Quality versus Quantity:
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. As the lines between university and commercial science become blurrier, science careers also take on a composite character. Increasingly, academic scientists are patenting and industrial scientists are publishing, particularly in the life sciences. We investigate gender disparities in *commercial* outcomes, and for scientists in *both* the academic and industrial sectors. Using a unique combination of archival data from the National Institutes of Health and patent data from the United States Patent and Trademark Office across a period of two decades, we present descriptive statistics and graphical trends of male and female commercialization. Specifically, we address: 1) the degree to which male and female scientists *engage* in patenting activity (to any extent), 2) the degree to which gender differences exist in the *quantity* of scientist's commercialization, 3) the degree to which gender differences exist in the *quality* or impact of scientist's commercialization, and 4) differences in gender disparities across employment sectors. Empirical evidence indicates that female scientists both engage in and produce less commercial work then their male counterparts, and that the degree of disparity remains constant across time. Female scientists participate and produce less, but the quality and impact of their commercial work remains the same or better than that of male scientists. These results suggest that gender differences in commercial productivity may originate in the structural job positions and environment women occupy, rather than their ability to do the work. We discuss these results and their implications for future research.

1. Theoretical Framework

The past two decades have witnessed significant changes in the organization and practices of scientific research within universities and industrial firms. The life sciences well illustrate two increasing and important movements 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-established 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. Certainly women are more likely in recent years to be trained as biologists. Nearly forty-five percent of the 2001 life science PhD recipients in the U.S. were female, compared to less than twenty-five percent 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; Smith-Doerr 2004a; Long 2001). This gap has frequently been analytically linked to assessments of men's and women's publishing productivity. Publications are generally taken as an indication of a scientist's research capabilities, and as such are important determinants of career outcomes.

During the past few decades a multitude of 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. A criticism of this 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 lacks consideration of how the organization of academic work is gendered. Grant, Kennelly and Ward (2000) argue that the traditional academic imperative to pursue high productivity during prime childbearing and 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, Dietz and Gaughan 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, and to view them 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 means 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. Although U.S. federal funding for the life sciences increased in absolute dollars, the real value provided per scientist declined 9.4% between 1979 and 1991 as laboratory costs became increasingly expensive (Brooks and Randazzese 1998). At the same time that relative funding levels decreased, legislative measures designed to stimulate commercial funding of academic science appeared. 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 some scholars have pointed out that the actual effects of the Bayh-Dole Act on patenting activity among elite universities is less than clear (Mowery and Ziedonis 2001), such legislative acts do visibly symbolize the federal government's commitment to promoting university-industry ties.

The growing similarities between universities and firms, particularly in the life sciences, have received attention in the social science literature. 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 (i.e., 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.

[1] For example, life science faculty members have been known to receive tenure primarily on the strength of their patents (Smith-Doerr 2004b).

These ties may take different forms—funding of research projects, collaborative R&D, exchange of graduate students, licensing of patents, informal advice networks. An array of social science nomenclature has developed to describe the growing interconnection and homogeneity between academic and commercial science, ranging from critical Marxist views to more Weberian value neutral descriptions of changes in the organization of science. Slaughter and Leslie (1997) take a critical view of universities' reliance on commercial firms for financial support, describing the change as "academic capitalism." Kleinman and Vallas (2001) have a modified conflict perspective, viewing the similarities between university and industry as "asymmetric convergence." Each influences the other, but the capitalist ethos of industry has the more powerful edge in the convergence of scientific practices and norms. Owen-Smith (2003) employs the more neutral terminology of a "hybrid order" across public and private science to show how advantages accumulate to organizations and scientists crossing traditional boundaries by both patenting and publishing at high rates. Indeed, the intermingling of practices, connections, influence and recursive change between the "triple helix" of university-industry-government has been the subject of a series of international conferences (Etzkowitz 2000), signaling the burgeoning social science research on this topic.

As the lines between university and commercial science become blurrier in the new economy, science careers also take on a composite character. Increasingly, academic scientists are patenting and industrial scientists are publishing, particularly in the life sciences (Owen-Smith and Powell 2001; Kleinman and Vallas 2001). A university dean interviewed by Kleinman and Vallas (forthcoming) 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 (Zucker, Darby and Brewer 1998;

Stephan 1996; Powell, Koput and Smith-Doerr 1996). The irony of how scientists perceive resource availability in the different organizational contexts is that they talk about the freedom to pursue research freely in firms, and express concern about how much time is spent on financing matters in the university (Smith-Doerr 2005). Research that has investigated 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 and colleagues (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, Kruytbosch and Kannankutty 2001). Bunker Whittington (2005) found that across science and engineering fields, gender disparities in the involvement in publishing and patenting activities were greater among 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? The work we present in this paper introduces this new topic using relatively hard to obtain data on male and female invention activity across two decades of cohorts of life science PhDs. We describe the male and female patenting population, and patenting trends by gender across time. We view this research as a first step in understanding the nature and extent of gender differences in commercial behavior, and hope to stimulate future research in this area.

In the academy, the act of 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. To this end, we argue that an understanding of gender disparity in commercial activity requires first conceptualizing the multiple ways in which men and women scientists may be involved. Differences may exist between men and women in the degree to which they commercialize at all and the length of time it takes them to begin patenting. Likewise, once involved, differences may exist in the *amount* of commercial productivity. Moving beyond simple participation, 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. We pay particular attention to disparities that may exist across employment sectors and the nature of these differences over time. Assessing the degree and nature of gender disparities at each level is important to understand the current landscape of male and female scientific productivity.

2. Data

The quantitative data for this analysis were collected by Smith-Doerr (2004b) and consist of a sample 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 (NIGMS). Smith-Doerr chose a random sample of universities from those awarded training grants in the areas of cellular and molecular biology, and acquired demographic, education, and career history information for all students in the university program (and within the past ten years) from the grant applications required by the NIGMS. The database includes information on 2,820 PhD careers. Although only six universities provide the database foundation, the university programs vary in prestige of school and regional location, and the addition of the educational histories of post-doctoral students adds diversity to the educational background of the sample. The complete information generates data for PhDs from over 100 different U. S. universities.

