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Women in Mathematics:

Change, Inertia, Stratification, Segregation

Cathy Kessel

Abstract

This chapter examines the participation of women in mathematics, focusing on academe. It begins with an overview of the international situation for graduate education in mathematics, illustrating national differences in proportions of female mathematics doctorates. These differences may be associated with national differences in gender segregation in all fields of study. Data collected within the US illustrate two other statistical phenomena: differences in proportions of women earning degrees and in academic departments, and stratification in professional awards and academic employment. These three phenomena are not unique to the US or to mathematics but the chapter draws many of its illustrations from the United States for several reasons. The US is among the major producers of PhDs in mathematics, its universities attract many of the world's top mathematicians, and it collects extensive statistical information on women in mathematics and other scientific fields. Because the representation of women in mathematics and other fields varies by nation, the chapter concludes by discussing conditions associated with such variations.

Introduction

More than a century ago, Germany was the acknowledged center of mathematical research, and aspiring mathematicians often earned doctorates or studied at the universities in Göttingen and Berlin. Two of these aspiring mathematicians were Grace Chisholm from England and Mary Winston from the United States. After petitioning, they were granted permission to enroll at the university in Göttingen. In 1895, Chisholm became the first woman to have enrolled as a student and earned a doctorate in mathematics. In 1897, Winston became the second, graduating magna cum laude (Green and LaDuke, 2009, pp. 39–40, 256). In earning a doctorate at Göttingen, they were preceded by the Russian Sofia Kovalevskaya who had been granted her degree in 1874 without being officially enrolled in the university. In matriculating, Chisholm and Winston preceded German women who had to wait until 1902.

Kovalevskaya and Chisholm were internationally celebrated, albeit in different ways. In 1889, Kovalevskaya became the first woman in modern Europe to hold a chair at a research university. She was the first woman to be on the editorial board of a major scientific journal, received the prestigious Prix Bordin from the French Academy of Sciences, and was the first woman elected as a corresponding member of the Russian Imperial Academy of Sciences (Koblitz, 1999, pp. 216–217). Although she did not hold a university position, Chisholm traveled in Europe to pursue her mathematical interests and learn about new ideas. She published joint work with her mathematician husband as well as solo work under her own name (Wiegand, 2005, pp. 39–45).

Winston did not have a notable career as a researcher and her later academic affiliations were not impressive. She returned to the United States, taught at a high school for one year and for three years at Kansas State Agricultural College. She resigned in order to marry a mathematician in another Kansas town, but, due to university anti-nepotism policies, could not obtain an academic position there. After her husband's death, she obtained academic posts, first at Washburn College in Kansas, then Eureka

College in Illinois, where she became the chair of its mathematics and science division (Green and LaDuke, 2011).

As the decades passed, aspiring US mathematicians did not flock to European universities as before. US universities recruited European mathematicians who helped them become centers of mathematical activity that attracted foreign talent and nurtured home-grown talent. Due to institutional policies and professorial preferences, that nurture was not always extended to women or minorities. The first African-American man known to have been awarded a mathematics doctorate was Elbert Frank Cox, who earned his in 1925 (Walker 2009). Euphemia Lofton Haynes, his female counterpart, earned her doctorate almost two decades later, in 1943. Like Mary Winston a half-century earlier, she obtained a position at a high school. Unlike Winston, she remained in that position for three decades, becoming the chair of its mathematics department (Murray 2012).[1]

Although these stories are old and much has changed, they illustrate some longstanding themes as well as individual variations. Studying at a center of mathematical activity is still important. It may involve learning in another culture and another language. Affordances and constraints may be different for foreign students than for native students, although today these tend to involve eligibility for scholarships rather than permission to matriculate. The “two-body problem”—having a mathematician or academic partner as did Mary Winston and Grace Chisholm—still exists and still affects employment, although anti-nepotism regulations are gone—at least in the US (Kessel, 2009). And, unusual talent and achievement are not necessarily associated with prestigious careers. Despite the talent and motivation that must have accompanied Mary

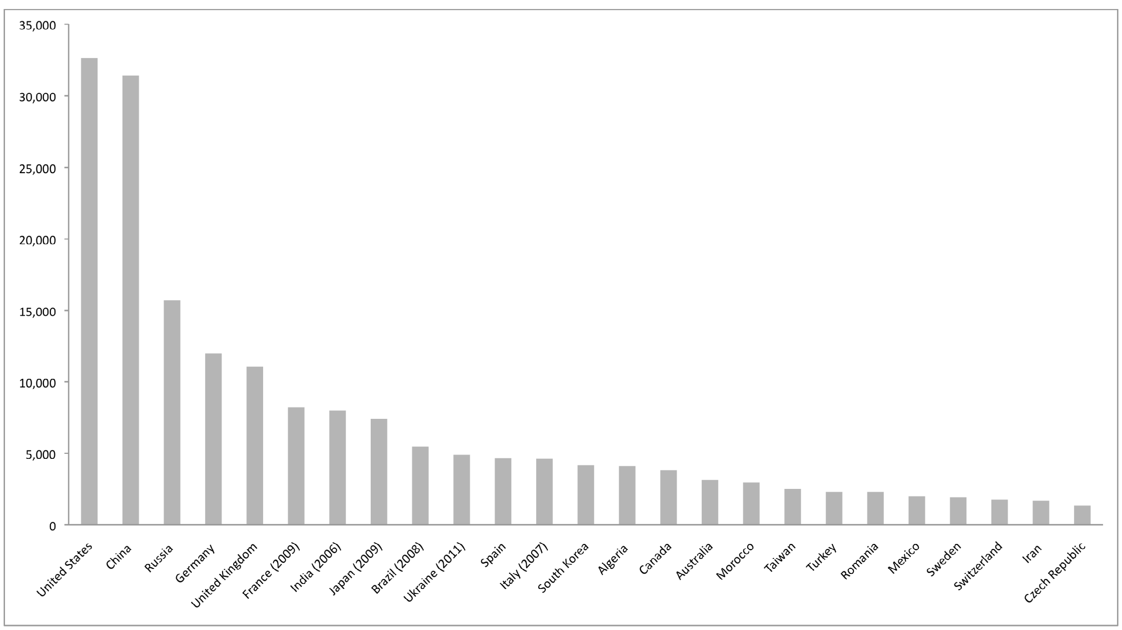
[1] See also http://www.math.buffalo.edu/mad/PEEPS/haynes.euphemia.lofton.html.

