers in parentheses indicate sample cell sizes for citation indicator = 1.
[b] Numbers in parentheses indicate sample cell sizes for citation, generality, and originality measures.
*** $p < 0.01$ ** $p < 0.05$ * $p < 0.1$ (two tailed).

scholarly publications. Measures constructed of these "patent citations" appear to be strongly correlated with the value of an innovation (Trajtenberg, 1990; Jaffe *et al.*, 2000). Accordingly, social scientists have taken the number of citations a patent receives from subsequent patents to be evidence of the "quality" or "importance" of the invention (Hall *et al.*, 2001).

Table 3 presents citation statistics for the male and female life scientists in this sample.[14] Because scientists in this sample are still in the process of accruing citations to their patents, we report statistics on the citation count *per year* since application date.[15] For scientists who patent more than once (65% of the patenting sample), we report the average citation rate per year across all of their granted patents. The majority of scientists received at least one citation to a granted patent (71%). This average is skewed by the high proportion of male scientists in the sample, however. When disaggregated by gender, 75% of men and only 54% of women received at least one citation to a patent. Despite this, there are no significant differences in the aggregate sample between men and women in the number of citations accrued per year. On average, both male and female scientists in this sample receive approximately 1 citation every 2 years after a patent has been issued. This suggests that while women are more likely to receive no citations for their work, the ones who do receive citations accrue enough to make the *average* count across men and women approximately equal.

Figure 3 shows gender differences in average citation counts across cohorts.[16] The downward sloping trend at the end of the nineties is, again, likely due to the amount of time scientists in these cohorts have had to patent and to receive citations to those patents. Within cohort year, women often receive a higher (or equal) number of citations than male scientists. When disaggregated by employment sector, there are no statistically significant gender differences in citation rates between men and women across sectors.[17]

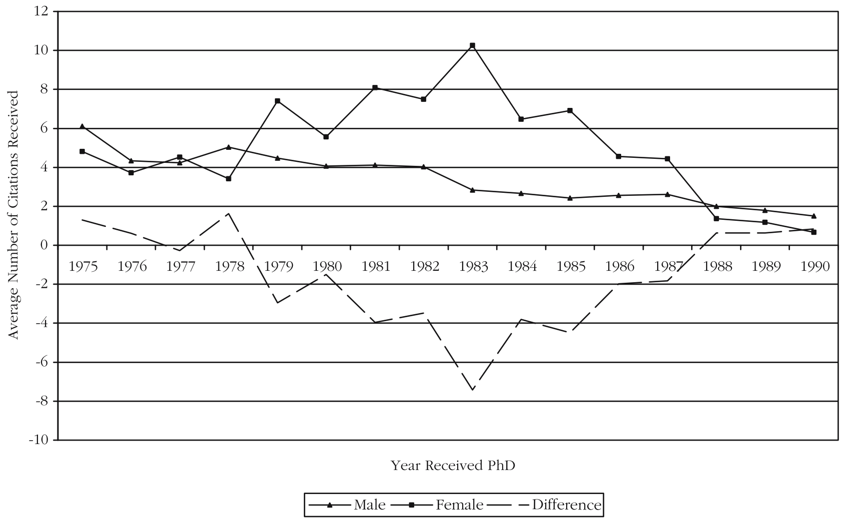


Figure 3. Percent gender difference in citations received (five year moving average). Values greater than 1 indicate that men have a greater average ciatation rate.

*Patent generality and originality*

Patent citation counts can also be used to create measures of the scope, depth, or applicability of an invention. Two such measures are "generality" and "originality", created by Hall *et al.* (2001) for every patent included in the NBER patent citations data file (see also Trajtenberg *et al.*, 1997). Hall *et al.* use "forward" and "back" citations to assess the degree to which an invention integrates broadly diffuse information (what they term "originality"), and affects future work across a wide array of technological categories ("generality"). Originality represents a measure of the technological diversity of citations made by the patent, defined by the variety of *cited* technology classes ("back" citations). Thus if a patent cites previous patents that belong to a wide range of fields, its "originality" will be high. Generality is the same concept, except it uses the technology classes of "forward" citations— later patents that subsequently cite a given patent. A patent cited by future patents from a broad variety of technological categories will have a high score on "generality".[18] Both originality and generality may be better understood as measures of an invention's interdisciplinary nature and its breadth of scientific "applicability."

