Women, Academia, Math: An Ephemeral Golden Braid

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1 Introduction

The relation among women, academia, and mathematics is a long-term romance which, as many love affairs, had its ups and downs (unfortunately, till nowadays more downs than ups, as we shall see).

The aim of this work is to investigate the figures of the presence of female mathematicians in Italian academia, to give an interpretation of their trends, and to suggest possible good practices and affirmative actions, with a special focus on young people, to reduce the gender inequality in this area. In particular, we will report on a new tendency in recruitment that arose in recent years, the so-called Glass Door phenomenon, i.e., the obstacles women face in entering the first levels of the academic career: while the recruiting of "ricercatori" was almost gender-balanced till 2010, in the last decade the presence of women dropped down also in this role, as it was turned to a temporary one.

One may ask why a paper dealing with such an issue appears as a chapter of a book whose title is "Imagine Math": both as a mathematician and a woman, I see gender issues as central ones in the transformations Italian society has to undergo in order to reach a better exploitation of its human potential; this is the reason why the mathematics I imagine for future generations is a gender-balanced one. I must confess this is not an original opinion: the fourth and fifth goals of the UN Sustainable Development Agenda are "Quality Education" (Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all) and "Gender Balance" (Achieve gender equality and empower women and girls), respectively.

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2 Two Faces of an Old Problem: The Leaky Pipeline and the Glass Ceiling

The global underrepresentation of women in academic jobs a well-known phenomenon that the many modifications which took place in the structure of our society in last times scarcely mitigated, in particular in STEM (Science, Technology, Engineering, Mathematics) areas. This paragraph is devoted to a concise analysis of two aspects of an important issue in female academic careers: the decreasing presence of women holding positions at the highest levels of the job ladder. This phenomenon is chiefly due to two concurrent causes: the Leaky Pipeline and the Glass Ceiling. The first expression deals with the fact that women are more likely to leave their academic employments for different sorts of professions (in Italy mainly school teaching) or for staying at home, while the second one concerns the difficulties women experience in reaching the highest levels of the job ladder. For a generalist approach to the reduced participation of women to academia, see, e.g., the She-Figures report 2018 [1], while an investigation more focused on early stages of the career is contained in the publications of the Garcia Project [2] (in particular, the leaky pipeline is discussed in [3–6]) and [7]; a useful source of references for the Glass Ceiling effect is [8].

The percentage of women and men at the different levels of academic career shows that moving from Ph.D. students to full professors a part of the female population "disappears." This evidence is clearly visible in the graph in the following page which displays the percentage of women (orange) and men (green) at the different levels of POST-DOC (assegnista di ricerca), RTD-A (temporary research assistant), RTD-B (tenured temporary research assistant), RTI (permanent research assistant), PA (associate professor), PO (full professor) for mathematicians in the year 2016 (dotted lines) and 2021 (continuous lines). The scissors-shaped curve marks the "evaporation" of a part of the female scholars as the level of the job increases (Fig. 1).

The surveys carried out in Italy for the Garcia project showed once more that

> "the uncertainties connected to these job positions, the lack of long-term perspectives [. . .] seem foster the decision to leave research"; moreover "men and women do not hold the pressure put by the greedy institution between personal and working lives the same way. From this sight, parenthood seems to hold a major role."[1]

[1] Garcia working paper n. 5, p. 6.

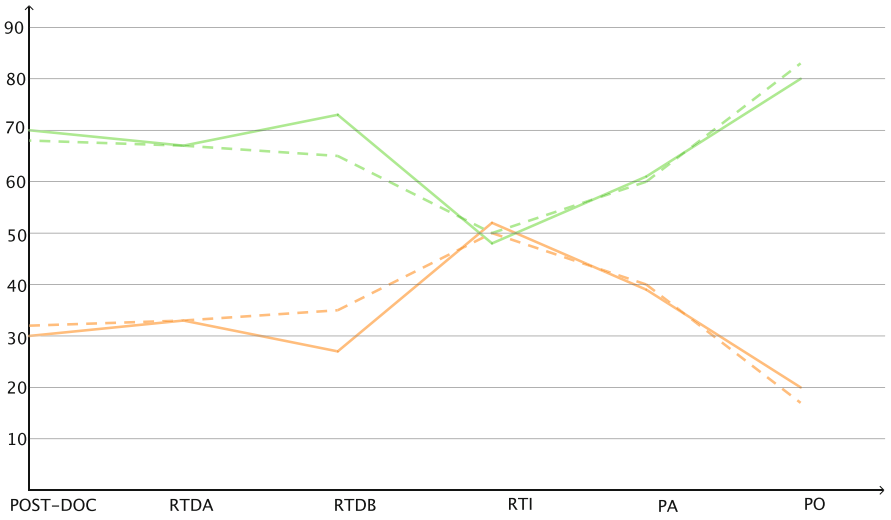

Fig. 1 Percentage of men (green) and women (orange) in academic positions in mathematics from post-doc to full professor; 2016 (dotted lines) and 2021 (continuous lines); elaboration on data taken from the database of the Italian Ministry for University