Winston’s and Euphemia Lofton Haynes’s acquisition of doctorates, their subsequent employment occurred in institutions not intended to support mathematical research. And all, from Kovalevskaya to Haynes, encountered problems of unequal access to education. With these considerations in mind, we turn to a statistical account of the current situation.

Graduate Education

To get a sense of the international situation for mathematics, we begin with an overview of doctorates for science and engineering granted by different countries. The US National Science Foundation has compiled statistics for 68 nations from the five continents and Oceania. The nations which grant the largest numbers of science and engineering doctorates are shown in Figure 1.

Figure 1. Number of Science and Engineering Doctorates Granted in 2010, by Nation.



Source: *Science and Engineering Indicators 2014*, Table 2-39, doctorates granted in 2010 unless indicated otherwise.

Mathematics Doctorates

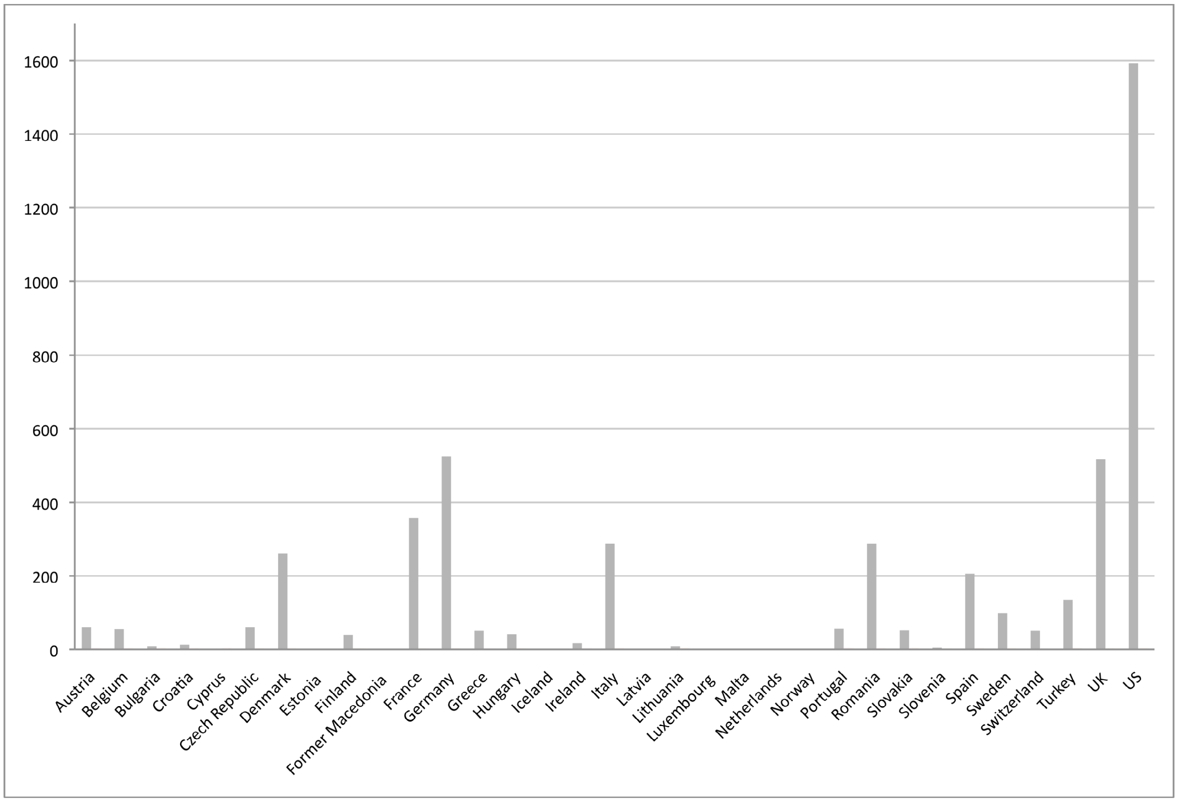
A less comprehensive compilation of statistics from the European Union shows the United States as the largest producer of doctorates in mathematics, followed by the United Kingdom, Germany, and France (see Figure 2 and chapter Appendix). Producing a relatively high number of science and engineering doctorates does not always imply doing the same for mathematics—and vice versa. For example, Denmark is not shown in Figure 1 because it produced a relatively low 728 doctorates in science and engineering, but is noticeable in Figure 2 because 261 of those doctorates were in mathematics. Nonetheless, the history of mathematics (Parshall and Rice 2002) and the prominence of China and Russia in Figure 1 suggest that they may also be major grantors of mathematics doctorates. Further statistical information about mathematics in these countries is not readily available, which is one reason why they receive little discussion in this chapter.

Another reason is that this chapter focuses on the US. Like Germany in the nineteenth century, the United States is a center of mathematical activity that attracts talented people from many countries. *The Mathematical Sciences in 2025*, a recent report on the mathematical sciences, concluded:

> In spite of concerns about the average skill of precollege students, the United States has an admirable record of attracting the best mathematical and statistical talent to its universities, and many of those people make their homes here after graduation. Assessments of capabilities in mathematical sciences research find the United States to be at or near the top in all areas of the discipline. (2013, p. 25)

However, as will be discussed later in this chapter, US tertiary institutions are many and varied. Not all are designed to support the best mathematical and statistical talent.

