Chapter 1

Production

In 2010, the Royal Society published a list of ten British women who had the greatest influence on science.[1] This list contains contemporary scientists such as geneticist Anne McLaren and Nobel laureate biochemist Dorothy Hodgkin. Most of these women have high educational achievements and laudations to accompany their robust pedigrees. One woman, however, is distinctively unadorned with academic accolades.

Mary Anning was born in Great Britain shortly before the turn of the nineteenth century (1799–1847). Her childhood and adolescence did not involve tutors or schooling, but rather days exploring in Lyme Regis on the southern shore of Britain. Her father was an occasional fossil collector and taught his daughter the skills of collecting and dealing. This provided a modest income for the family, as they were lucky enough to live near a rich Jurassic-era marine fossil bed. Around age twelve, Anning found the first full ichthyosaurus to be known to the scientific community. She subsequently discovered the first plesiosaur and pterodactyl fossils. These fossils were purchased by museums and collectors, many of whom noted her strong knowledge of paleontology. Despite this, she received little recognition for her work, besides an obituary notice from the director of Her Majesty's Geological Survey and president of the Geological Society of London—an association to which neither she nor another woman was admitted until 1904. Her sole published work is a letter to the editor in the *Magazine of Natural History*. Despite having her fossils featured in the Natural History Museum and other prestigious institutions, her contributions to paleontology were largely forgotten after her death. Her gender and social class prevented her from being able to contribute to the permanent scientific record. Anning was engaged in research "activity," but she did not "produce" science.

It took another generation for women's work to be made visible in scientific publications. British engineer, mathematician, and physicist Hertha Ayrton (1854–1923) was also featured on the list of notable British scientists. Among her scientific honors is the distinction of being the first woman to read her own research before the Royal Society. Unlike Anning, Ayrton was well schooled, attending Cambridge University and the University of London. As with many successful scholars of her era, Ayrton's entrance into the scientific community was facilitated through marriage: she met and married her professor, William Ayrton, when she was attending classes at Finsbury Technical College in the late 1880s. The marriage, however, hampered some of her subsequent success. Although she was nominated as a fellow of the Royal Society of London, she could not be elected due to her marital status. Her marriage also led to some disquieting authorship issues. Ayrton's aging husband was unable to maintain his productivity; to facilitate, Ayrton continued doing his work and publishing under his name in parallel with her own work. She therefore stands at an interesting intersection in the history of scientific production for women: her marriage provided her entrance into science yet also made many of her contributions invisible. Despite these constraints, she eventually developed an independent voice in the scientific community, receiving several notable awards and publishing in the most reputable journals of the day.

One of the leading publication venues then (and now) was *Nature,* a generalist scientific magazine founded in 1869.[2] In Ayrton's time, the editor in chief (and founder of the journal) was Sir Joseph Norman Lockyer, who was married to a strong advocate for women's rights and a noted suffragette, Mary Broadhurst Lockyer. When Ayrton was considered for the Royal Society, Mary Lockyer strongly advocated in her favor. Her husband was similarly supportive of women's entrance into these societies. In 1904 and 1908, women chemists petitioned the Royal Chemical Society to admit women fellows.[3] A *Nature* editorial ran in support of the 1908 petition, noting the positive contribution of women scientists to the journal: "It cannot be denied that women have contributed their fair share of original communications. Indeed, in proportion to their numbers they have shown themselves to be among the most active and successful of investigators. The society consents to publish their work, which redounds to its credit."[4]

Nature editorials also expressed support for women scientists seeking admittance to other societies, such as the Geological Society, where Anning might have been admitted were she of another century. Not all editors were equally supportive. The editor who succeeded Lockyer at *Nature,* Richard Gregory, was far less sympathetic to the cause. He published an obituary of Ayrton by fellow chemist Henry E. Armstrong strongly suggesting that Ayrton's success should be credited to her husband: "I never saw reason to believe that she was original in any special degree; indeed, I always thought that she was far more subject to her husband's lead than either he or she imagined."[5]

Progress toward equity was slow. In 1924, a letter to the editor from renowned physicist Norman R. Campbell requested that *Nature* replace the offensive term *man of science* with the more inclusive term *scientist*.[6] Gregory responded that he would inquire among many "distinguished men of science" on their opinions on the matter. As noted in the introduction, it was not until 2000 that *Nature* adopted a new mission statement, eliminating the reference to "men of science." It took nearly two more decades after this change for a woman to be appointed to the helm: *Nature* hired its first woman editor in chief, geneticist Magdalena Skipper, in 2018. More than two centuries passed, from Anning to Skipper, for women not only to be recognized for producing science but to serve in the highest echelons of gatekeeping.

Women and the Professionalization of Disciplines

The stories of Anning and Ayrton and the controversy in the pages of *Nature* foreshadow tension between the professionalization and feminization of scientific disciplines. Before the twentieth century, science was associated with amateurism, which allowed wealthy women and those who married scientists to participate in scientific activities. Beginning in the 1870s, women increased their membership in scientific organizations and began obtaining employment in museums and observatories.[7] By the end of the nineteenth century, however, science began a process of professionalization that served to decrease women's access to scholarship.[8] When science became codified as a professional—and therefore masculine—domain, women were further isolated from participation.

The rise of higher education and the expansion of employment for women happened in parallel with this professionalization. Several institutions across the world opened their doors to women in the late nineteenth century, and by 1910, a large share of universities allowed women to receive degrees across the disciplinary spectrum. This led to an environment where women were being educated but not employed or advanced at the same rate as men. Women were therefore corralled into careers that were perceived as appropriate for their "special talents." Gender segregation in labor, well established in other professional sectors, intensified in science. Women initially took their science degrees into museums, botanical gardens, and other cultural institutions where they could receive modest employment. Over time, the rise of larger, collaborative teams opened new opportunities for women as science assistants.[9] For example, women's roles as "computers" in astronomy and physics confirmed their ability to conduct patient and painstaking labor in the lab.