Patenting information for the sample was collected using available data from the National Bureau of Economic Research (NBER) Patent Citations Data File (Hall, Jaffe, and Trajtenberg 2001). These data comprise detailed information on all U. S. 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, written by Bunker Whittington, that matched respondents on first, middle, and last name. 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.[3] Because many departments listed only first (or first and middle) 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 (Fox 1996; Davis et al. 1996; NRC 1998; NSF SESTAT 1995). 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" (government, non-profit institute or hospital or health care clinic, etc.).[6] Much like the

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[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 view them as an indicator of involvement, albeit "unsuccessful" or "unpatentable"). This data is not archived by the United States Patent and Trademark Office.

[3] Only approximately 1% (N = 19) of the sample was unidentifiable

[4] A decision to submit initials versus a full name 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 character.

[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 present statistics on this category together with academia and industry largely for completeness.

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 of 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 1,084 scientists included in the final sample. Unless otherwise noted, all comparisons reported in this research are significant at the $p < .05$ level or below, although 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 the extent to which male and female scientists differ in their involvement in commercial activity, to any degree. We consider involvement as an indicator variable - a value of 1 specifies scientists have patented at least once in the period between receiving their doctorate degree 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.

TABLE 1 ABOUT HERE

This disparity holds true across generational cohorts. Figure 1 shows involvement in patenting activity across cohorts of male and female scientists, defined by year of doctorate graduation. 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 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

[7] Fourteen scientists in the sample (1.2%) applied for a patent prior to earning their doctorate degree. We do not consider patents granted before graduation when we report on commercial activity as it relates to places of employment obtained *after* graduation. We stop at 1999 because this is the boundary of available patent data from NBER.

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, women engage less in commercial science than men.

FIGURE 1 ABOUT HERE

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

In the aggregate population, women may be less likely to participate in commercial science then men, but it is also important to examine whether those who are involved begin at an earlier or later stage in their careers than their male counterparts. 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 incline in slope in the total number of patents applied for per year. There are few gender differences in the extent to which male and female scientists increased their patenting activity over time, although the highest peak of activity in our sample comes approximately two years later for female scientists. Figure 2 presents the distribution of patent counts per application year by gender. This graph should be interpreted with caution, however, as it does not control for the *number* of scientists in the field in our sample each year. The subsequent decline in the number of applications is likely due to the time lag between a filed and issued patent. If we were to examine these trends 5 years from now there would probably not be a decrease in activity for the graphed years.

FIGURE 2 ABOUT HERE

Figure 2 suggests that male and female scientists follow similar trends of involvement overall, although women may be a couple of years behind men. This difference may stem from the slow increase in female involvement in the life sciences, or it may indicate the women receive a slightly delayed access to, or impetus for, commercial involvement. One way to investigate how this difference may occur is by considering whether or not male and female scientists begin their commercial involvement in the same time frame. 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 7.5-8.0 years to file their first granted patent. This is true *within* cohorts as well as across them. Figure 3 plots scientists' average number of years since graduation until filing for first patent, by gender and cohort. Men and women follow the same time trajectory across all cohort years. While not the immediate focus of this research, Figure 3 also demonstrates the changing influence of commercial practices on scientific work across time. Across cohorts, the average length of time before scientists file a first patent has changed dramatically, from ~12 years in the mid-70s to ~3 years in the early 90s. 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. The trendline suggests that commercial work is increasingly an activity that scientists become quickly become involved in, and hints at its growing importance in scientific careers.

FIGURE 3 ABOUT HERE

We also investigate gender differences in time to first patent by work setting. Table 1 shows that industrial scientists start commercializing after graduation approximately 1½ 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 remain similar to those reported in the aggregate Figure 3 above. 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 in a scientists' portfolio. Across all sectors, approximately 20% of scientists were "first inventor" on all of patents in their portfolio. The *typical* inventor in this sample 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. Although statistically insignificant, female scientists are slightly more likely than male scientists to be first inventors across all patents in their portfolios (23% versus 19%, respectively). The average male and female scientists in this sample are 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 remain remarkably similar.

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.

This first section, however, does not account 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 Productivity

We operationalize male and female commercial *productivity* as the sum total of patents in a scientist's portfolio. 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.[8] As such, this analysis uses "patents per year" as a measure of commercial quantity.

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 .07 per year. As is common with productivity counts, this average is heavily skewed towards the 75% who have *no* involvement. Excluding those who have never patented brings the average patenting rate up to 4.7 patents across all years, or .31 per year. This average is also somewhat biased by over-dispersion in the count data, where the majority patent a little, and a handful of "star" scientists patent a lot. The *median* level of productivity is 2 patents across all time (or .2 patents per year since graduation) and the *mode* is 1 (or .1 patents per year).

TABLE 2 ABOUT HERE

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 .1 per year. In contrast, female scientists hold an average of .4 patents, and patent at a rate of .03 per year. Gender disparities decrease when excluding those who do not patent from the statistics. When looking at only those

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[8] 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.

who patent to any degree, men hold an average of 4.9 patents (.3 patents per year) as compared with the female average of 2.6 patents (.2 patents per year). Although still significant, the gender gap narrows dramatically when looking at differences that exist among those who patent at all.

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. Figure 4 presents the percent gender difference across the distribution of patenting by year. The figure shows 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.

FIGURE 4 ABOUT HERE

The male to female productivity difference is constant across time, neither increasing nor decreasing in disparity. Figure 5 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.[9]

FIGURE 5 ABOUT HERE

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 also patent at a lower *rate* than industry scientists. Excluding those who do not patent, academic scientists produce an average of 1 patent every 4 years, as compared with approximately 1 every 3 years for industry scientists.