Figure 2. Number of Mathematics Doctorates Granted in 2010, by Nation.



Source: *She Figures 2012*, Annex 2.3.

National origins of US doctorates. Annual surveys conducted by the American Mathematical Society indicate that at least half of mathematics PhDs granted by US universities are earned by people who are not citizens or permanent residents of the US, and that this has been the case for at least thirty years.[2] Table 1 gives some sense of their relative proportions by showing the national origins of temporary or permanent US residents who were granted PhDs from US universities between 1991 and 2011.

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[2] See surveys at http://www.ams.org/profession/data/annual-survey/annual-survey. Note that students in the United States generally fall into one of three categories: citizen, permanent resident, or temporary resident. In contrast to permanent residents, temporary residents are permitted to stay only for a specific purpose such as graduate study or a particular job.

Table 1. US Mathematics Doctorates with Non-US Origins, 1991–2011

Country of origin	Number of doctorates
Middle East	741
North & South America (outside USA)	1,058
Europe	3,015
Asia	7,356

Source: *Science & Engineering Indicators 2014*, Tables 2-14, 2-15, 2-16.

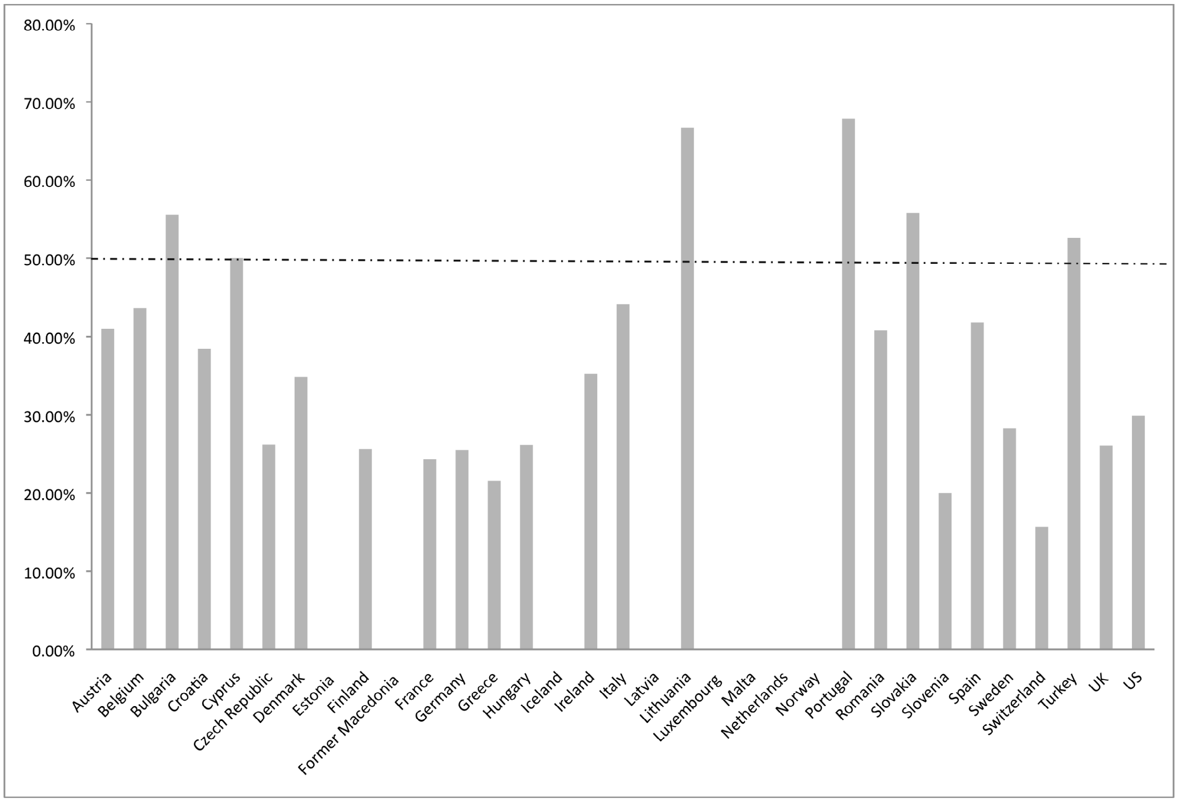
Surveys of recent US doctorates in mathematics show that many intend to remain in the United States (NSB, 2014, Table 3-22), although this varies with national origin. These responses are consistent with findings from annual surveys of new doctorates conducted by the American Mathematical Society. For example, of the 1,623 doctorates from 2012 who responded to the survey, 1,300 reported taking a job in the United States. Only 211 reported non-US jobs. Others were not seeking employment or still seeking it (see 2012 Survey, Table E.3; also five-year trends in Cleary, Maxwell, and Rose 2013).

Similarly, about 45% of UK mathematics doctorates go to students from outside the UK (McWhinnie and Fox 2013). It may also be the case that the large numbers of doctorates granted by countries with relatively small populations such as Germany and France are due in part to large proportions of foreign graduate students.

Doctorates Granted to Women and Gender Segregation

As illustrated in Figure 2, annual numbers of mathematics doctorates granted vary considerably by country. So do women's shares of these degrees (see Figure 3). For 2010, the highest percentages occurred in Portugal where women earned 38 of 56 doctorates granted (68%) and Lithuania where women earned 6 of 9 doctorates granted (67%). The lowest non-zero percentages occurred in Slovenia (20%, 1 of 5) and Switzerland (16%, 8 of 51). Women earned no mathematics doctorates in countries such as Estonia, Iceland, and Malta but these countries granted (respectively) 2, 1, and 0 doctorates. (Details for other EU countries are given in the Appendix.)