As women matriculated at higher rates, they were more likely to enter disciplines associated with care and domesticity—such as education, child psychology, librarianship, social work, and the newly emerging field of home economics.[10] It is not surprising that Nobel laureate Marie Curie was cast in a caregiving role in her fund-raising trips in North America: rather than being touted for her scientific discoveries, she was aligned with the potential to cure cancer and her work on the military front. It was easier to place a woman in a care-related role than to perceive her as a scientist.[11]

Caregiving fields were feminized at the start of the twentieth century and remain so. In contemporary research, women account for less than a third of authorships (30.9%), with few research specialties where women are in the majority.[12] In practical terms, this means that for every woman scientist, there are about 2.3 men. As our data show, only 10 of the 143 specialties in the National Science Foundation journal classification have more authorships by women than men (Figure 1.1): nursing (75.8%), social work (64.1%), speech-language pathology and audiology (62.2%), developmental and child psychology (61.2%), public health (52.2%), rehabilitation (53.7%), social sciences, biomedicine (53.6%), education (53.5%), geriatrics and gerontology (53.5%), and nutrition and dietetics (50.3%).[13] All these woman-dominant fields have a distinctive service aspect to them, thereby reinforcing the perception of women as more suitable for care-oriented disciplines.[14]

The disciplines and specialties with stronger representation from women are often associated with depressed salaries, leading to a cyclical reinforcement rooted in this history: only women were willing to work in fields with lower salaries, so those fields with a high proportion of women could offer lower incomes.[15] Such devaluation of women's work is common across the world. In the United States, for instance, studies have shown that occupations with a greater share of women pay less, and as more women enter a field, the pay drops.[16] The opposite is also true. Programming was historically done by women "computers," but when men outnumbered women in the field, the pay and prestige increased.[17]

On the other side of the spectrum, twenty specialties have less than 20% women authorships. Except for one—orthopedics—all are in the disciplines of engineering, mathematics, and physics: aerospace technology (13.9%), nuclear and particle physics (15.2%), mechanical engineering (15.6%), fluids and plasma physics (15.9%), and nuclear technology (16.2%).[18] Most of the disciplines with a lower percentage of women are shrouded in certain myths of the innate talent and brilliance required—that is, an inflated notion of the skill level necessary for entry and performance—and are also often associated with notions of competition and solitary work that may discourage participation from women.[19]

Similar mechanisms can be observed in the humanities: for example, the discipline with the lowest participation of women is philosophy, where associations of the field with masculinity serve as a deterrent for participation.[20] In social sciences, women are underrepresented in economics, which has a long history of hostility toward women scholars.[21] A certain proportion of women in a discipline may be required to dispel myths and prevent cultural barriers to entry. For example, a study by sociologists Catherine Riegle-Crumb and Chelsea Moore found that the dominant predictor of girls' propensity to take high school physics courses in the United States was the percentage of women in the community employed in STEM careers.[22] A similar conclusion was reached by scholars examining undergraduate majors and degree obtainment at US institutions: they found an association between the percentage of women faculty in a department and the percentage of women receiving a degree.[23] The fact that "degrees received" was a more sensitive variable than "percentage of majors" suggests the importance of role models not only for recruitment into a field but also for successful career outcomes within the field. Overall, we observe that representation matters: it is important for individuals to be

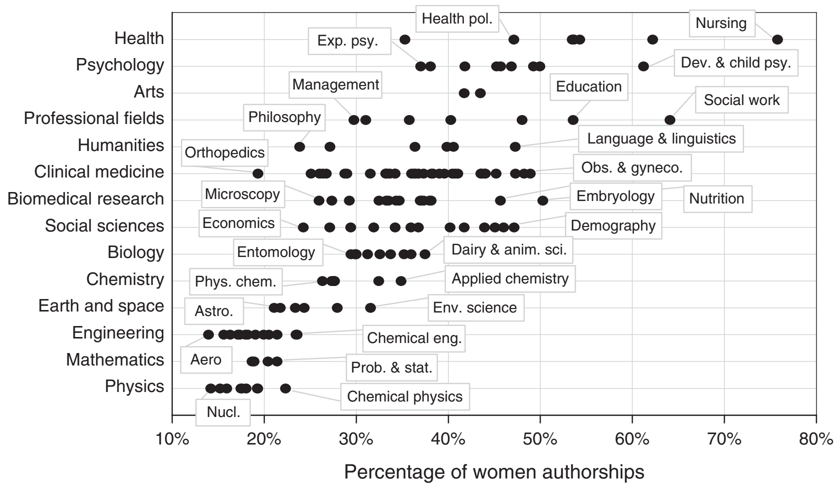

FIGURE 1.1. Percentage of women authorships, by National Science Foundation specialty and discipline, 2008–2020. Data from Web of Science core collection.

able to imagine themselves in professions through the embodiment of others who carry their same characteristics.

The Endless Productivity Puzzle

Authorship is a function not only of the number of women in the scientific system but also of their individual productivity. The distinction between the share of authorships and productivity is an important one. The percentage of authorship presents the contribution to scientific knowledge from women, *in the aggregate*. It provides the average percentage of all authors on a paper who are women but does not distinguish between a few women authoring many papers or many women each writing a single paper. Productivity, on the other hand, expresses how many papers are written by unique individuals. These distinctions provide different lenses on gendered production in science—one at the universal level and the other at the individual level. As sociologist Mary Frank Fox has observed, "Until we understand factors that are associated with productivity, and variation in productivity by gender, we can neither assess nor correct inequities in rewards, including rank, promotion, and salary . . . because publication productivity operates as both cause and effect of status in science . . . Productivity reflects women's depressed rank and status, and partially accounts for it."[24]

For all disciplines and researchers who published at least once between 2008 and 2020, we observe a sizable gap in productivity, with men publishing over the period an average of one paper more than women (4.0 versus 3.2) (Figure 1.2, left panel). For all disciplines, save arts and health, men published at least 20% more than women, with differences that reach as high as 50% more in psychology and more than a third as many articles in physics, mathematics, and social sciences. One explanation could be the gendered productivity bias that comes with age: that is, that there are more men in senior ranks and these individuals are more productive.[25] As heads of laboratories, these individuals benefit from a larger network of collaborators, which, in turn, is likely to increase publication counts.[26] To control for age differences, we examined the research productivity of a cohort of researchers who published their first paper in 2008 (Figure 1.2, right panel).[27] When only the 2008 cohort is analyzed, the productivity gender gap is much smaller, with men publishing 4.2 papers and women 3.9 over the 2008–2020 period (all disciplines combined). The arts exhibit slightly higher productivity for women than for men, and the gender gap is less than 10% in clinical medicine (3.6%), biomedical research (8.3%), biology (8.9%), and earth and space (9.9%) when the cohort of younger researchers is considered. This is likely an effect of the influx of women into these disciplines: As women have become more prominent