Academic life scientists experience a smaller gender difference in patenting rates per year than industrial scientists. Whereas the difference between male and female academic scientists is .11 patents per year (approximately 1.8 patents across career), the industrial difference is .24 patents per year (approximately 3.7 patents across career). The employment sectors have a similar level of gender disparity once non-patenters are excluded, however.

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

[9] 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.

industry than academia in the percentage of scientists involved, there is no employment sector difference 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 impact than their male colleagues? The next section investigates a third dimension of how commercial work may be gendered – its average originality, generality, and impact.

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 originality, and the degree of their technological influence. The United States Patent and Trademark Office 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 scholarly publications. If a patent is cited by numerous later patents, this may be a signal that the technology in the cited patent holds some degree of scientific significance. 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). Previous research has suggested that patent citations appear to be strongly correlated with the value of an innovation (Trajtenberg 1990; Jaffe, Trajtenberg and Fogarty 2000).

It takes time to accrue citations after a patent has been issued, however. Using statistics gleaned from all US granted patents between 1963 and 1999, Hall, Jaffe, and

Tratjenberg (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. The mean citation count per patent in US drug and medical patents is approximately 10 citations across all years (until 1999) (Hall et al. 2001). Because ours is a young sample – the average age of the patents in this database is 4.9 years (median 3.3) – the average citation count is lower than the full population of drug and medical patents,. We see 3.8 citations per patent (median 1) by 1999.[10] 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. For scientists who patent more than once, we report the average citation rate per year across all of their granted patents.

Table 3 presents citation statistics for the male and female life scientists in this sample. 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

[10] Data from the USPTO suggest that the average citation count of this sample is on par with similar samples of life science patents. The most common application date for both men and women in this sample is between 1993-1997. Using the full USPTO data, Hall et al. report average citations in the drug and medical field for patents received in these years to be between 3.8 (1993 patents) and .10 (1997) (2001, Table 2a).

citations for their work, the ones who do receive citations have enough to make the *average* count across men and women approximately equal.

TABLE 3 ABOUT HERE

Figure 6 shows gender differences in average citation counts across cohorts.[11] 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. Figure 7 presents the ratio of the male to female citation rates found in Figure 6. Except in the tail years of the dataset, women are much more likely to receive higher citation counts than men. The increase in the right hand tail is interesting here. Although in earlier years the citation rates for men and women are equal or higher for women, in recent cohorts, where there is little time to establish high citation rates, men appear to be more able than women to quickly translate science into "useful" (or perhaps more noticed) patentable research.

FIGURES 6 AND 7 ABOUT HERE

When disaggregated by employment sector, there are no statistically significant differences in citation rates between men and women. 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

[11] Figure 6 portrays average citation counts rather than average citations per year. We present citation counts instead of citation rates because both graphs depict the same findings, and citation counts are easier to interpret.

than academic men. Women in industry are cited at a much lower rate than their male counterparts.

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, Jaffe, and Henderson 1997).[12] 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.[13] Both originality and generality may be better understood as measures of an invention's interdisciplinary nature and its breadth of scientific "applicability."

[12] See Hall et al. (2001) for a detailed discussion of the creation of these measures and their characteristics across all patents granted by the USPTO.s

[13] 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.

Table 3 reports generality and originality statistics for men and women in the sample. The average life scientist had a generality score of .28 and an originality score of .38.[14] Across all cohorts, men and women do not differ in average generality. The significant difference in originality, while marginal, suggests that women tend to produce more broadly applicable inventions than men.

Trends across time for men and women are revealing. Figure 8 presents five year moving averages of male and female originality and generality across cohorts. Again, the decline in the generality measure at the tail end of the graphed years is likely due to the amount of time these scientists have had to patent (and accrue citations to those patents). The graphs show that, 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 (or in the case of originality, lower) 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.

FIGURE 8 ABOUT HERE

Across employment sectors, there are no significant differences between men and women in patent originality. The results are similar for generality except for scientists in

[14] 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 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). Originality in this sample is slightly higher than average for the population. Hall et al. point out that biotechnology patents tend to be higher on these measures than other drug and medical patents, which may be one reason for this discrepancy.

academia. Women in the academy patent work with a higher degree of generality then academic men.

The trends in this section portray a 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 the most significantly higher difference in quality and impact factors than in other work settings.

4. Discussion and Conclusion

Our results suggest that the nature of commercial gender disparity is a complicated one, not easily depicted by a single measure or count of patents, or without considering location-level factors such as firm type or 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 both the point of access in commercial activity as well as its production. Women engage less and produce fewer patents than their male counterparts.

Female scientists participate and produce less, but the quality and impact of their commercial work is equal to or better than that of male scientists. In addition, men and women become involved with commercial work after a similar length of time since graduation. The quality of women's patenting activity suggests that gender differences in commercial productivity may stem more from the structural job positions they occupy, rather than their ability to do the work. The gender gap in patenting at all may especially reflect conditions in academic science. 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. Patent statistics and citations cannot speak to scientists' motivations and interests in commercial work, 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.

In addition, 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. We find a consistent level of disparity in activity between male and female scientists over time. Gender differences remain constant across cohorts from the past two decades, despite the rapid growth and popularity 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 (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.

Lastly, we address how employment sectors differ in the nature of commercial gender disparity. Scientists in the two sectors differ in their level of involvement in commercial science: as might be assumed, industrial scientists have a higher degree of participation than academic scientists. The most notable 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. 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 scientists 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 guiding productivity differentials between the sexes.