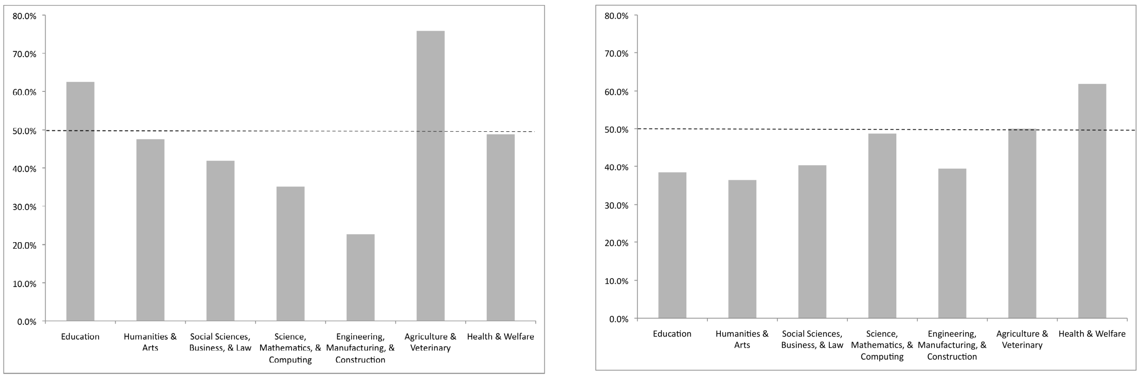
Figure 3. Percentages of Mathematics Doctorates Granted to Women, 2010.



Source: *She Figures 2012*, Annex 2.3. The dashed line at 50% is shown for reference.

Each of these percentages can be considered within the context of its country. For example, in Turkey almost equal proportions of men and women earned doctorates in mathematics. We might wonder if gender ratios for other fields of study were also close to parity in Turkey, and in fact, most were (see Figure 4). In contrast, more fields of study in Switzerland had gender ratios that were far from parity. These differences between nations can be described in terms of *gender segregation* (also called *horizontal segregation*), e.g., Turkey shows less gender segregation among doctorate fields of study than does Switzerland. This suggests that the percentages shown in Figure 3 may be, at least in part, associated with national characteristics rather than characteristics particular to mathematics. We return to this point at the end of this chapter.

Figure 4. Doctorates Granted to Women by Broad Field: Switzerland and Turkey, 2010.



Switzerland Turkey

Source: *She Figures 2012*, Annex 2.2. The dashed line at 50% is shown for reference.

Differences between domestic and foreign doctorates. We should not conclude, however, that percentages shown in Figure 3 are simply proxies for measures of gender segregation within a given country. The percentages shown by country conceal an important source of variation: doctorates awarded to foreign students. In the UK and US, women occur in greater proportions among doctorates granted to foreign students than to resident students (see Table 2). In 2011, women earned one fourth of all mathematics doctorates granted in the UK, but less than one fifth of doctorates granted to UK residents were granted to women. Women from outside the UK earned a much larger share of doctorates than resident women: 31% of the doctorates granted to EU-domiciled recipients, and 33% of the doctorates granted to those domiciled outside the United Kingdom and European Union. Without its foreign students, the UK percentage would be between the two lowest in Figure 3: Slovenia and Switzerland.

Table 2. Number and Percent of Mathematics Doctorates Granted to Women, 2011

	Resident Women	Non-resident Women	Total Women PhDs
UK	50 (19%)	70 (33%)	120 (25%)
US	228 (28%)	296 (34%)	524 (32%)

Sources: Computed from McWhinnie and Fox 2013; AMS Annual Survey of the Mathematical Sciences 2011, Supplemental Table D.2.

Statistics reported for the United States do not show such a pronounced difference between US citizen graduates and non-US citizen graduates. However, for both the US and UK, statistical differences between resident and foreign graduates suggest other differences between countries.

Differences in Cultural Attitudes

As already mentioned, studying mathematics in a foreign country may involve learning in a different language and a different culture. The latter may include different attitudes about women and mathematics. Women arriving for graduate study in the UK and US are sometimes surprised to learn that, in the words of a British mathematician, it is considered “rather odd for a woman to be mathematical” (Case and Leggett, 2005, p. 136). For instance, writing in 1992, a mathematician from Brazil described her experiences in England:

> I had never thought there was anything special in being a woman mathematician until I arrived in Warwick to do my PhD. At a party organized . . . for women graduates in the Maths Institute I asked why the other women had not come. To my surprise they had all come. That year had been particularly good, with five new female graduate students (there were over twenty men). (Case and Leggett, 2005, p. 131)

A decade and a half later, a mathematician from Romania described similar experiences in the US:

> As a child growing up in Romania, she liked mathematics, and her parents encouraged her interests through participation in mathematics camps and enrollment in a high school for science and mathematics. However, if she stayed in Romania, her only option would have been to teach; doctoral studies were not an option. Cojocaru made the difficult decision to leave the familiarity of home, traveling first to Italy to continue her studies and later to Canada. It was not until she entered a program at Princeton University that she was ever confronted with being female and a mathematician. For Cojocaru, the gender component was not something about which she had ever really given much thought. (Kirkman and Scriven, 2008, p. 15)

Table 3 illustrates how proportions of women on university mathematics faculties vary by nation. Countries are ordered by percentage of female professors, from the Czech Republic (2.2%) to Portugal (32.1%). Table 3 includes percentages from the top hundred US departments, with the US assistant, associate, and full professor listed, respectively, as lecturer, senior lecturer, and professor. The percentages at Princeton during Cojocaru's time, however, were far smaller (Andreescu et al. 2008; Case and Leggett 2005, pp. 169–170).

