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GOING BEYOND TEST SCORES: THE GENDER GAP IN ITALIAN CHILDREN'S MATHEMATICAL CAPABILITY

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ABSTRACT

This paper investigates the relationship between gender, attitudes, and test scores in mathematics. The study argues that measures of children's capability in mathematics must include some indicators of attitudes toward the subject. These are particularly important when analyzing gender gaps because attitudes toward mathematics differ by gender. To this end, the study first analyzes the gender gap in attitudes and test scores separately using school fixed effects models. Second, it estimates a structural equation model, which takes into account that mathematical capability is a latent construct for which some indicators (test scores and attitudes) are observed. Using data from the Italian National Institute for the Evaluation of Education Systems (INVALSI) for school years 5 and 10 in 2014 and 2015, results confirm that when mathematics capability, including both attitudes and test scores, is measured, the gap between boys and girls changes, and it is therefore relevant to consider both concepts.

KEYWORDS

Math gender gap, attitudes, structural equation models, school achievement

JEL Codes: J16, C31, I21

HIGHLIGHTS

- Italy has one of the highest gender gaps in mathematics in the OECD.
- Gender gaps are substantial both in children's attitudes and their test scores.
- Tackling gender stereotypes may improve women's self-confidence in mathematics and the gender gap in scores.
- This may also help close the gender gap in STEM occupations.

INTRODUCTION

Gender-based differences in educational achievements are a very important aspect of differentials in employment success, earning profiles, and, ultimately, gender parity and instances of discrimination in the labor market and the society. Gender is an important factor that needs to be considered in the analysis of all dimensions of education (Fessler and Schneebaum 2012) and important gender differences exist in performance and attitudes toward learning.

Gender disparities in learning are an important source of concern for policymakers (Organization for Economic Cooperation and Development [OECD] 2019). According to recent Program for International Student Assessment (PISA) data, boys tend to underperform girls in literacy and girls tend to underperform boys in mathematics. This is problematic for both groups for various reasons. Boys who lag behind in their reading abilities may be disadvantaged in their future education and labor market performance, and these gaps can lead to an underrepresentation of men in humanities and arts. Similarly, girls' underachievement in mathematics may lead to underrepresentation of women in science-, technology-, engineering-, and mathematics- (STEM) related fields of study and occupation, where mathematical skills are highly valued.

Theoretically, each individual would be better off following her/his own preferences and attitudes in educational choices and effort. Nevertheless, individual preferences are strongly constrained by societal values. Girls' and boys' preferences for different subjects are shaped during childhood by cultural beliefs, gender norms and stereotypes, and expectations regarding education that constrain preferences and influence educational choices (Nollenberger, Rodriguez-Planas, and Sevilla 2016; Rodriguez-Planas and Nollenberger 2018). Feminist scholars have very clearly stated that "a concept such as preferences cannot be regarded in economic analysis as exogenous but as, at least partly, socially constructed" (Sent and van Staveren 2019: 5). Institutions tend on average to reinforce stereotypes on gender norms and roles, influencing preferences' formation (Wood and Eagly 2012).

A complete analysis of gender disparities in learning is beyond the scope of this paper, where we specifically focus on the problem of girls' underperformance in mathematics, and consider the importance of gender in affecting both test scores and attitudes toward this subject. This issue is particularly relevant for Italy, where the gender gap in mathematics is among the highest in OECD countries and has not improved significantly in the last ten years (OECD 2019).

The gender gap in mathematics achievements (in favor of boys) represents an important and policy relevant issue because it can cause underrepresentation of women in highly technological and innovative labor markets that also yield high wages (European Commission 2006, 2012, 2015; National Academy of Science 2007). Further, numeracy is a key factor in predicting financial literacy (Skagerlung et al. 2018), and therefore, the gender gap in mathematics could also have important consequences for women's ability to be empowered in managing their own finances.

At the OECD level, there are larger gender differences in the fields of study chosen in higher education, and the gender gap in STEM fields grows with age. At age 15, far fewer girls (4.7 percent) than boys (18 percent) – even among the top performers in mathematics and science – reported that they expect to have a career in engineering or computing (OECD 2017). This gap in aspirations can be worsened by the existence of stereotypes transmitted to children by their families, teachers, and society at large. Indeed, data from PISA (Program for International Student Assessment) reveal that parents are more likely to expect their teenage sons than their daughters to work in STEM occupations – even when their daughters perform just as well as in STEM fields (OECD 2015). These preconceptions may affect girls' confidence in their ability to excel and pursue a career in STEM fields.