At first, the finding that women academics have a higher citation rate and women industrial scientists have a lower citation rate than their male counterparts appears to run counter to the finding that women were more likely to participate in commercial activity in industry. Similarly, women academics' patents have greater generality than men's, but there is no gender difference among industrial scientists' patent generality. However, the fact that women may participate less, but outperform men in the academy, lends support to the commonly discussed notion that academic women feel the need to produce higher quality science than their male counterparts to be considered equal. Given that commercial activity is not a universal requirement of faculty, perhaps academic women withhold commercializing unless their research will have high impact. Perhaps if women have less time in their schedule for patenting activity (e.g., because of heavier teaching and family responsibilities), they make their patents count. A more structural explanation is 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). Perhaps universities and their technology licensing offices are only noticing the high impact inventions of female scientists and failing to support commercializing female scientists' inventions unless they are "widely applicable."

Further investigation is needed to understand the effects of the employment locations of male and female scientists on their patenting activity, however. The academic and industrial employment sectors, while representative of two broad categories of scientific work, are composed of a diverse degree of work settings. This is particularly so in industry, where life scientists frequently choose between employment in large, diversified, corporate laboratories and 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 difference may stem from relative equality in small, dedicated research firms rather than the industrial 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, 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 prevalent within the academy, the ability of academic researchers to commercialize their research is becoming increasingly important for job- and career-level outcomes. Our preliminary results indicate 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. The gendered wage disparity that appears among biological scientists in later career stages may only be exacerbated by this trend. Our future research will investigate the contextual factors within organizations and employment sectors that contribute to gender disparities in commercial involvement.

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 (Owen-Smith and Powell 2001, Packer and Webster 1996, Audretsch and Stephan 1999). 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 research tools and 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.

The results also suggest that women are commercializing science with equal or greater "importance" as defined by patent citations. This previously unknown finding has significant bearing on the urgency with which factors that work against equal commercial participation among men and women should be addressed. Although women do not commercialize in the same quantity as their male counterparts, their production of commercial science with an equal or higher degree of applicability and quality suggests that commercial science may be losing out by not encouraging women to patent. As commercialization becomes more common and has more repercussions for academic science careers, this trend has considerable implications not only for the scientific labor market, but the wider pursuit of knowledge as well.

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Table 1. Means of Commercial Involvement by Gender

	Male N = 745	Female N = 339	Gender Ratio (M/F)	Total N = 1,084
Involved in Commercial Activity (0-1)	.30***	.14	2.1	.25
Academia	.23***	.10	2.3	.18
Industry	.52*	.36	1.4	.48
Other	.33	.13	2.5	.27
Time to First Patent (years since PhD)	7.5	7.9	.95	7.6
Academia	8.5	8.2	1.04	8.4
Industry	6.7	7.9	.85	6.9
Other	6.6	6.7	.99	6.6
Inventor Sequence (average author order on patent)				
First Inventor on all patents (0-1)	.19	.23	.83	.20
Average Inventor Position	2.2	2.5	.88	2.3
Academia	2.1	2.6	.81	2.2
Industry	2.2	2.4	.92	2.3
Other	2.3	2.5	.92	2.4

*** $p < .01$ ** $p < .05$ * $p < .1$ (two tailed)

Table 2. Means of Commercial Productivity by Gender

	Male N = 225	Female N = 48	Gender Ratio (M/F)	Total N = 273
Patents per year since PhD, Non-Patenters Included (count of patents/years since phd)	.10***	.02	5.0	.07
Academia	.06***	.02	3.0	.04
Industry	.22***	.07	3.1	.18
Other	.10***	.02	5.0	.07
Total patents since PhD, Non-Patenters Included (count of patents)	4.9***	2.6	1.9	4.6
Academia	.92***	.21	4.4	.68
Industry	3.5***	1.1	3.2	2.9
Other	1.4***	.38	3.8	1.1
Patents Per Year since PhD, Non-Patenters Excluded (count of patents/years since PhD)	.31***	.17	1.8	.14
Academia	.25***	.15	1.7	.24
Industry	.43***	.19	2.3	.38
Other	.29	.18	1.6	.27
Total Patents since PhD, Non-Patenters Excluded (count of patents)	4.9**	2.6	1.9	4.5
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

*** $p < .01$ ** $p < .05$ * $p < .1$ (two tailed)

Table 3. Means of Commercial Impact by Gender

	Male N = 225	Female N = 48	Gender Ratio (M/F)	Total N = 273
Citation Statistics – At least one citation (0-1)	.75***	.54	1.4	.71
Academia	.70	.57	1.2	.67
Industry	.81	.47	1.7	.74
Other	.80	.63	1.3	.78
Citation Statistics – Avg. citations per year across all patents	.54	.56	.96	.54
Academia	.43	.69	.63	.48
Industry	.68	.43	1.6	.63
Other	.55	.42	1.3	.54
Generality – Avg. generality across all patents	.27*	.35	.77	.28
Academia	.23**	.39	.59	.26
Industry	.29	.33	.88	.29
Other	.31	.26	1.2	.30
Originality – Avg. originality per year across all Patents	.38	.40	.95	.38
Academia	.35	.44	.80	.37
Industry	.39	.36	1.1	.38
Other	.41	.37	1.1	.41

*** $p < .01$ ** $p < .05$ * $p < .1$ (two tailed)

Figure 1. Percent Involvement in Patent Activity By Cohort and Gender (Five Year Moving Average)