Table 3. Percent Women in Mathematics: PhDs, 2010; Faculties, 2005

Nation	PhDs	Lecturers	Senior Lecturers	Professors
Czech Republic	26	37.2	11.9	2.2
UK	25	24.8	12.6	2.8
Switzerland	16	26.7	14.3	3.1
Australia	–	28.5	22.9	3.6
Denmark		19.6	7.7	3.8
Germany	26	19.5	13.1	6.8
US, top 100*	30	26.8	18.4	7.1
Canada	–	18.5	11.9	8.8
France	24	16.1	30.7	10.3
Spain	42	31.0	25.9	12.9
Italy	44	50.4	40.3	15.1
Portugal	68	50.4	45.9	32.1

* US faculty for top 100 departments, 2007.

Sources: *She Figures 2012*, Annex 2.3; Hobbs and Koomen 2006, Table 2; Nelson and Brammer 2010, Table 11.

In the United States, the low numbers of female mathematics professors at elite universities are accompanied by the popular belief that women are not expected to do mathematics. Even six-year-old children may show awareness of the stereotype “Girls don’t do math” (Cvencek, Meltzoff, and Greenwald 2010) or cultural stereotypes such as “Asians are good at math” (Ambady et al. 2001).

The apparent paucity of women in mathematics is sometimes explained, even by mathematicians, in terms of “hard-wired” biological differences, e.g., “male and female human brains are physically different . . . biology cannot readily be changed” (Hill and

Rogers 2012, p. 23).[3] Such explanations are offered by psychologists in popular books such as *The Female Brain* and *The Essential Difference: Men, Women and the Extreme Male Brain*, despite the shakiness of their evidence (Buchen 2011; Else-Quest 2007; Tallis 2012; Young and Balaban 2006).

Newspapers discuss claims such as “the leakage of women continues even after starting careers as assistant professors—especially in math and physical sciences, and this trend continues as women advance through the ranks” (Ceci and Williams 2011). Juxtaposed statistics suggest that leakage is occurring. “Only one-fifth of physics PhDs in this country are awarded to women . . . of all the physics professors in the United States, only 14 percent are women” said the *New York Times*, a prominent US newspaper (Pollack 2013). *Nature*, a major international science journal, also juxtaposes percentages of doctorates and professors: “women earn about half the doctorates in science and engineering in the United States but comprise only 21% of full science professors and 5% of full engineering professors” (Shen 2013). Another example occurs in a prestigious US science journal:

> Today, half of all MD degrees and 52% of PhDs in life sciences are awarded to women, as are 57% of PhDs in social sciences, 71% of PhDs to psychologists, and 77% of DVMs to veterinarians. . . . Among the top 100 US universities, only

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[3] This neglects findings about plasticity. The neuroscientist Lise Eliot notes:

> The notion that sex differences in the brain, because they are biological, are necessarily innate or fixed is perhaps the most insidious of the many public misunderstandings on this topic. Neuroscientists know that, in the absence of proof of genetic or hormonal influence, any sex difference in adult neural structure or function could be shaped through experience, practice, and neural plasticity. (p. 897)

8.8–15.8% of tenure-track[4] positions in many math-intensive fields (combined across ranks) are held by women, and female full professors number ≤10%. (Ceci and Williams 2011, p. 3157)

These are dramatic differences. However, they are not, in fact, evidence that disproportionate losses are occurring now, although such losses have occurred in the past. The proportions of women in mathematics have increased, but have been masked by two types of phenomena: demographic inertia and gender stratification.

The next section reviews the evidence and illustrates these phenomena. Although their context is US academic mathematics, these phenomena can and do occur in other disciplines and other countries. The final section of the chapter discusses such national variations.

Change, Demographic Inertia, and Gender Stratification

In the United States, there are three main post-secondary degrees granted in mathematics: baccalaureate (BA), masters degree (MA), and doctor of philosophy (PhD).

Change in the Pipeline: Tertiary Education to Assistant Professor

Women have earned about 40% of baccalaureates in mathematics for at least forty years. In contrast with the trend for undergraduate degrees, percentages of women earning PhDs in mathematics have more than tripled over the past forty years, from 8% in 1971 to 31% in 2010. As noted earlier, these percentages differ by nationality. Women earned 28% of PhDs awarded to US citizens and 34% of those awarded to non-citizens in 2011.

[4] "Tenure-track" has two different meanings in the US. Here it means "faculty who are tenured or eligible for tenure." Because the other meaning is "eligible for tenure," this statement affords the very discouraging (and incorrect) interpretation that, relative to their shares of doctorates, women are currently underrepresented in junior faculty positions at top universities in fields such as mathematics, physics, computer science, and engineering.

Recent surveys find that women's share of tenure-eligible positions is similar to their share of new doctorates (see, e.g., Blair et al., 2013, Table S.16). Even at the top 50 mathematics departments, the proportions of female assistant professors now reflect their share of PhDs (Nelson and Brammer 2010).

The trajectory from baccalaureate to PhD to first academic position is often construed as a pipeline. Percentages of women at each stage are compared (e.g., 40% earning baccalaureates vs 30% earning PhDs) and differences interpreted as leaks. Thus, the pipeline appears to be leaking between undergraduate and graduate school, without obvious leaks between entrance to graduate school and first academic job (Cleary, Maxwell, and Rose 2013).

Demographic Inertia in the Trough: Faculty Employment

Overall, women are currently 23% of full-time doctorate-holding mathematics faculty in four-year colleges and universities (Blair et al. 2013, Table F.1).[5] We might consider this to be evidence of a leak: 31% of PhDs now go to women but 23% of doctorate-holding faculty are women—a difference of 8 percentage points. And, as noted earlier, such differences have, in fact, been interpreted as indicating that women are leaving mathematics, leading to well-publicized articles that offer explanations.[6]

These differences in percentages are not, however, unambiguous evidence of recent leaks. This is because the pipeline metaphor does not work well in interpreting statistics for all faculty, tenured faculty, or full professors rather than a cohort of doctorates. Comparing only percentages of women in faculty positions and among recent PhDs omits past history. In typical departments (as opposed to newly created

[5] This figure includes only tenured and tenure-track faculty at four-year institutions who hold PhDs. It does not include post-docs or other full-time faculty.
[6] See Kessel 2014 for examples.

departments), preparation pipelines from four decades feed into the same “trough.” Some faculty members were hired during the 1970s when women were earning 8% of PhDs; some during the 1980s when women earned 20% of PhDs; and some when women earned 30% of PhDs.