Another motivation for the small fraction of female full professors is the so called vertical segregation, that is the fact that women experience a greater difficulty than men when applying or competing for the highest level positions (a stunning evidence is given by the fraction of women rectors in Italy which in 2021 was equal to $6/84 = 7\%$); this fact is called the Glass Ceiling phenomenon, where the expression refers to an invisible ceiling which prevents women to go beyond a given level.

In particular, the Glass Ceiling Index (GCI) is a relative index that compares the proportion of women in academia with the proportion of women in top academic positions (full professor level). If the GCI is equal to 1, then the fraction of women in all grades is equal to the fraction of women in the highest level while a GCI greater than 1 denotes a Glass Ceiling phenomenon.

The table in the following page contains the trend for GCI in all mathematics disciplines in the last ten years: the first line displays the percentage of women in academia, that is the quotient of the number of women in all grades (W) and the total number of academics (T), the second one displays the percentage of women in top positions, that is the quotient of the number of female full professors (Wf) and the total number of full professors (Tf). Comparing the GCI for the mathematical area with the general GCI for Italy shows that our field is not an exception to the harder times women experience in STEM, since the global GCI was 1.73 in 2013 and 1.68 in 2016.

An optimistic interpretation of the trend of GCI for mathematical disciplines would underline the fast decrease of this indicator in the last 5 years, implying that it should reach 1 around 2032 (estimate obtained with a linear regression method).

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
W/T	36.1	36.4	36.6	36.8	36.2	36	35.5	35.3	34.7	34.2
Wf/Tf	16.9	16.6	16.6	17.1	17.3	18.3	19.2	19.3	19.8	20.1
GCI	2.14	2.2	2.21	2.14	2.09	1.97	1.85	1.83	1.75	1.66
GCI_m	0.77	0.76	0.76	0.76	0.77	0.78	0.8	0.8	0.81	0.83
GCI/GCI_m	2.78	2.88	2.91	2.8	2.72	2.52	2.32	2.29	2.15	2

Fig. 2 Percentage of women in all grades (W/T) and women full professor (Wf/Tf), Glass Ceiling Index (GCI), male Glass Ceiling Index (GCI_m), and ratio between GCI and GCI_m; figures obtained from data taken from the database of Italian Ministry for University

Unfortunately, this hopeful analysis is spoiled by the content of the next paragraph, where a new obstacle in the direction of gender balance (the Glass Door) is outlined.

A more revealing indicator for the measurement of the obstacles women find in reaching full professorship is the ratio between GCI (which is computed for the female population) and the same index computed for male population (GCI_m); this number evaluates the difference in the arduousness in becoming a full professor for women and men: even though this quantity has been rapidly decreasing in the last decade, still in 2020 the hardship women undergo for this goal is twice as big as men do (Fig. 2).

Again, linear regression optimistically predicts parity in this parameter around 2031; nonetheless, we must be aware that this index gives a necessary condition for gender equality which is not sufficient at all. Indeed, a trivial algebraic manipulation shows that GCI is equal to 1 if GCI_m is equal to 1 and this is equivalent to the fact that percentage of women at all levels is equal to the percentage of women who are full professors: so a hypothetical academic system in which women hold 1% of the positions of assistant professors, 1% of the positions of associate professors and 1% of the positions of full professors would result in a GCI equal to 1, while being strongly gender unbalanced.

The reasons of the difficulties women experience have been widely investigated and cannot be explained only on a lower tendency to apply for higher rank or on a smaller scientific productivity, as shown in [8], where a detailed study on the cohort of scholars who already obtained Abilitazione Scientifica Nazionale is performed. Authors use years of seniority, macrodisciplinary area, university of affiliation and a parameter that measures individual scientific productivity (standardized h-index, standardized number of citations, standardized number of publications and an overall measure of productivity) as control variables of five different statistical models. In all cases, no matter how scientific productivity is measured, they find that the probability of career advancement for women is significantly lower than for men. In particular, on average female assistant professors have a probability to advance to associate professor which is 8% lower than their male colleagues; this percentage increases to 17% when they consider associate professors looking for a promotion to full professorship.