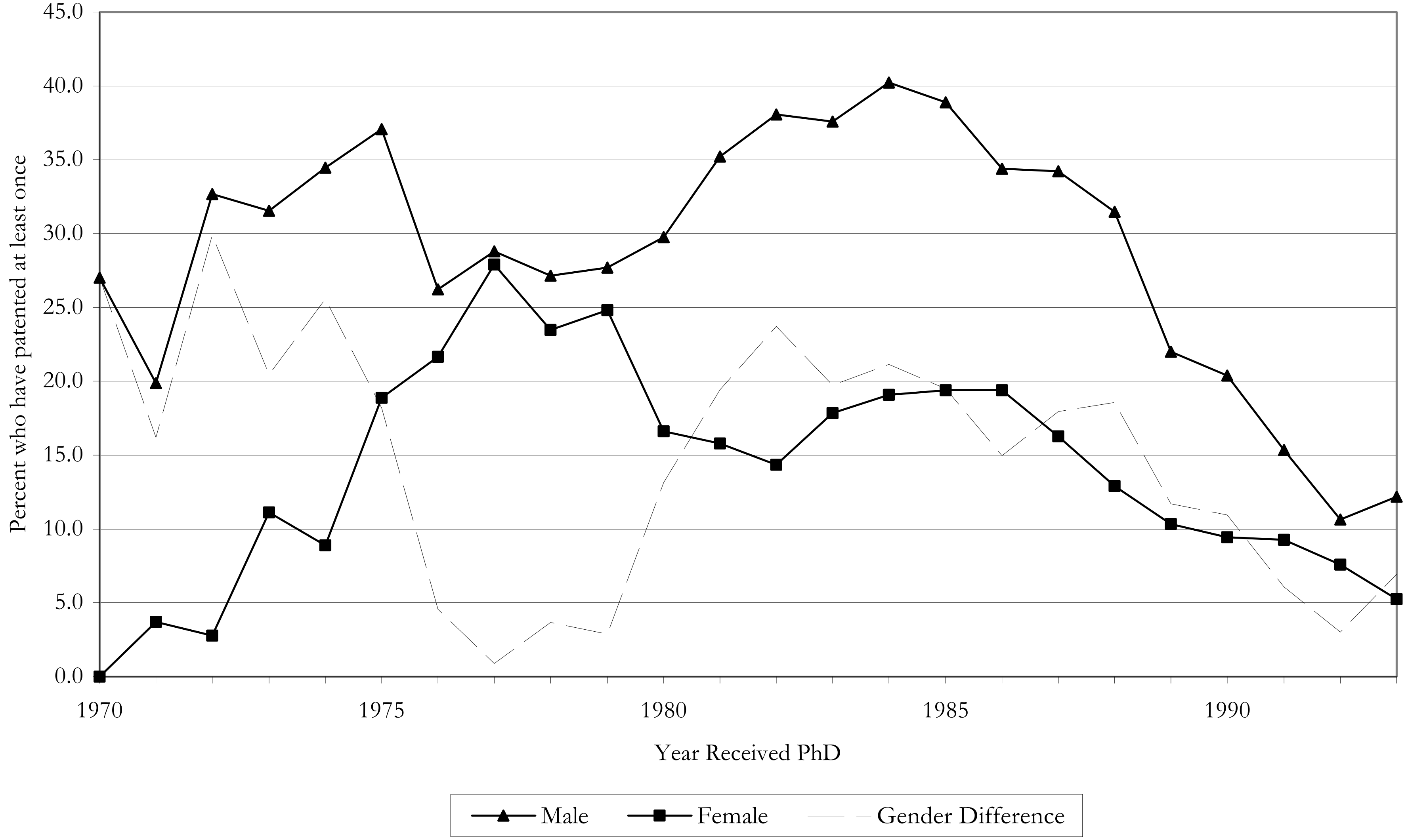


Figure 2. Number of Patents by Application Date and Gender

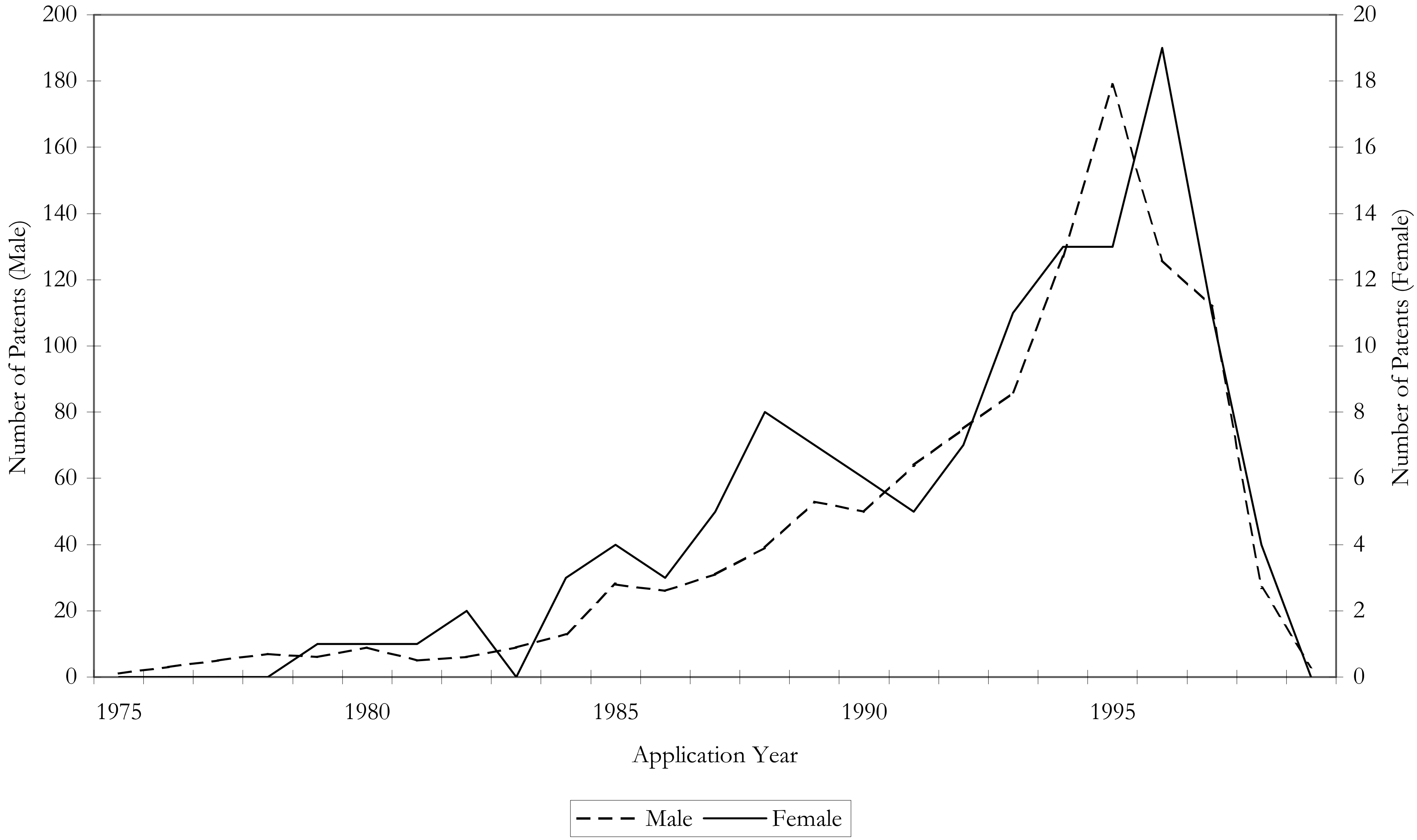


Figure 3. Time to First Patent by Gender and Cohort (Five Year Moving Average)