Rates at which women were hired and retained in mathematics also differ according to decade. During the 1970s, women who had earned doctorates did indeed leave academic mathematics more than men. In contrast, a longitudinal survey conducted in 1995 found that equal proportions of women and men who had earned PhDs in 1980 were tenured or had tenure-track jobs fifteen years later. But, the same survey found that men who earned PhDs in 1985 were more likely to have tenure ten years later than their female counterparts (Long 2001, pp. 127, 153, 167). Analyses of cross-sectional statistics for new doctorates’ first jobs found that gender differences in unemployment rates were 2% or less for 1991–1995 and 1996–2008 (Flahive and Vitulli 2010).

In interpreting trough statistics, the notion of *demographic inertia* is useful. This is “the tendency for current population parameters, such as growth rate, to continue for a period of time; there is often a delayed population response to gradual changes in birth and mortality rates” (Glossary n. d.). Because of demographic inertia, workforce or academic demographics must change slowly if no new positions are created and there is no forced retirement, even assuming equitable outcomes at every stage of hiring and promotion.

Consider the following example for the decade of 1999–2009. The American Mathematical Society reports that between about 1.25% and 4% of mathematics department faculty members retire or die each year.[7] Suppose that all of these faculty members are male,[8] they are replaced by new hires, and women do not leave after they are hired. Since 1999, the lowest annual percentage of PhDs earned by women was 27% and the all-time high was 34%. These yield 3% and 14% as lower and upper bounds for percentage point increase in female faculty members after ten years.

Statistics from the Conference Board of the Mathematical Sciences surveys show an increase of 6 percentage points between 2000 and 2010. In 2000, women were 17% of tenured or tenure-track faculty members at mathematics departments, increasing to 20% in 2005, and to 23% in 2010 (Blair et al. 2013, Table F1.1; Lutzer et al. 2007, Table F.1).

Consistent with these figures for mathematics, a detailed statistical study of academic sciences in the US between 1980 and 2005 finds "Much of the current underparticipation of women in academia can be explained by the time lags associated with overcoming historically very low representation" (Shaw and Stanton 2012, p. 3739).[9]

Stratification in Academic Employment, Awards, and Degrees

Although the overall percentage of faculty members who are women has increased, tenured women are not uniformly distributed by type of department. As shown in Figure 5, tenured women tend to be scarce in departments that grant PhDs. Currently women are about 11% of the tenured faculty members at these departments. Like Mary Winston (the first US woman to be awarded a PhD at Göttingen), women are

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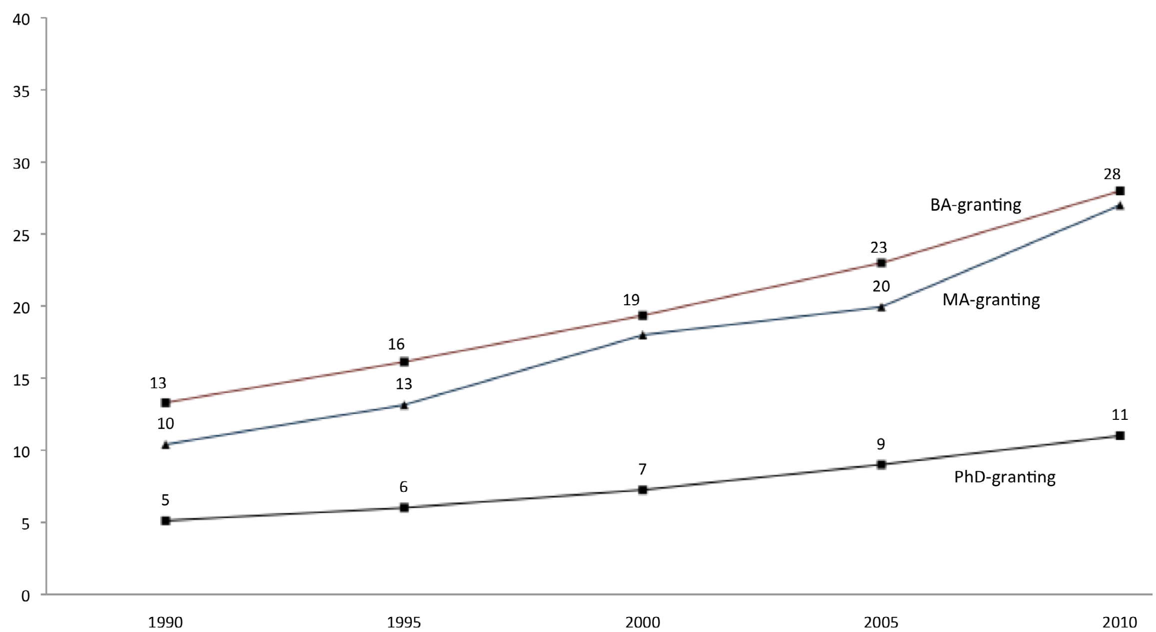
[7] See e.g., 2009 Survey Third Report, Figure 2. The rates for Groups I, II, III, IV, and Va are between 1.25% and 2.5%. These rates increase when MA- and BA-granting institutions are included.

[8] A look at Blair et al. 2013, Table F.4 suggests this is a correct assumption for PhD-granting institutions, but less so for departments which grant BAs and MAs.