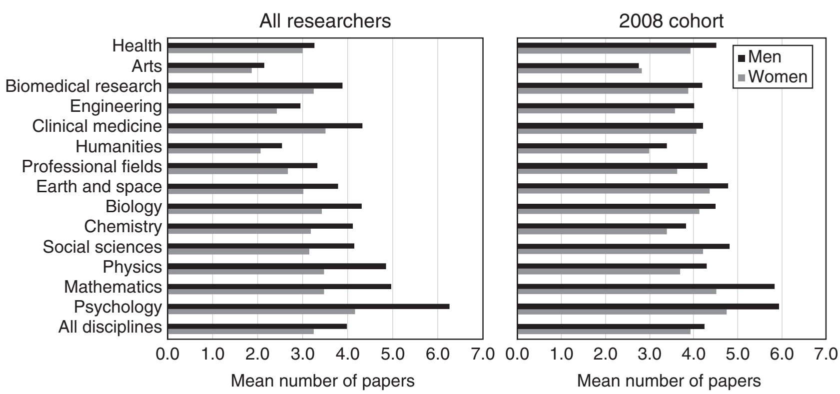

FIGURE 1.2. Total number of papers published by men and women who published their first paper in 2008 (right panel) and for all researchers who have published at least one paper over the 2008–2020 period (left panel), by discipline. Data from Web of Science core collection.

in disciplines related to medicine, average productivity for women has increased. This may reinforce the circular benefits of parity: when there are more women in a field, the climate for women improves and provides opportunities for them to thrive.

Given the wide variations in rank structures across countries and lack of standardized data, it is impossible to control for rank in these analyses. Controlling for year of first publication can be useful in creating a proxy for seniority, but not for rank, given that women are less likely to attain the rank of full professor (in the United States) or to achieve it as

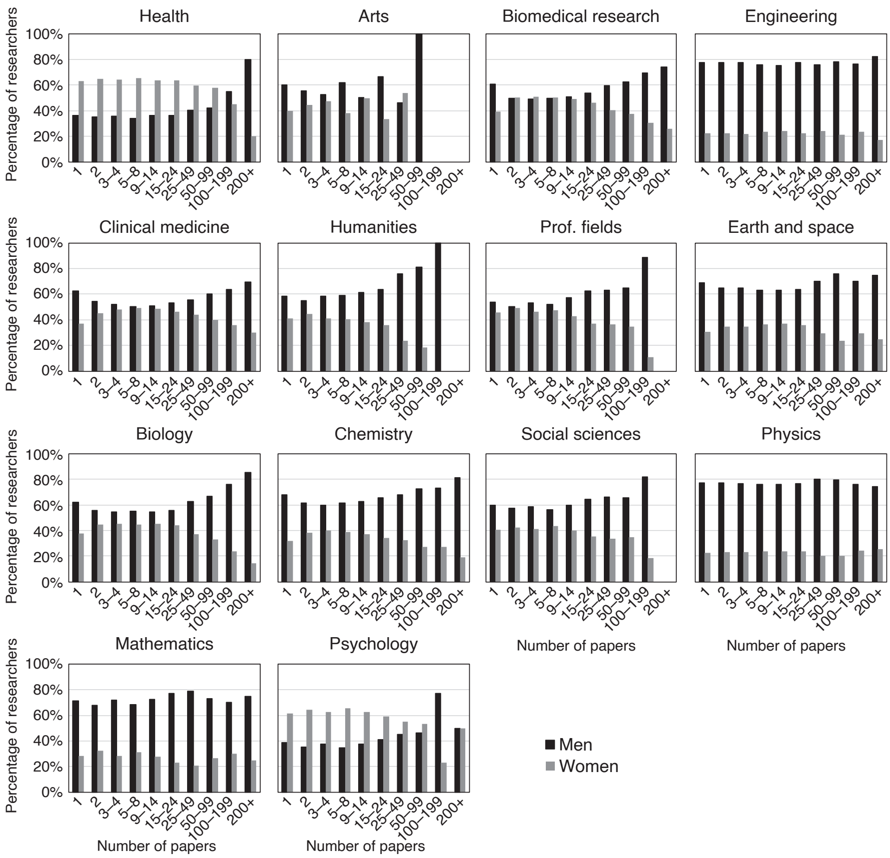

FIGURE 1.3. Percentage of men and women, as a function of research productivity over the 2008–2020 period, for the cohort of researchers who published their first paper in 2008, by discipline. Data from Web of Science core collection.

quickly.[28] Despite these limitations, our results provide some evidence to support previous findings of the mediating effect of rank on gender and productivity, suggesting that interventions focused on senior faculty would have strong effects on the field.[29]

Averages, of course, obscure differences in the distribution of research productivity. One way to examine this is to measure, by field, the percentage of women across different levels of individual research productivity, from those who have only authored a single paper to women with more than 200 papers over the 2008–2020 period (Figure 1.3). Some fields are relatively static in the proportion of women by research productivity: there is little difference in engineering and physics, for example, in the relative share of women who have one paper and those with more than 200. However, there are more women than men in all categories of production in health and psychology until the number of papers reaches 50—at this point, there are proportionally more men than women. The life sciences fields (biomedical research, clinical medicine, and biology) demonstrate inverted U-shaped curves, where there is a greater disparity at the low and high ends of production but closer to parity in the middle range of production. Given that these data are taken from a single cohort (those who published their first paper in 2008), one cannot interpret the results as merely a slow progression through time, with the influx of women changing the distribution of some fields. Rather, this suggests different patterns of production at the intersection of gender and discipline. The mechanisms that cause this continued "productivity puzzle" warrant deeper evaluation, particularly as they pertain to expectations for rank advancement in academia.[30]

Women in the World

Rates of women authorship vary by country, with few countries reaching equal representation by gender. To visualize how countries differ in their percentage of women authorships, we present two world maps: one that demonstrates how countries diverge from absolute gender parity (Figure 1.4a), and the other showing how countries diverge from the global mean percentage of women authorships of 30.9% (Figure 1.4b). Five countries—the United States, China, Japan, Germany, and the United Kingdom—account for more than half of all fractionalized authorships, thereby strongly influencing the world average (30.9%). Among these high-producing countries, Japan has the lowest rate of women authorship (17%), falling far below the world average and lower than other Asian countries. More than a quarter of Chinese authorships are women (26%), placing China at a nearly identical gender rate to Germany's (27%).[31] The United States stands above the world average, with 33% women authorship—a ratio of two men for each woman in the research system—while the United Kingdom's percentage of women authorship is slightly higher than the world average at 32%.