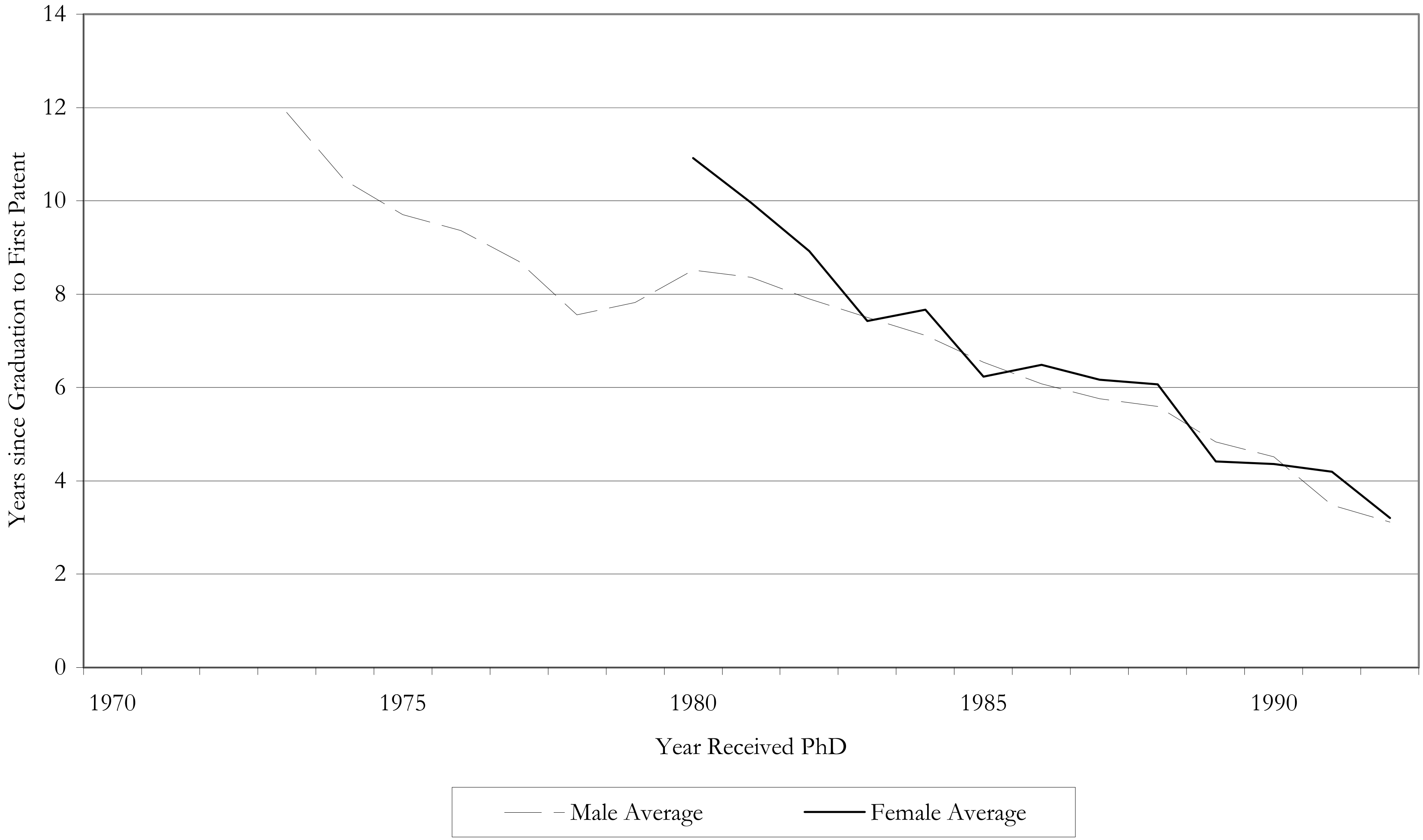
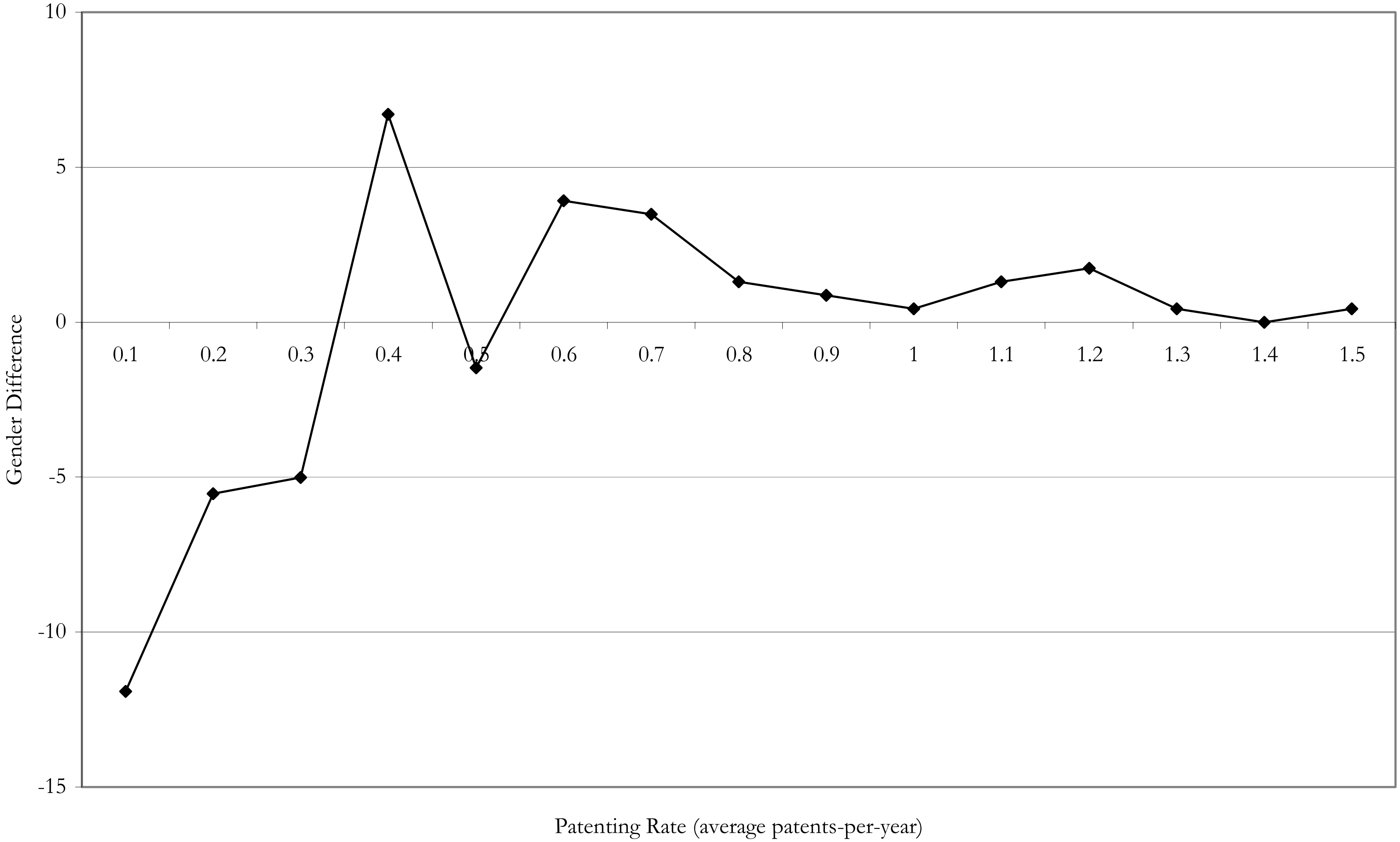