3 A New Problem: The Glass Door

While the Leaky Pipeline and the Glass Ceiling phenomena have always been a problem in Italian mathematical academia, the access to the lowest degrees of temporary (Ph.D. and post-doc) or permanent (ricercatore/ricercatrice, i.e., research assistant) positions has been almost equal for both men and women for a long time (see [9] for a detailed analysis of the data).

Nonetheless, the modifications of the recruitement rules due to Legge 230/05 and Legge 240/10, which abrogated the permanent position of "ricercatore a tempo indeterminato" and introduced the temporary positions of "ricercatore a tempo determinato di tipo A/B," caused a new phenomenon, which in analogy with the "Glass Ceiling" has been designated as the "Glass Door."

This expression means that access to academic positions is harder for women than for men; this difficulty is measured by an indicator, called Glass Door Index (GDI), which was introduced by Picardi in [10] (see also [11, 12]); GDI is given by the quotient of the percentage of women who work in positions equal or below the first step of academic ladder (that is, post-doc and assistant professor, both temporary or permanent) by the percentage of women who work in positions at the first step of academic ladder (that is, assistant professor, both temporary or permanent). Unfortunately, the computation of this number is more complicated than one could expect, since some of the data are not easily accessible: while the database of the Italian Ministry of University for the academic staff displays many different parameters (level, sex, year, scientific discipline, generic area of research) which allow a simple selection, the database for post-doc positions is very rigid (in particular, there is no sorting for sex) and it contains only current post-docs (Fig. 3).

The GDI for 2011, 2016, and 2021 are easily computed from the numbers in the table and are equal to 0.96, 0.89, and 0.91, respectively.

Since a GDI smaller than 1 denotes that there is no bottleneck for women in the transition from post-docs to more "stable" positions ("personale strutturato" in the

	2011 total	2011 females	2011 ratio	2016 total	2016 females	2016 ratio	2021 total	2021 females	2021 ratio
RTI	887	407	46%	560	283	50%	294	154	52%
RTDA	1	0	0%	87	29	33%	141	46	33%
RTDB	14[2]	5	36%	79	28	35%	200	54	27%
RTD(A+B)	15	5	33%	161	54	34%	341	100	29%
Total	902	412	46%	721	337	47%	635	254	40%
Post-doc	291	108	37%	278	90	32%	354	106	30%

Fig. 3 Figures of "Ricercatori a tempo indeterminato" RTI (total and females), "Ricercatori a tempo determinato di tipo A/B" (total and females), post-docs in mathematics in 2011, 2016, 2021; data come from the databases of Italian Ministry for University. ([2]The figures of 2011 and 2016 RTDB include also a different temporary position, namely ricercatore a tempo determinato L. 230/05, legge Moratti.)

jargon of Italian bureaucracy), these results would give a favorable account on the situation. Nonetheless, the use of raw data introduces a distortion that increases with time and must be taken into account: while in 2011 RTI where the almost totality of assistant professors, in 2021 people covering this role were recruited more than 10 years ago and we are comparing their cohort with present post-docs which will never become RTI, since enrollment in this position was canceled by Law 240/10.

In my opinion, a more significant index for 2016 and 2021 (the number of RTD is too small to make this computation meaningful for 2011) is therefore given by using only RTD-A and RTD-B as "stable" positions and comparing them with post-docs; with this restriction we find that the modified Glass Door Index (GDI_m) is equal to 0.98 for 2016 and to 1.01 for 2021, thus showing a trend which is closer to reality: in recent years the obstruction to female entrance in academic staff has the same strength at post-doc and at assistant professor level.

The figures contained in the above table allow a more detailed analysis of the modifications at the first level of recruitement in academia. In particular, two important trends can be underlined: the first is the fact that the fraction of women who are now "ricercatrici a tempo determinato" is much smaller than the fraction of women who were "ricercatrici a tempo indeterminato" ten years ago (29% vs. 46%); the second is that the portion of women in RTD-B positions, who are tenured and in 3 years become associate professor permanent jobs, is smaller than the portion of women in RTD-A positions, who are truly temporary (winners are appointed for 3 years which can be extended for 2 more years, then the contract is over).

So, formally, in Italy, there is no rule which prevents women from entering academy, but an invisible door (a glass one, indeed) keeps them off and this happens at the very beginning of the career. Unexpectedly, this happens also in fields like mathematics which till some years ago were more open to female participation.