Of all countries and territories, only ten have an equal or higher percentage of women authorships, though eight of these countries are relatively small, with fewer than 200 fractionalized authorships over the thirteen-year period studied. The two countries with more than 200 fractionalized authorships and 50% or more women authorships are Latvia (51%) and Romania (50%). Coming close to parity are North Macedonia, Argentina, Bulgaria, Ukraine, Croatia, and Serbia, which obtain above 48% women authorships. The unique status of former Yugoslavian countries is particularly notable. In 1939, before Josip Broz Tito's communist regime, only 19% of students enrolled in institutes of higher education were women. With a commitment to promoting gender equality, the new communist regime opened higher education to women, thus increasing their percentage to nearly 30% by 1961–1962, and then to more than 40% by 1973–1974.[32] Similar trends are also observed for science-related occupations: in the 1970s and 1980s, women accounted for 43%–44% of the scientific workforce—sizably above the Yugoslav average for all sectors of the economy combined (35.5% in 1980), and above the average participation of women in most countries.[33] This is in keeping with the history of several former communist countries, which have a strong history of incorporating women into the workforce, including academe.

Despite not reaching parity in scientific production, several countries in North and South America are above global rates, with Argentina (48%) and Brazil (41%) nearing parity. Most European countries are also above average, particularly Poland (44%), Portugal (44%), Spain (40%), Scandinavian countries (35%–42%), and Eastern European nations (39%–51%). German-speaking countries—Germany (27%), Austria (28%), and Switzerland (27%)—as well as Greece (29%) and Hungary (29%), are the exception, with percentages of women authorships below the world average. These groupings reflect the cultural aspects of gender in science and suggest that religion, history, and political systems have a demonstrable effect on the composition of the scientific workforce.

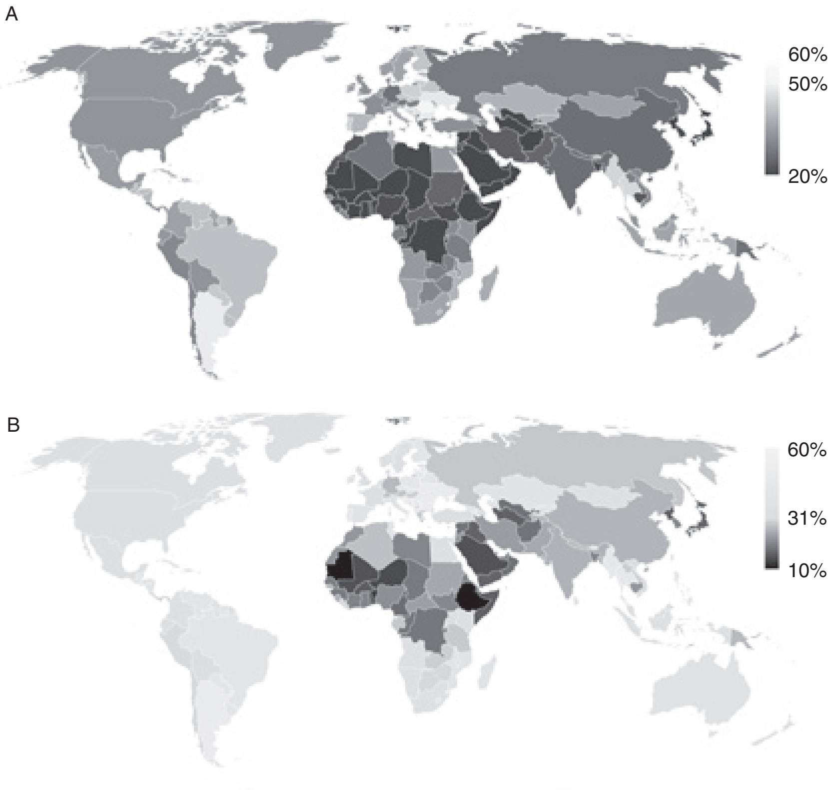

FIGURE 1.4. Proportion of women authorships by country, 2008–2020. Panel A presents the data with a color coding that emphasizes gender parity (50%). The darker the shade, the higher the dominance by men; the lighter the shade, the closer the country is to gender parity. Panel B presents the data with a color coding that emphasizes countries' relationships with the world average (30.9% women authorships). Darker shades denote countries that are below the world average in terms of their percentage of women authorships; lighter shades denote countries that are above the world average in terms of women authorships. Data from Web of Science core collection.

Many Middle Eastern and African countries—with Angola, Namibia, Mozambique, South Africa, and Tunisia as exceptions—can be found at the other end of the spectrum. Among those, Iran (23%), Jordan (22%), Bangladesh (20%), the United Arab Emirates (20%), Cameroon and Qatar (18%), Saudi Arabia (15%), and Ethiopia (10%) are worth noticing given their low rates of women authorship.[34] Farther east, several

Asian countries show lower than average proportions of women authorships: India (26%) and the Republic of Korea (21%) join Japan (17%) with low representation of women on the bylines of scientific articles.