Table 3 reports generality and originality statistics for men and women in the sample. The average life scientist had a generality score of 0.28 and an originality score of 0.38.[19] Across all cohorts, men and women do not differ in average originality. The significant difference in generality, while marginal, suggests that women tend to produce more broadly applicable inventions than men. These findings suggest that while fewer women may engage in patenting, the work that is commercialized by women is more applicable to a wide variety of technological fields.[20] This difference in generality may well be driven by scientists in academia. Women in the academy patent work with a higher degree of generality then academic men. There are no significant differences across employment sectors between men and women in patent originality.

The trends in this section portray a slightly different story from previous sections. While women participate less in commercial science, those who do have equal or better citation rates, originality, and broad applicability than male scientists. These findings are consistent across generational cohorts for a period of two decades. Interestingly, academic women are less likely to patent at all, but those who do have a significantly higher measure of quality and impact than academic men.

## 6. Discussion

Our results suggest that the nature of commercial gender disparity is complicated: not easily depicted by a single measure or patent count, and furthermore requires consideration of locational variables such as employment sector. We find substantial benefit in looking at three levels of commercialization behavior—engagement in patenting activity, patent quantity, and quality—to investigate commercialization differences between male and female scientists across sectors. It is important to examine factors that contribute to scientists' *decisions* or *opportunities* to patent in the first place, in addition to the amount that they patent. We find that gender differences occur at the point of access to commercial activity as well as its production. Women engage less and produce fewer patents than their male counterparts. Although female scientists participate and produce less, the quality and impact of their patents is equal to or better than that of male scientists.

Trends in female involvement in commercial activity might be described similarly to the traditional gender "pipeline" analogy (Berryman, 1983). As the degree of commercial involvement increases (from simple participation to accruing a substantial number of patents), the numbers of women involved proportional to men decrease. Evidence from the women who "survive" this winnowing process, albeit few, suggests a similar or higher degree of performance compared with their counterpart males. These results imply that a necessary focus for future work is to understand the personal, structural, and organizational reasons behind this filtering process which leads to such a small proportion of female inventors.

We also find that the level of gender disparity in commercial activity varies by employment sector. Scientists in the two sectors differ in their level of involvement in commercial science: as might be assumed, industrial scientists are more likely to have ever patented than academic scientists. The most notable gender difference between the two sectors is the gender disparity in involvement, to any degree. Female scientists in industry are involved in commercial activity similarly to their male counterparts, more so than are female scientists in academia (see also Bunker Whittington, (2005)). Although the gender disparity in patenting *involvement* is lower for industrial scientists than those in academia, there are no significant differences in the *rates* at which male and female inventors patent across the two sectors. Hence, differences between the academic and industrial sectors appear to stem largely from unequal opportunities to *engage* in such behavior rather than the amount of *productivity* once involved. These findings highlight the importance of the role of organizational context in productivity differentials between the sexes.

Because academics are typically free to choose their research topics, gender differences within the university may suggest that fewer women: (1) are interested in becoming involved with commercial work, (2) have a research focus that lends itself to commercial applications, or (3) have exposure to knowledge about how the commercial process works. A more structural explanation for this difference may be that women lack institutional support for patenting. A wealth of previous research suggests that women receive less support and research attention from their universities, departments, and scientific discipline than their comparable male colleagues (Long and Fox, 1995; Etzkowicz *et al.*, 2000; Fox, 2001; Long, 2001). Perhaps universities and their technology licensing offices are noticing the high impact inventions of female scientists after the fact but fail to support initial commercialization for female scientists. Patent statistics and citations cannot speak to scientists' motivations and interests in commercial work, however, or their opportunities to become involved. Without qualitative interviews or more detailed data, we will not know the extent to which these differences arise from issues of unequal access to resources, differences in structural locations or job types, or individual choices. We present these statistics with the hope of stimulating future research in this area.