As already noticed in the previous paragraph, the reduction of the rate of female mathematicians at the lowest level of the academic career creates a deceptive effect on the trend of the GCI: paradoxically, since the portion of females at the first step of the ladder diminishes, the Glass Ceiling phenomenon is less evident.

Moreover, notice that the fact that the percentage of women in RTI positions is increasing also points in the direction of an analogous of the Glass Ceiling phenomenon at the level of associate professor: since 2010 none entered this particular post of employment anymore, the only variations are due to retirements (which statistically affect men and women in comparable proportion) and promotions to associate professor level (which are more frequent for men than for women).

4 Good Practices and Affirmative Actions for the General Public

In the last years, many strategies of very dissimilar nature have been suggested in order to eliminate, or at least reduce, gender gap in academia in general and in STEM disciplines in particular. They include the creation of a process that estimates

gender equality in universities by measuring several parameters (just to give an example, these evaluation systems can range from the adoption of a Gender Equality Plan to the implementation of a systematized policy on the model of English Athena Swan Awards); the introduction of some kind of quotas in the recruitment process, or at least a sort of reward in FFO (Fondo di Finanziamento Ordinario, the amount of money the Ministry annually gives to state universities) for public universities which decrease gender inequality; the computation of 18 months of career break for each maternity leave; the development of a mentoring scheme for female M.Sc. and Ph.D. students and Post-docs.

In this paragraph, I am going to speak of a different kind of actions that can be undertaken in order to increase the participation of women to academic staff by means of good practices whose goal is the popularization to a wider public of the perception of the existence of women doing research in mathematics.

In the last decades of the twentieth century, in Italy a large majority of high school professors in mathematics and physics were women, but most of their students had a very low awareness of the existence of female professional mathematicians. Asking young people for a list of women in mathematics would probably come out with a couple of lines (usually featuring Ipatia and Maria Gaetana Agnesi), and only a few ones who were most interested in mathematics could be able to add one among Sophie Germain, Sofja Kovalevskaja and Emmy Noether.

The increased attention to gender inequality which developed during the last years, brought to a different perception of the presence of women in the history of mathematics (and science in general); thanks to an impressing commitment of intergovernmental organizations, learning societies, activists for women's rights, scholars and experts in women's studies, authors, screenwriters, directors and producers, names like Ada Lovelace, Katherine Johnson, Maryam Myrzakhani, are now a common heritage for most learned people.

The tools which can be used to give to the general public, and to girls and female teenagers in particular, an opportunity to become more familiar with the idea of women working in mathematical research are of a very different nature: events organized for special days, films, plays, articles on newspapers and magazines, science girl camps and many other such initiatives, all help to spread the familiarity with women in mathematics.

The introduction of days dedicated to women in several fields of science followed different paths: in 2009 with a pledge on a British civil action site, Pledgebank, the blogger, journalist, and social software consultant Suw Charman-Anderson founded Ada Lovelace Day (which is held on the second Tuesday of October) in order to celebrate the achievements of women in STEM (science, technology, economy, and mathematics); the 2020 edition saw more than 60 events taking place worldwide.

In 2015, the United Nations General Assembly declared February 11th the International Day of Women and Girls in Science; the strength and commitment of UNESCO and UN-Women, which organize the day in collaboration with many institutions and civil society partners, quickly made this date an important pivot for the promotion of women in science.

Nevertheless, the most specific initiative concerning women in mathematics is almost a new-born, since it was established at the World Meeting for Women in Mathematics-(WM)ˆ2-on July 31th, 2018. On that occasion, the Women's Committee of the Iranian Mathematical Society proposed that May 12th, the birthday of Maryam Mirzakhani, the first woman to receive a Fields Medal, would be used for celebrating women in mathematics. In its first edition, in 2019, more than 100 events took place in 36 countries, (see [13] for a report on the organization, an account on the happenings in each continent and planning for future years).

In 2020, the website of the initiative, funded by the International Mathematical Union Committee for Women in Mathematics, European Women in Mathematics and the Association for Women in Mathematics, was turned perennial and adapted to annual events, so that it could support the celebrations taking place each year. Even if the COVID-19 pandemic made the organization of in-presence conferences, exhibitions, and film projections very complicated or even impossible, more than 150 events were planned worldwide (in over 100 countries) and the participation of a large audience was possible thanks to the fact that more than one-third of the events were online ones (see the report available at [14]).

One of the key points of the success of May 12th, 2020, is "Secrets of the Surface: the Mathematical Vision of Maryam Mirzakhani", a documentary film by George Csicsery about the life and work of the Iranian Fields Medalist.