As discussed earlier, percentages of authorships are a function of the number of women in the research system. If we examine the distinct number of women who have contributed to scholarly papers over the last thirteen years, instead of the proportion of women authorships, we see a slightly different picture. For almost every country, there is a higher proportion of distinct women authors—that is, of women who have authored at least one paper—than of their share of authorships (Figure 1.5). More specifically, while women account for 30.9% of authorships at the world level, they constitute 36.6% of distinct authors.[35] Therefore, most countries are closer to parity in terms of unique authors, and thirty have reached gender parity. Among the countries with at least 10,000 papers published between 2008 and 2020, those countries to have reached parity in women authors include Argentina (55%), Croatia (55%), Romania (54%), Portugal (53%), Thailand (53%), Tunisia (53%), Poland (52%), Slovakia (52%), Bulgaria (52%), Uruguay (52%), Lithuania (52%), Finland (51%), Brazil (50%), Czechia (50%), Estonia (50%), Serbia (50%), and Spain (50%).[36]

Geographic and political divisions in terms of women authors are particularly visible in Figure 1.5b, where we examine the percentage of women researchers compared with the world average (36.6%). European countries, as well as those located in North and South America, are all above average, while most countries in Africa and the Middle East, as well as China (29%), India (31%), and Japan (26%), are sizably below average. The gap between authors and authorship could be explained in two, slightly contradictory, manners: it could indicate a retention issue, where women enter the system but leave with few publications; or it could suggest that the research systems in these countries allow for the retention of women in science at lower levels of productivity.

Although the percentage of women as distinct authors is higher than the proportion of women authorships, these variables are strongly related: countries with a higher number of women in their research system as authors also have a higher percentage of women authorships (Figure 1.6, inset). However, there are exceptions to this, which shows that productivity levels by gender exhibit country-level variations. Among those countries with a sizable number of articles, Iran, Saudi Arabia, Germany, and Japan are notable examples, where the propor-

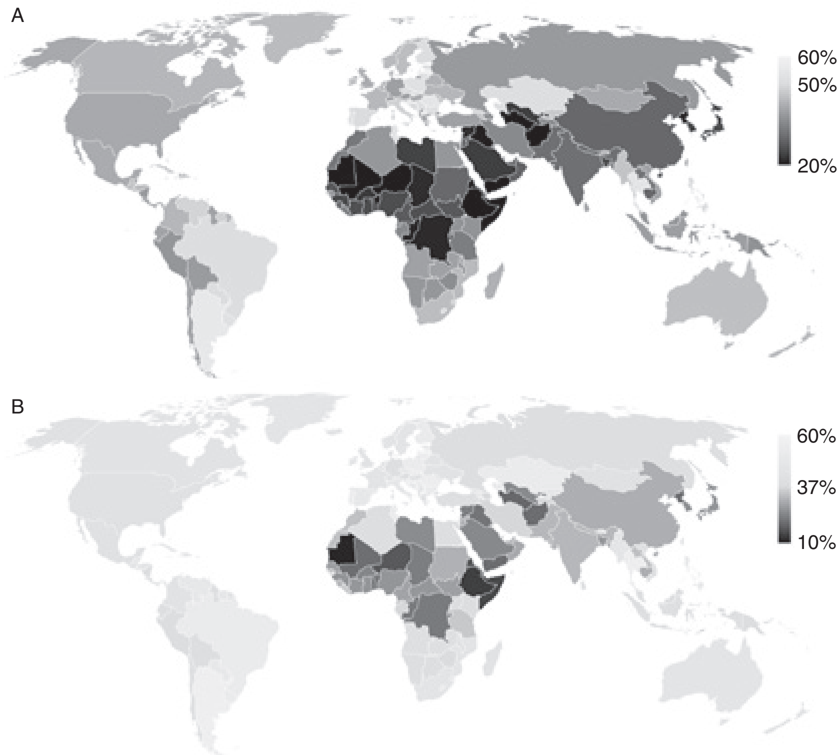

FIGURE 1.5. Proportion of women authors, by country, 2008–2020. This percentage is obtained by dividing the number of distinct women researchers who have authored a paper while affiliated to a country by all distinct researchers who have authored a paper affiliated to that country. Similar percentages are obtained when only researchers with more than one paper are included. Panel A presents the data with a color coding that emphasizes gender parity. The darker the shade, the higher the dominance by men; the lighter the shade, the closer the country is to gender parity. Panel B presents the data with a color coding that emphasizes countries' relationships with the world average (36.6% women authors). Darker shades denote countries that are below the world average in terms of their percentage of women authors; lighter shades denote countries that are above the world average in terms of women authors. Data from Web of Science core collection.

tion of women authors is 50% higher than their share of authorships. In other words, their presence in the workforce exceeds what would be expected given output alone. At the other end of the spectrum, the percentages of women authorships and distinct researchers are almost identical for China, South Korea, and Taiwan, which suggests that men