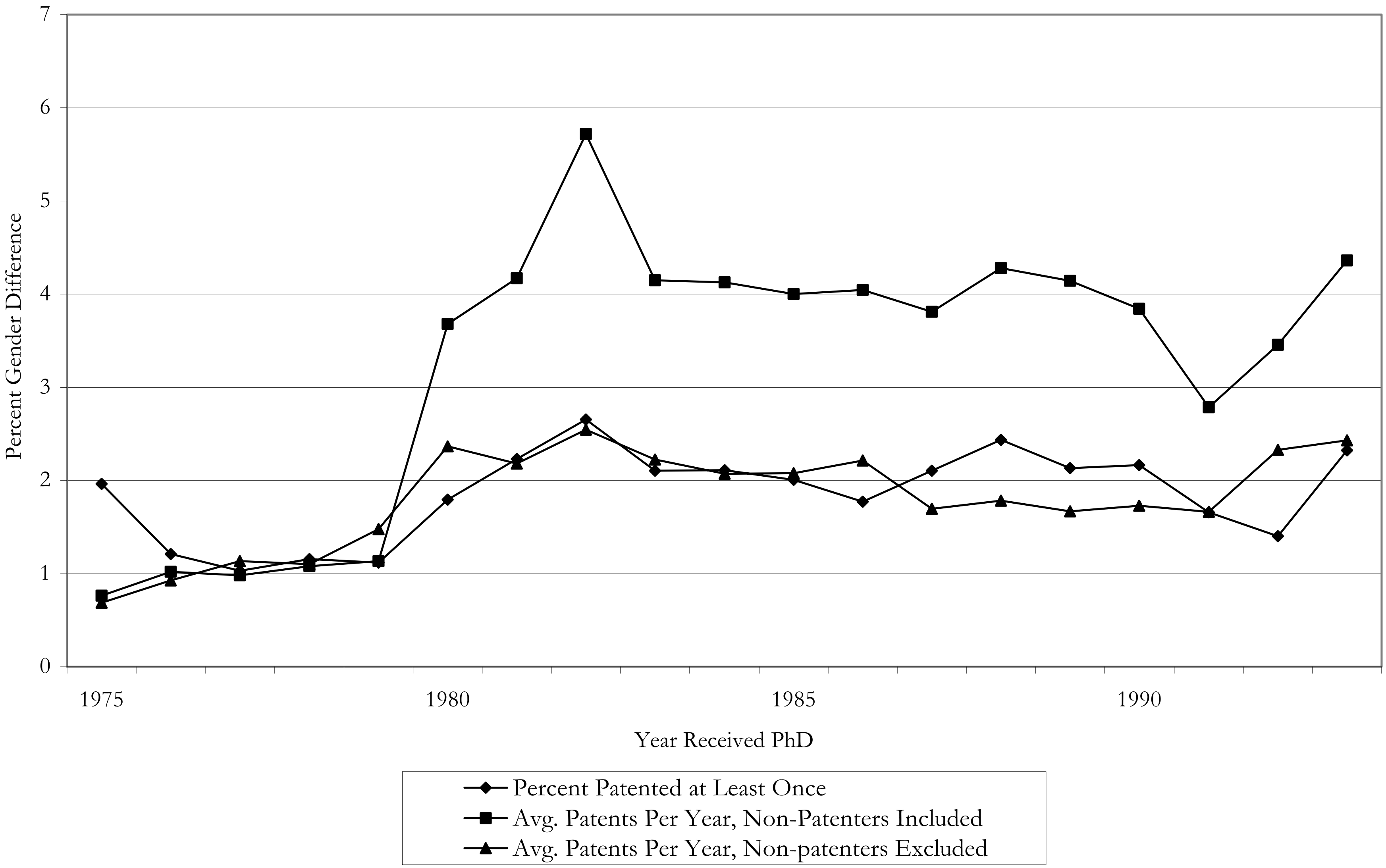