In 2020 Zala films, the production society, decided to support the May 12th initiative: between April 1st and May 19th, both individual and institutions were allowed to access the film freely just by filling a form on the May 12th website: they received more than 20,000 requests. Zala films also offers a very stimulating discussion guide for educators in order to support them in presenting the film to students involved in a women and gender study curriculum; in my opinion it could also be used fruitfully for senior students of Italian high schools (in particular the ones attending liceo scientifico) (Fig. 4).

(WM)ˆ2 was also the occasion for the premiere of the first edition of "Journey of Women in Mathematics," a 20 minutes film created by the IMU Committee for Women in Mathematics, filmed and edited by Micro-Documentaries, funded by a grant of the Simons Foundation. In the first part, three women mathematicians (Neela Nataraj from India, Aminatou Pecha from Cameroon, and Carolina Araujo from Brasil) are featured at their home institutions, while the second part, shot at (WM)ˆ2, shows the atmosphere of the event and contains six interviews of women from Latin America; the film is freely available at the IMU website ([15]).

Of course, there are many other films that showed a wider audience the work of women in mathematics: just to make an example, Hidden Figures, the biography of three Afro-American female mathematicians (Katherine Johnson, Dorothy Vaughan, and Mary Jackson), who worked at NASA during the Space Race, grossed $236 million worldwide and received three nominations at the 89th Academy Awards; in its first screening on Italian TV (Rai1) in 2019 it reached over 4.3 million single spectators.

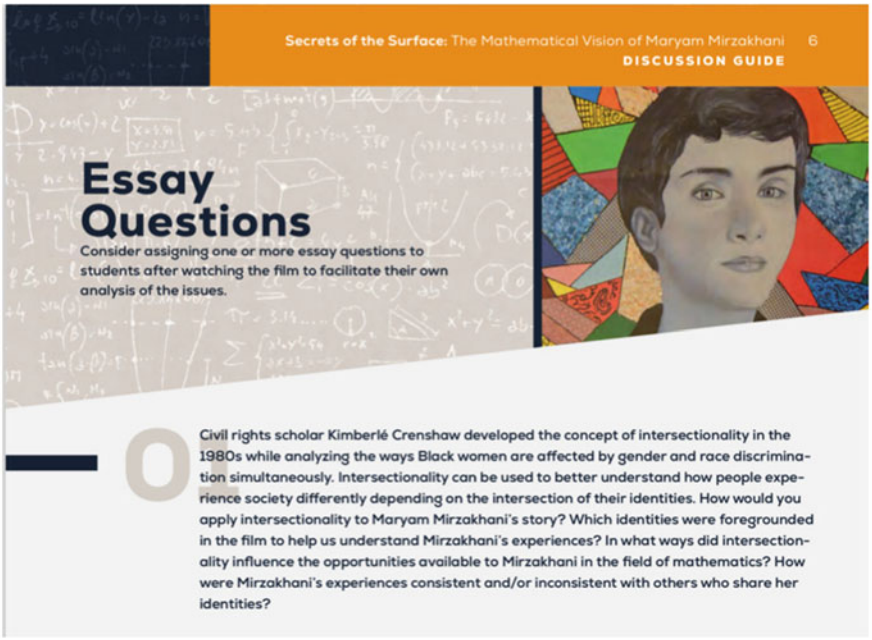

Fig. 4 Essay Questions page from Secrets of the Surface Discussion Guide-Courtesy of Zala films

A different strategy to ease the approach of girls and young women to STEM in general and maths in particular is the creation of science girl camps in which groups of children or teenagers get in touch with scientific subjects suitable for their age (the groups can consist of girls only or of some boys joined with a majority of girls) (Fig. 5).

In June 2020, the Italian Ministry for Equal Opportunities opened a call for the organization of summer camps addressed to groups of pupils aged 3–18 with the purpose of overcoming some of the by-products of the pandemic: 3 million euros were made available for schools, universities, municipalities, non-profit associations with a strong background in education with the aim to run at least 2 weeks of activities focused on STEM disciplines. Events with a longer tradition like "Pinkcamp" at Università dell'Aquila (which was established in 2018) or new-comers such as "STEM in Ancona!" (a pun with the double sense of "Stem" which means "Let's remain!" in the local dialect) offered several scores of secondary schools students the possibility to improve their knowledge of STEM subjects (mathematics, chemistry, physics, and computer science) and to realize that "women" and "science" can be an impressive and sound couple.

Fig. 5 Flyer of STEM in Ancona activity

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