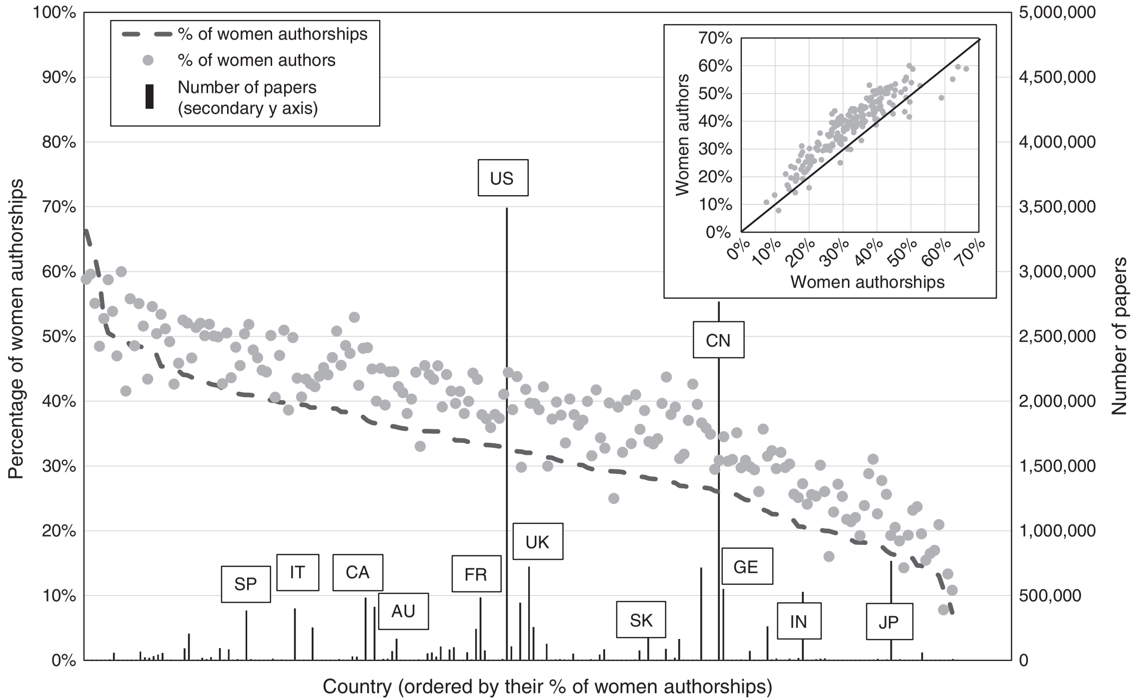

FIGURE 1.6. Percentage of women authorships, percentage of women authors, and total number of papers (fractionalized authorships), 2008–2020. Gray dots represent the percentage of distinct women authors from the country, while the dotted line shows the percentage of women authorships. Countries are ordered by their percentage of women authorships, with the black vertical bars demonstrating the number of papers. Inset: correlation between percentage of women authorships and women authors. Data from Web of Science core collection.

and women produce at rates equal to their representation in the workforce. These different cases suggest different policy interventions. In cases like Iran, Saudi Arabia, Germany, and Japan, the higher number of women may suggest strong educational systems but working climates that are unsupportive of women's employment in scientific fields. This reinforces the disconnection between educational and occupational access that has persisted in various countries across the past century. The equal rates of authors and authorship in China, South Korea, and Taiwan might suggest that an increase in women in the workforce will yield a concomitant rise in production.

The Interplay between Country and Discipline

Both country and discipline influence the participation of women in science. The interaction among these variables, however, is less understood. Does country specialization in a certain discipline yield higher degrees of women participation? Or does the presence of women in the labor force lead to country specialization in particular disciplines? To investigate this, we examine the participation rates of women at the intersection of discipline and country for the most productive countries (Table 1.1). We observe a strong influence of country: those that have higher percentages of women authorships overall also have higher-than-average percentages of women authorships in each discipline.

Health is the only domain with higher proportions of women authorship overall. However, several countries overcome disciplinary gender barriers, with women's participation rates in other disciplines higher than the global average.[37] Portugal, for example, has higher rates of women's participation in mathematics than would be expected given the global average. In fact, several Spanish- and Portuguese-speaking countries (Portugal, Brazil, Spain, and Mexico) outperform what would be expected across many disciplines. The same is true for Asian countries, with Taiwan being the most striking example. Despite these country distinctions, disciplinary cultures remain strong—see, for example, the low rates in engineering and physics across most countries. Overall, the data suggest a strong interplay between the scientific and cultural dimensions in predicting rates of participation by women. That is, gendered production in science is highly contextualized and situated in the intersectional space of discipline and country. Policies to alleviate gender

TABLE 1.1. Percentage of women authorships, by country and discipline, 2008–2020. Thirty countries with the most papers over the period. The color coding emphasizes countries' relationship with the world average, all disciplines combined (30.9% women authorships). The darker the shade, the higher the dominance by men; the lighter the shade, the closer the country is to gender parity. Data from Web of Science core collection.

Country	*Health*	*Psychology*	*Arts*	*Professional fields*	*Humanities*	*Clinical medicine*	*Biomedical research*	*Social sciences*	*Biology*	*Chemistry*	*Earth and space*	*Engineering*	*Mathematics*	*Physics*	*All disciplines*
Portugal	57	56	46	44	44	50	55	39	53	47	45	25	34	22	44
Poland	58	55	48	42	45	51	55	44	53	48	47	27	21	24	44
Czechia	54	51	46	40	31	54	52	39	47	38	41	32	23	36	42
Finland	68	56	60	52	48	48	46	48	44	35	39	24	16	20	42
Brazil	68	52	41	34	35	47	49	33	38	39	36	23	16	16	41
Spain	53	49	40	45	45	45	46	38	44	39	38	26	23	21	40
Taiwan	52	47	49	44	49	41	43	41	43	37	38	36	36	34	39
Italy	49	52	44	37	36	41	49	33	42	41	33	23	29	17	38
Australia	66	52	50	47	44	41	37	40	30	24	26	18	17	16	37
Sweden	66	42	52	43	39	42	38	38	35	27	32	18	17	16	36
Israel	62	53	53	53	37	39	41	36	34	31	25	22	17	17	35
Mexico	52	48	36	36	41	42	43	34	34	35	33	21	19	17	34
Netherlands	52	46	42	36	36	37	35	31	27	21	25	17	17	17	33

Canada	63	51	50	42	41	39	35	38	33	23	26	16	16	15	33
United States	61	50	48	43	40	36	34	35	31	23	25	18	18	16	33
Denmark	58	47	43	37	36	38	35	32	32	22	26	15	13	12	33
France	47	44	45	34	40	38	42	33	36	31	29	21	18	18	32
United Kingdom	56	46	44	39	38	36	35	35	30	22	24	16	16	14	32
Turkey	62	51	52	38	37	34	39	34	32	36	30	21	27	19	32
Belgium	47	42	42	38	36	36	37	32	30	26	26	19	18	16	32
Singapore	54	48	33	36	31	38	34	30	33	27	30	22	19	22	29
Russia	48	58	55	46	38	51	46	38	43	35	29	21	15	15	28
Austria	47	43	44	38	36	32	35	33	32	23	23	14	15	12	28
Switzerland	46	41	36	30	35	31	32	31	29	23	24	17	16	14	27
Germany	43	43	35	32	34	30	34	30	33	22	24	15	15	14	27
China	38	34	28	29	27	30	29	26	29	28	25	22	25	23	26
India	37	39	45	28	40	31	32	34	29	24	26	21	22	23	26
Iran	37	34	33	21	25	32	31	20	23	28	19	14	17	19	23
South Korea	43	35	28	25	30	25	27	22	26	21	20	13	16	13	21
Japan	34	27	28	23	30	19	22	18	22	16	16	11	11	10	17
All countries	57	47	43	40	37	35	35	34	33	28	27	20	20	18	31

disparities, therefore, must take both discipline and country as strategic organizational sites.