[9] Although it does not report these trends for mathematics, this may be due to the study design which combines NSF figures for mathematics and statistics with figures for computer science. Many more undergraduates earn BAs in computer science than in mathematics and statistics (e.g., in 2001, 43,597 vs 11,437). But the reverse holds for PhDs (e.g., in 2001, 768 vs 1,001).

disproportionately represented at less prestigious institutions. These institutions tend to have fewer resources such as journal subscriptions and funding for professional travel. This type of phenomenon, in which women within a profession tend to be clustered in less prestigious and advantageous positions, is known as *gender stratification* (also *vertical segregation*).[10]

Figure 5. Percent Women in Tenured Positions, by Department Type, 1990–2010.



Source: American Mathematical Society annual reports, http://www.ams.org/profession/data/annual-survey/annual-survey.

Stratification also occurs for awards in mathematics. Relative to their presence as tenured faculty members, women are overrepresented as recipients of service awards, but underrepresented when it comes to awards for scholarship.

Figure 5 shows percentages of awards given to women by three professional societies. Each society has a different focus and thus a different primary nominee pool for awards. The American Mathematical Society (AMS) focuses on research in pure and

[10] Examples for other professions are given in Kessel 2014.

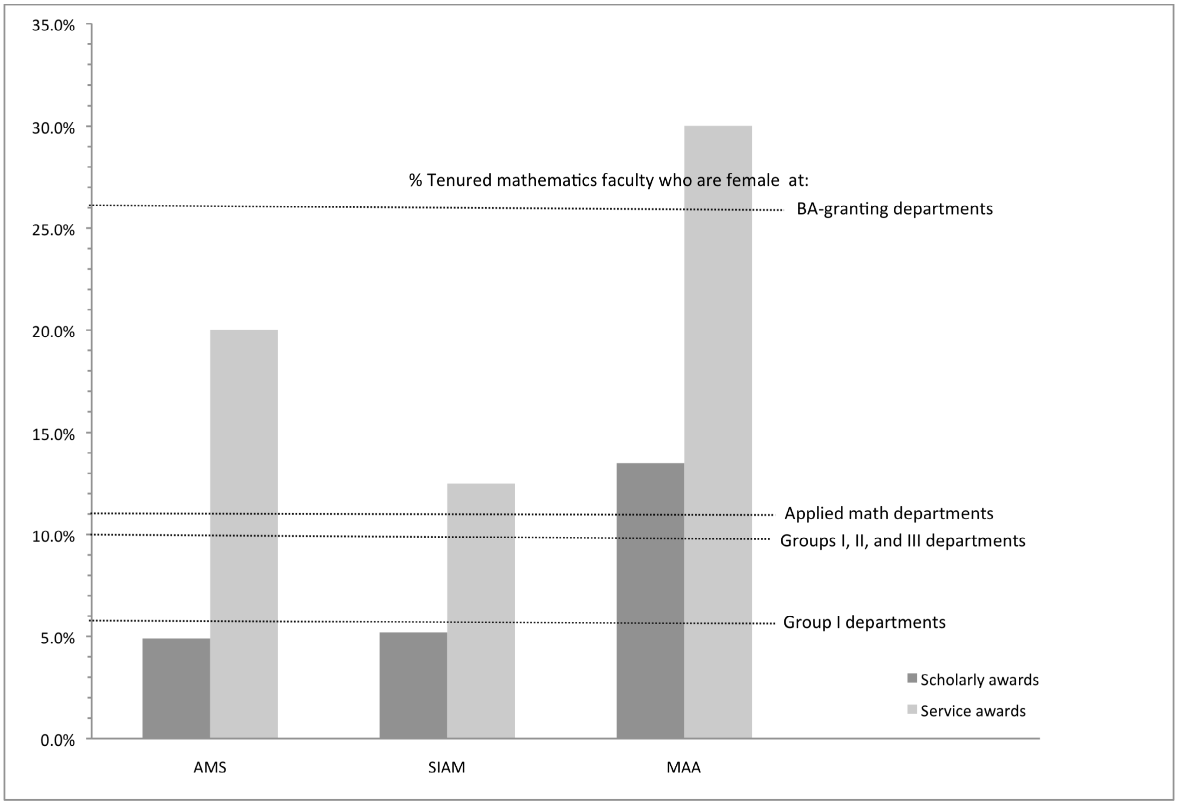
applied mathematics. Its primary nominee pool is members of PhD-granting mathematics departments, each of which has an AMS classification as Group I, II, or III.[11] Group I departments are the most prestigious. As shown by the horizontal dotted line in Figure 5, less than 6% of the faculty in these departments is female. As shown by the grey bars, fewer than 5% of AMS awards for research go to women, but at least four times as many awards for service.

The Society for Industrial and Applied Mathematics (SIAM) focuses on applied mathematics. Among academic departments (as opposed to government or industry) its primary nominee pool includes faculty in departments of pure or applied mathematics.

The Mathematical Association of America (MAA) focuses on advancing mathematics, especially at the undergraduate level. Its nominee pool is thus larger than that of AMS and its awardees more often include members of BA- and MA-granting departments.

[11] Note that AMS classifications changed in 2012 to include applied mathematics in Groups I, II, III. See http://www.ams.org/notices/201209/rtx120901262p.pdf.

Figure 5. Women's Awards vs Women's Representation.



Source: Redrawn from Popejoy and Leboy 2012. "BA-granting department" is their "four-year institution."

Stratification also occurs for degrees in mathematics. Percentages of baccalaureates awarded to women vary by type of department: higher in BA- and MA-granting and lowest in PhD-granting. Similarly, percentages of doctorates awarded to women vary by type of PhD-granting department, as shown by AMS annual surveys (e.g., Supplemental Table F.1).