The academic and industrial employment sectors, while representing two broad categories of scientific work, are composed of diverse work settings. This is particularly so in industry, where life scientists may choose between employment in large, diversified, corporate laboratories or smaller, dedicated biotechnology research firms. Previous work by Smith-Doerr (2004a) suggests that greater gender equality in the promotion of scientists exists in biotech firms as opposed to large drug companies. If similar processes hold for research activities, much of this industrial equality for women may stem from small, dedicated research firms rather than the sector as a whole. Our future work will incorporate multivariate models to investigate the extent to which gender differences in the academic and industrial sector are explained by type of work setting once educational, career, and demographic background have been controlled.

In sum, this research addresses whether the durable gender inequality in publication productivity applies to commercial activity, and the extent to which changes have occurred over time. Gender differences remain constant across cohorts from the past two decades, despite the rapid growth of commercial activity within the academy, and the complementary increase in patenting among industrial scientists. This gap is especially striking given the recent increases in the numbers of women in the life sciences. Scholars of gender stratification have suggested the recent increased proportion of women in the life sciences to be both the cause and the result of decreasing inequalities in the field (for example, Schiebinger, 1999). Apparently numerical increases have not greatly influenced women's commercial participation. One limitation of the sample is that it stops with the 1995 scientific cohort, along with the patent data bounded at 1999. Since this time period, academic (and industrial) patenting has increased to an even greater extent, as has the percent of life scientists who are female. These two factors may have an impact on the nature of current gender differences in commercial behavior.

Our results highlight the importance of looking beyond the academic sector and publishing activity to examine gender disparities in scientific research. As commercially motivated science becomes more prevalent within the academy, the ability of academic researchers to commercialize their research is becoming increasingly important for job- and career-level outcomes. Understanding how men and women become differentially involved in patenting is important given the current climate in science. Within the academy, scientists now make decisions in the face of university, department, and peer pressure about the level of involvement they will have in commercial work (Packer and Webster, 1996; Audretsch and Stephan, 1999; Owen-Smith and Powell, 2001). Those who choose to engage in commercialization are frequently rewarded well for their involvement. Commercial activity can bring the academic scientist significant increases in research funding, access to better equipment, potentially large gains in personal wealth, and an increased attractiveness to prospective graduate students, post-docs, and other academic and industry collaborators. All evidence suggests that the increasing overlap between the reward systems of academia and industry accelerates advantages to the scientist who can succeed in both worlds. We find that male academics are doing a better job of crossing the boundaries of university and industry, perhaps benefiting commercially from their scientific work at greater rates.

Although women do not commercialize as much as their male colleagues, their production of patents with an equal or higher degree of applicability and quality suggests that commercial science may be losing out by not encouraging women to patent. The policy implication is that universities and science intensive firms would benefit from devoting resources to enabling women scientists to commercialize. These resources might take a variety of forms: e.g., onsite daycare to free more time for applied science in addition to other research, education and legal expertise on the patenting process. True, we need to know more about the role early socialization or other individual factors play in the propensity to commercialize. Yet removing barriers to women's commercialization is logical not only for the good of gender equality in careers, but also for the good chance that it will create innovation and competitive advantage at organizational and national levels.