Economic and Political Factors

One example of the strength exerted within a country can be observed in Iran. Our results show that Iranian women are relatively underrepresented in every discipline. Yet this is not a consequence of a lack of capacity. Take, for example, Maryam Mirzakhani, the only woman and Iranian to win the Fields Medal for excellence in mathematics. That she was extraordinary is undoubtable. There may, however, be several young women who do not receive a chance to excel. Girls score much higher than boys on science and mathematics in primary school in Iran and across other countries in the region. Saudi Arabia has the highest gap in favor of female achievement in grade 4, with Bahrain, Oman, Kuwait, Qatar, and the United Arab Emirates following.[38] In Iran, the female achievement gap continues in grade 8 but is smaller. By grade 12, the differential is lost, although women who take college entrance exams enter at higher rates than men (42% of women compared with 29% of men).[39] This leads to a slight overrepresentation of women among undergraduate students (51%), but attrition is quickly observed. Women represent only 28% of researchers, slightly below the global average.

Political pressures explain some of these differences. Mirzakhani studied mathematics in Iran at the undergraduate level before going to Harvard University for graduate school. Systematic barriers, however, prevent other women in Iran from achieving a similar trajectory. For instance, in 2012, thirty-six Iranian universities banned women from seventy-seven different fields of study.[40] This made disciplines such as accounting, engineering, and chemistry only available to Iranian men. At the University of Tehran, Mirzakhani's field of mathematics moved to exclude women. This decision was purely ideological, rather than empirically based, reinforcing the role that geopolitical factors play in creating global gender disparities.

At the macro level, other geopolitical factors can be observed through economic and development data, such as those available from the World Bank.[41] Figure 1.7 presents several relationships between country-level variables and the proportion of women as authors of scholarly papers. There is, unsurprisingly, a linear relationship between women in the labor force, generally, and in science, specifically. The relationship is particularly strong for high-income countries and speaks to the ability of women to leave the domestic sphere and enter various sectors of society. However, there is a slightly negative relationship between women's participation in science and gender differences in advanced education. In almost all countries, a higher proportion of women obtain advanced education (university degrees), yet the proportion of active researchers remain lower than that of men. This suggests that advanced education alone will not diminish gender disparities in science. Similarly, political empowerment—which is measured through the percentage of women in seats in national parliaments and the percentage of ministerial positions—has little relationship to women's proportion of scholarly papers (Figure 1.7).

Furthermore, as highlighted in the introduction, higher percentages of women in the workforce may be a sign of economic destabilization, as is the case for many Soviet countries.[42] For example, participation of women in science is positively associated with men's unemployment. In a strong economy, we might expect women to enter into the labor force at similar rates to men; however, in less robust economies they are more likely to fill a vacuum left by men who are unemployed or where scientific work is not associated with high degrees of social and economic capital. The most striking evidence of this paradox is the relationship between life expectancy and women authorships, the strongest correlation in our analysis. In countries where men die younger, there are more women in the scientific labor force, suggesting that substitution and brain drain effects are present.[43] The countries with the highest proportion of women authorships are marked examples of this. In Latvia, men's average life expectancy sits at 68.8 years, whereas women live, on average, an additional 10 years (78.8).[44] The same gap is observed in Ukraine: women's life expectancy at birth stands at 75.8 years, whereas men's life expectancy is 65.5 years. When there is an absence of men (through either war or mobility), women are disproportionately represented in science.[45]

Another factor that seems to have a positive (though relatively weak) association with women's participation in science is the number of paid maternity days. The provision and reporting of leave days varies across countries; however, among those that provided information, we can observe that countries with longer paid maternity leave (mostly former Yugoslavian countries) also have a higher proportion of women authors.

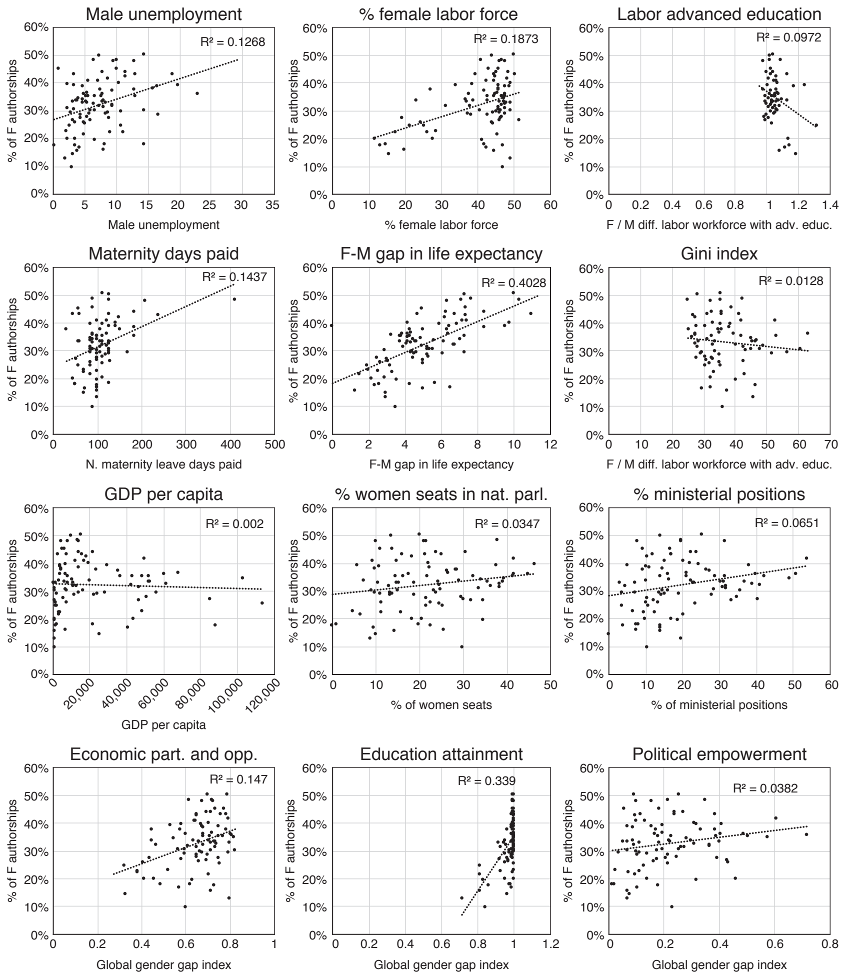

FIGURE 1.7. Correlations between percentage of women authorships and selected country-level indicators of economic and social development (World Bank Open Data). For countries with more than 500 fractionalized authorships over the 2008–2020 period.