Recent studies have shown that gender differences in mathematics anxiety may be driving the gender gap in performance in this subject. Even in countries where the proportion of women working in STEM occupations is relatively high, mathematics anxiety is more prevalent among girls, as other sociocultural values may be driving these differences (Stoet et al. 2016). On average, in the OECD countries, fewer than one in three engineering graduates and fewer than one in five computer science graduates are women. Even when women do study STEM subjects, they face a glass ceiling and are less likely to hold senior positions (OECD 2017).

The Italian context is particularly relevant because the gender gap in mathematics for Italian students is one of the highest among OECD countries, according to the latest PISA results (revealing a 16 point difference in Italy against an average difference of 5 points in the OECD; OECD 2019), even if the overall mathematics test scores for Italian students are aligned to the OECD average results. Similar results also emerge from Trends in International Mathematics and Science Study (TIMMS) 2015, showing that the gender gap in mathematics for Italian children in fourth grade is the highest among all countries included in the survey (Mullis et al. 2016). Dalit Contini, Maria Laura Di Tommaso, and Sylvia Mendolia (2017) use data from the Italian National Institute for the Evaluation of Education Systems (INVALSI) and show that boys outperform girls in mathematics from second to tenth grade. Further, the gender gap in mathematics increases with age, even after controlling for individual, school, and family characteristics. Lastly, the gender gap in career expectations among top performers in mathematics and science (that is, the gender gap in the percentages of top performers who expect a career in the field) is higher in Italy than in the average of OECD countries (OECD 2019).

Girls have been found to display less mathematics self-efficacy (self-confidence in solving mathematics-related problems) and mathematics self-concept (belief in their own abilities), and more anxiety and stress in doing mathematics-related activities (Else-Quest, Hyde, and Linn 2010). Sarah Lubienski et al. (2013) used data from the US (ECLS-K) for grades 3 and 5 and found that gender gaps in confidence were substantially larger than gaps in actual performance, with disparities in interest being smallest of all. These findings are consistent with TIMSS and PISA reports of girls throughout the world having substantially less mathematical confidence than boys (Mullis et al. 2008; OECD 2016). Overall, at various educational levels, girls and women have been found to have less optimistic expectations about their ability to succeed in male-dominated fields of learning, such as mathematics and economics, and this factor may harm their actual performance in the selected courses (Ballard and Johnson 2005). A variety of explanations have been proposed for the existence of a gender gap in mathematics. Some studies point to the role of parents' and teachers' beliefs about the innate mathematical abilities of boys and girls (for example, Fryer and Levitt 2010), others to the role of cognitive and noncognitive abilities (Heckman and Kautz 2012), and others to the existence of gender social norms and stereotypes, which affect preferences (Rodriguez-Planas and Nollenberger 2018). Further, recent evidence has shown that the level of gender equality at country level also plays an important role in the mathematics gender gap, and that countries with higher level of women's empowerment and more progressive beliefs about women's role in society show lower gaps in mathematics achievements between girls and boys (Nollenberger, Rodriguez-Planas, and Sevilla 2016).

This paper defines a mathematical capability of children, which includes both test scores in mathematics and attitudes toward mathematics. While these variables are highly correlated, in this paper we do not try to explore the complex causal relationship between them, also due to the lack of Italian longitudinal data collecting all this information over time. Other studies have suggested the existence of a reciprocal relationship between these dimensions, with mathematics test results being a particularly strong predictor of future mathematical confidence and interest, and, to a lesser extent, mathematical confidence being a predictor of later performance (Ganley and Lubienski 2016).

In this paper we refer to the theoretical construct of the capability approach of Amartya Sen and to the economics of education literature on the importance of cognitive and noncognitive skills (Heckman 2008; Cunha, Heckman, and Schennach 2010; Sikora and Pokropek 2012; Cornwell, Mustard, and Van Parys 2013; Gutman and Schoon 2013) in order to show that the use of test scores is limited and to highlight the importance of including other noncognitive dimensions related to mathematics.

The capability approach (Sen 1985, 2009; Nussbaum 2003) represents an alternative framework for the evaluation of human well-being, which does not primarily focus on income and wealth, but also includes other important dimension of well-being such as education, bodily integrity, social interactions, and so on (Sen 2009). The concept of capability has been used in previous literature to analyze important aspects of children's well-being and substantial gender differences in this area (Addabbo, Di Tommaso, and Maccagnan 2014).