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## Notes

1. For example, life science faculty members have been known to receive tenure primarily on the strength of their patents (Smith-Doerr, 2004b).
2. This analysis does not include information on the number of patents *filed* by each scientist during this time period, which may be higher then the number of patents issued (some may arguably by viewed as an indicator of involvement, albeit "unsuccessful" or "unpatentable"). This data is not archived by the United States Patent and Trademark Office.
3. See Bunker Whittington (Dissertation) for a detailed description of the name-matching algorithm.
4. A decision by some administrators to submit lab members' initials versus their full names on the application is a personal choice that is not likely tied to any tangible difference in the backgrounds or quality of the scientists in the sample. Thus the matchable scientists should still represent a random sample of the life science doctorate population. Statistically, there is no significant difference in the missing data that is tied to the matchable/unmatchable distinction among scientists.
5. Seven percent of the sample had androgynous names where the gender of the scientist was unable to be determined. Most of these names are of foreign descent; in particular, the English spelling of Chinese names makes it impossible to ascertain gender without seeing the Chinese characters.
6. Because of small sample numbers, we are not able to break down the "Other Organization" category into appropriate subcategories of employees in similar work settings (Non-profit research hospital or institute, government, etc.). As such, the Other category represents an occupational "mixed bag" of sorts. We regard the largely insignificant statistical results for this category to be a feature of the small numbers of scientists in these work settings, as specified in the tables; however, we present statistics on this category for completeness.
7. We do not consider patents granted before graduation when we report on commercial activity (fourteen scientists in the sample (1.2%) applied for a patent prior to earning their doctoral degree). We stop at 1999 because this is the boundary of available patent data from NBER.
8. Figure available from the authors upon request.
9. Figure available from the authors upon request.
10. Specifically, we calculate patents per year by dividing an individual's total number of patents by the number of years from receipt of their PhD to 1999.
11. Because of the overdispersion in patent data, all *t*-test statistics for this sample were also run using *logged* measures to address non-normality. All reported statistical directions and significances were comparable for the logged versus non-logged measures.
12. The fact that men have more patents on average than women begs investigation into whether gender averages are biased by the few "star scientists" who patent prolifically. In tables not included here, we find that female scientists are over-represented in the lower patenting rate categories, and men in the mid-range categories. Only marginal differences exist among those who patent at the higher rates.
13. The cohort trends control for the number of years since graduation, but do not take into account scientists' job *positions*. Because women may have disproportionately left the work force temporarily (due to childbirth or family responsibilities, for example) or enter different *types* of jobs upon graduation, it is possible that these disparities would look different if job position or type of job were controlled in this analysis.
14. It is difficult to assess the importance of measures that are limited to those who *do* patent, given the significant number of those who *do not*. We investigate these measures because only a few research studies have suggested that women patent less than men, and no studies that we are aware of are able to address gender disparities in commercial impact. We discuss the significance of group differences in this selected sample below.
15. It takes time to accrue citations after a patent has been issued. Using statistics gleaned from all US granted patents between 1963 and 1999, Hall *et al.* (2001) report that, on average, a patent receives approximately 50% of its citations after ~10 years, and another 25% after 20 years. Although it is impossible to ever know the true time table of full citations (as patents can be cited by other patents after *any* number of years since issue), it is still important to view citation counts in light of the time the patent has had to be cited. Data from the USPTO suggest that the average citation count of this sample is on par with similar samples of life science patents (Hall *et al.*, 2001).
16. We present citation counts instead of citation rates in Figure 3 because both graphs depict the same findings, and citation counts are easier to interpret.
17. Although not statistically significant, the means of these groups do imply some interesting trends that may hold true in larger samples of scientists. In this sample, academic women have a notably higher citation rate than academic men, while women in industry are cited at a lower rate than their male counterparts.
18. Hall *et al.* (2001) show that these measures tend to be positively correlated with the number of citations made or received, and they caution that this can lead to potentially misleading inferences. This may sound intuitively obvious - highly cited patents may tend to have a broad impact, for example. They have developed an adjustment to deal with the nature of this bias, and in general, they find that measures of originality and generality are biased downwards. It is unlikely that this potential bias affects men and women differently. Because we are interested in relative differences between the sexes, we present here the raw, unadjusted data. Please see Hall *et al.* (2001) for more details on these measures.
19. These statistics are meant to be benchmark numbers only. They do not control for patent age and other confounding factors (see Hall *et al.*, 2001). The generality and originality scores for inventors in this sample are on par with the general population of drug and medical inventors, according the statistics calculated by Hall *et al.* (2001).
20. The data show this trend to be stable across time. For many of the cohort years, women receive higher generality and originality scores than their male counterparts. Only in the later years do the originality or generality measures of men and women become more equal. Figure available from the authors upon request.

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