Figure 4. Percent Gender Difference in Distribution of Patenting Rates (non-patenters excluded)*



* Positive values indicate that more men than women patent at the indicated patenting rate.

Figure 5. Ratio of Male to Female Involvement in Patenting Activity by Cohort (Five Year Moving Average)*

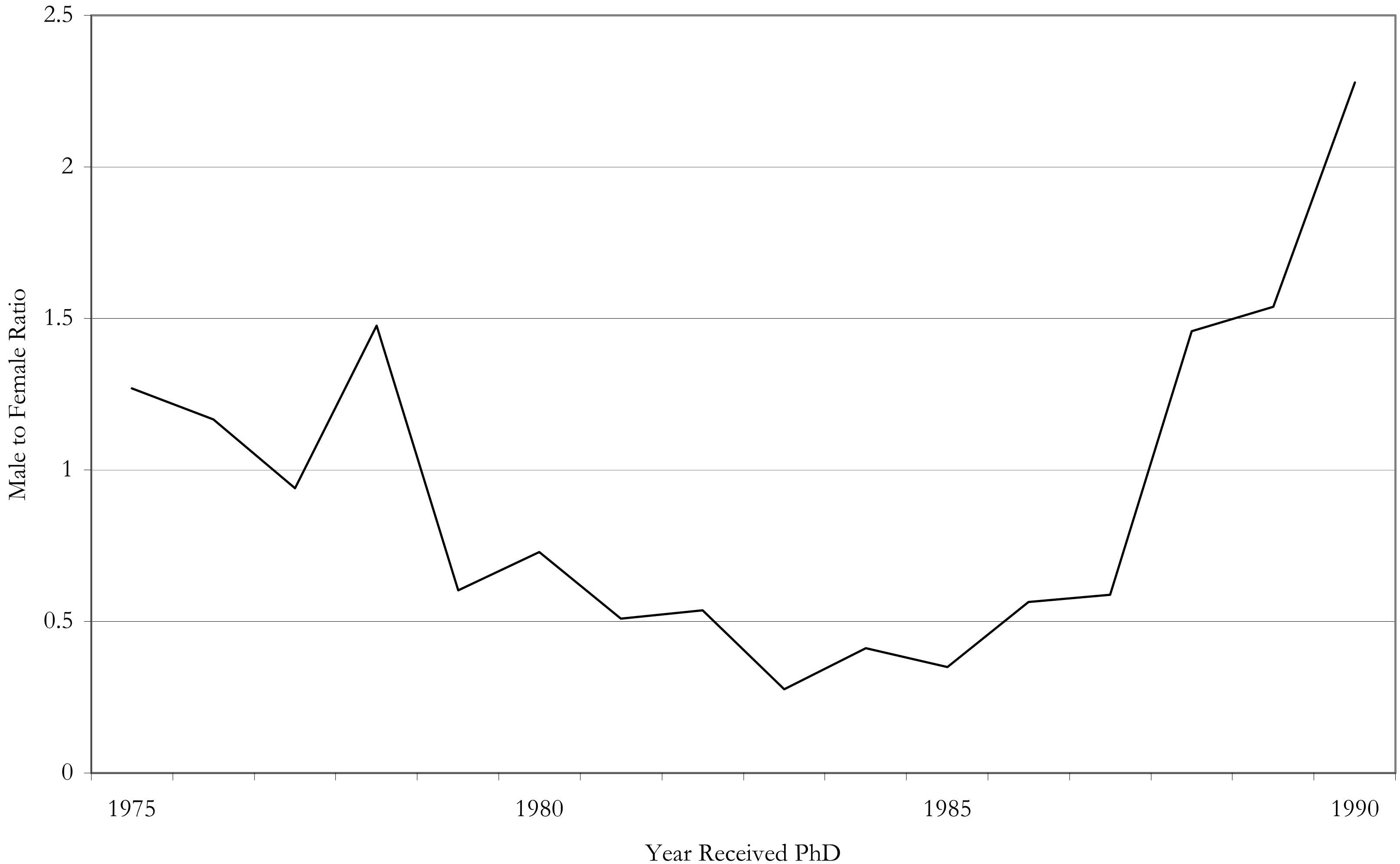


* Values greater than 1 indicate greater involvement by male scientists

Figure 6. Percent Gender Difference in Citations Received (Five Year Moving Average)*

* Values greater than 1 indicate that men have a greater average citation rate.

Figure 7. Male to Female Ratio of Citations Received (Five Year Moving Average)*



*Values greater than 1 indicate greater citations received by male scientists as compared with female scientists.

Figure 8. Generality and Originality by Cohort and Gender