Concluding Remarks

This chapter has reviewed variation in gender segregation across nations; and two phenomena that occur within nations: gender stratification; and differences in percentages of women earning PhDs and on department faculties. How do these phenomena vary and what might cause variation?

Gender segregation, GDP, and societal attitudes. The sociologists Maria Charles and Karen Bradley studied educational outcomes in countries from all five continents and Oceania.[12] They identified an association between gender segregation in tertiary education outcomes for 44 countries and industrialization: increased gender segregation occurs with increased gross domestic product (GDP). Charles (2011) sets this finding in a larger context of trends in education and labor force participation, offering the explanation that developed societies have an ideology of free choice but deeply-seated beliefs and unconscious biases about gender which affects a woman's evaluation of her own abilities—and their evaluation by others. Examples of such beliefs were given in this chapter's section on "Differences in Cultural Attitudes."

Charles and Bradley note that economic necessity seems to play a larger role in developing or transitional societies. However, it should be noted that their study combines first, second, and third tertiary degrees (BAs, MAs, and PhDs in US parlance). It seems easier to explain choice of field for a first than third degree in terms of financial incentives. In many fields, a doctorate is generally a path to an academic career, and the salient financial difference may be between academic and non-academic occupations rather than between fields. However, the pathway to a third tertiary degree generally includes a first degree and is likely to be smoothed by the presence of same-gender peers and social acceptability. This may help to explain the cultural differences that surprised the two graduate students arriving from Brazil and Romania, and why percentages of women are larger among foreign doctorate recipients at UK and US universities (as in Table 2).

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[12] These were countries which participated in the Trends in International Mathematics and Science Survey (TIMSS), thus very low income countries are underrepresented.

Are these differences due to more women from countries with less gender segregation? If so, research in mathematics education suggests a possible mechanism: women arriving from countries with less gender segregation may be more likely to already see themselves as part of the mathematical community (Herzig 2004), thus more likely to finish their graduate studies.

Gender stratification, unconscious bias, and demographic inertia. As a student becomes more deeply involved in mathematics, the effects of gender stratification may become a more salient part of daily experience—at least in developed countries, as illustrated by the US examples. One explanatory mechanism for gender stratification is unconscious bias in professional judgment. In the US, the latter has been documented by several studies with similar design and similar findings. An example is a recent study of the psychologist Corrine Moss-Racusin and colleagues. Two groups of physicists, chemists, and biologists from research-intensive US universities evaluated an application for lab manager from a student. The materials given to the two groups were identical, except for the name of the applicant: Jennifer or John. "Jennifer" received lower ratings than "John" on competence and hireability. She was offered less mentoring and a lower salary.

Although large percentages of men in academic departments may be more due to demographic inertia than unconscious bias or attrition, causal differences are not readily distinguishable. A further complication is that, independent of their cause, large proportions of males in an academic department may contribute to unconscious bias (Banaji and Greenwald 2013). In some countries, higher education is rapidly expanding and new universities are being created (e.g., China, UNESCO Institute of Statistics

2014). In such institutions, demographic inertia need not play a large role in determining proportions of faculty men and women, especially at the junior level, providing the potential to avoid reinforcing stereotypes unconscious bias and stereotypes about fields of study.

Change. Within the US, UK, and many European nations, proportions of female mathematicians and mathematics professors have generally increased between 1993 and 2005 (Hobbs and Koomen 2005).[13] In the US, a notable change is the increase in women at junior levels at elite mathematics departments over the past decade. Practices that reduce the effects of unconscious bias may be part of the explanation (see Kessel 2014).

Returning to the mathematicians whose stories began this chapter, we can interpret their choices as occurring in national contexts with different affordances and constraints. At the same time, their stories suggest possibilities for the future. Kovalevskaya emigrated from her homeland (marrying in order to be allowed to do so), studied in one country, and obtained a university post in another—both in locations of substantial mathematical activity. Chisholm studied abroad and returned to her homeland, maintaining an active mathematical life and contact with other mathematicians, but without an academic position. Winston also studied abroad and returned to her homeland (not then a center of mathematical activity), obtaining undistinguished academic posts—a form of gender stratification. Although Haynes did not leave her country to earn a doctorate, she undoubtedly encountered cultural obstacles in education and employment due to her minority status.

[13] The Czech Republic is a counterexample.

Which of these are stories that must be as higher education expands? Mathematicians and policy-makers will have important roles in determining the answer.

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Appendix, Mathematics PhDs in 2010, by Gender and Nation

Nation	Women	Men	All PhDs	% Women
Austria	25	36	61	40.98%
Belgium	24	31	55	43.64%
Bulgaria	5	4	9	55.56%
Croatia	5	8	13	38.46%
Cyprus	1	1	2	50.00%
Czech Republic	16	45	61	26.23%
Denmark	91	170	261	34.87%
Estonia	0	2	2	0.00%
Finland	10	29	39	25.64%
Former Macedonia	0	0	0	0.00%
France	87	270	357	24.37%
Germany	134	391	525	25.52%
Greece	11	40	51	21.57%
Hungary	11	31	42	26.19%
Iceland	0	1	1	0.00%
Ireland	6	11	17	35.29%
Italy	127	161	288	44.10%
Latvia	0	0	0	0.00%
Lithuania	6	3	9	66.67%
Luxembourg	0	2	2	0.00%
Malta	0	0	0	0.00%
Netherlands	0	0	0	0.00%
Norway	0	0	0	0.00%
Portugal	38	18	56	67.86%
Romania	117	170	287	40.77%

Slovakia	29	23	52	55.77%
Slovenia	1	4	5	20.00%
Spain	86	120	206	41.75%
Sweden	28	71	99	28.28%
Switzerland	8	43	51	15.69%
Turkey	71	64	135	52.59%
UK	135	382	517	26.11%
US	476	1116	1592	29.90%
Total	1548		4795	32.28%

Source: *She Figures 2012*, Annex 2.3.