However, once these countries are removed, the relationship dissipates. This can be linked with the paradoxical nature of parental leave: the more generous the leave is, the longer the researcher will be out of the field and, therefore, the less likely he or she is able to contribute to scholarly articles.

Several other economic and gender-related variables seem to have an insignificant relationship to women's participation in scientific activities and, in some cases, a negative association. For instance, indicators of economic development (GDP per capita) and concentration of wealth (Gini index) have little relation with women's scientific production: countries that are more developed and where income is more equally distributed do not exhibit greater gender parity in science.[46] Inversely, there are many countries in southeast Europe, the Caribbean, Latin America, and central Asia with lower levels of scientific infrastructure and high concentrations of wealth that are achieving parity.

Our previous work suggests that these relationships—between parity in production and indicators of human development and gender equity at the country level—are not linear.[47] In fact, those ranking the highest on human development indicators often have less gender parity in production than those in the lower category, with the greatest equity observed in the countries ranked in the middle. It is necessary to repeat the warning of sociologists J. Scott Long and Mary Frank Fox here: "It is not enough to ask whether particularism of universalism operates in science . . . Rather, given the patterns observed, it is important to understand more fully the processes leading to the lower participation and performance of women and minorities in science."[48]

A Parity Paradox

Several studies suggest that trends toward parity in production are, at least partly, driven by brain drain: among the countries with a higher share of women authors are also those where a large proportion of scholars have left the country in order to access better resources in other countries.[49] Our analysis of mobility suggests that men are likely to have greater degrees of mobility than women; therefore, in cases of brain drain, women are likely to be the ones left behind.[50] This is one of the cases where we observe a "parity paradox"—a growing rate of gender parity in a country does not necessarily indicate that this country has achieved greater equity. In fact, it may demonstrate the reverse; gender parity in scientific production may have equalized due to greater opportunities for men in other sectors within the country and to scientific opportunities outside the country.

This is exemplified by Poland, one of the only countries with substantial production and parity in the scientific workforce—women represent

51.8% of publishing authors, although they still lag in terms of authorships (42.5%). Poland has a strong history of women's participation in the workforce: by 1970, women formed half of the workforce for all economic sectors combined; by 1980, 60% of medical students were women. Women occupied a sizable proportion of jobs in finance, health, and education and even ran 20% of farms.[51] However, the rate of women in these sectors came at the expense of women in politics and government, where there was a "male monopoly on power."[52] Communism espoused principles of equality; therefore, turning to a market economy led to greater discrimination among women, as it was associated with a "revival" of the traditional role of women.[53] Despite Poland's election of its first woman prime minister in 1992, there has been a regression of women's rights in recent years. In 2017, the police raided women's rights associations, and sexual rights (such as sex education and abortion) have diminished.[54] Poland's regression is an example of the parity paradox, where equity has eroded although parity remains.

Poland's story is not unlike that of its northern neighbor, Latvia, and several other former Soviet states. Latvia has a high proportion of women researchers (60%) and a long history of gender equity—in terms of access to education, employment, and equal pay.[55] Following the fall of the USSR, several conditions accentuated the entrance of more women into the workforce. The first were the harsh economic realities of former Soviet countries, where a single breadwinner could no longer sustain a household, which led to an increased proportion of women seeking work.[56] However, there was another, more morbid reality, as discussed earlier. Across all countries—and strikingly for Latvia—one of the strongest predictors of a higher participation of women in science is a gendered difference in life expectancy.[57] The fact that most university students are women and women have low unemployment may not necessarily be a positive indicator for the country, but rather a reaction to the lower volume of active men within the society.[58] This overbalance toward women has led to a devaluation of labor in Latvia: women make roughly 25% less than men in Latvia, and academic salaries are among the lowest in Europe.[59] This follows several global examples of depressed salaries for woman-dominated occupations.[60]

Gender parity in Poland masks a clear economic and social segregation: women have had equal access to education and relatively equal participation in research for decades. However, they suffer from higher unemployment rates, are paid approximately 30% less, and perform a higher proportion of domestic duties.[61] Therefore, this parity does not constitute equity. Rather, parity in the scientific workforce reflects feminization of a sector to which a lower symbolic value is given. This relates to the social and economic capital associated with men's work: politics and government were held in higher regard; therefore, men concentrated in these areas, leaving academe open for women. The same can be observed in disciplinary specialization, with women appearing in disciplines that are at the lower levels of the hierarchy of disciplines and receiving lower pay, even in highly feminized disciplines.[62] Parity in science is a valuable goal but one that should not be pursued at the expense of equity.

Of course, equity is unlikely to occur without parity. Therein lies the paradox. Those of a more quantitative bent will focus on the numbers and rejoice when these numbers hit their quota. There is reason to celebrate achieving parity; however, we argue that although necessary, it is not a sufficient criterion for mitigating disparities in science. Parity can often mask underlying inequities. The goal of this book, therefore, is to bring to light as many of the dimensions underlying these differences as possible. As data scientists Catherine D'Ignazio and Lauren F. Klein have argued, "Counting and measuring do not always have to be tools of oppression. We can also use them to hold power accountable, to reclaim overlooked histories, and to build collectivity and solidarity."[63]

Measurements of production can and have been used to exacerbate inequities in the scientific workforce. Therefore, we use them with caution, to document disparities, but with a careful critique of parity in the absence of equity. The following chapters seek to dig deeper into these numbers, to occasionally leave the numbers and allow the women to tell their own stories, and to weave in the historical, sociological, and economic factors that are essential for understanding how we can move toward equitable parity in the scientific ecosystem.