In this paper we use data from INVALSI for students in year 5 and year 10 because these are the only years in which data on attitudes toward mathematics are collected. We begin by describing the differences by gender in both test scores and attitudes using an OLS model with school fixed effects. Next, in addition to the test scores in mathematics, we use indicators of attitudes toward mathematics to estimate a structural equation model, which takes into account that mathematics capability is a latent construct for which we observe only some indicators (test scores and attitudes).

Our main results confirm the existence of a substantial gender gap in attitudes toward mathematics, as well as in test scores. Girls are less confident in their ability to perform well in mathematics, and systematically lag behind boys in test scores. The effect of gender on attitudes toward mathematics and test scores is strong and significant, and greater in size than most of the other socioeconomic characteristics included in the analysis. Further, results confirm that when we measure mathematics capability including attitudes in addition to test scores, the gap between boys and girls changes and it is therefore essential to consider both items when evaluating the gender gap in mathematics.

These results have important economic implications. First of all, these results provide new insights in understanding the gender gap in mathematics achievements. In particular, they show that individual confidence and attitudes play an important role in determining the gap, which is actually different when we consider attitudes and test scores together. Therefore, policies aimed at attracting and retaining women in sectors where mathematical skills are required (such as STEM or finance) should target achievements in test scores and confidence at the same time. Second, the existence of a gender gap in mathematics is particularly worrying from both a macro- and microeconomic perspective. Specifically, gender gaps in mathematical performance at school levels are related to lower enrollments of women in STEM subjects at university; lower engagement of women in the labor market in STEM fields; and existence of the gender wage gap (through occupational segregation). These are important economic issues and have substantial negative impacts on countries' overall levels of productivity, and ultimately, economic growth (Jovanić 2017; European Institute for Gender Equality 2017b).

In addition, at an individual and microeconomic level, the lack of mathematical confidence may have important negative effects on women's performance in the labor market (through inability to gain employment in sectors requiring mathematical or quantitative skills, and therefore increased unemployment rates, and decreased earnings), as well as on women's financial independence and ability to manage their own careers.

DEFINITIONS OF ATTITUDES

The concept of attitudes toward mathematics has been defined in the context of mathematics education.[1] The origin of "attitude" comes from social psychology (Allport 1935) in the context of predicting choices based on preferences like buying goods or voting. Early studies about attitudes in mathematics education are placed in this framework and focus on the relationship between attitudes toward mathematics and school mathematics achievement, trying to highlight a causal relationship. As Daniel Neale (1969: 631) underlines: "Implicit … is a belief that something called 'attitude' plays a crucial role in learning mathematics. … positive attitude toward mathematics is thought to play an important role in causing students to learn mathematics." Nevertheless, many studies about attitudes do not provide a clear definition of the construct itself: often attitudes are defined implicitly and a posteriori through the instruments used to measure them (Leder 1985; McLeod 1992; Ruffell, Mason, and Allen 1998; Daskalogianni and Simpson 2000). Further, studies that explicitly define attitudes do not share a single definition. In the variety of meanings attributed to the construct, three main different types may be identified: (a) a simple definition that describes attitudes as the positive or negative degree of affect associated with mathematics (Haladyna, Shaughnessy, and Shaughnessy 1983); (b) a tripartite definition that recognizes three components in attitudes: emotional response toward mathematics, beliefs regarding mathematics, and behavior related to mathematics (Hart 1989); and (c) a bidimensional definition in which, with respect to the previous one, behaviors do not appear explicitly (Daskalogianni and Simpson 2000).

Another critical point in research on attitudes toward mathematics, related to the choice of a definition, is measurement. Surveys generally propose items like: "Mathematics is useful," "I like problem solving," and "I think about arithmetic problems outside school." Since these items are related to the three different dimensions – beliefs, emotions, and behaviors, respectively – questionnaires make implicit reference to the tripartite model. Di Martino and Zan (2010) investigate how students talk about their own relationships with mathematics, proposing the essay "Me and

Maths" to more than 1,600 students (1st to 13th grades). Students' attitudes toward mathematics come out as multidimensional constructs. The study also shows how the relationship with mathematics is rarely described as stable, even by older students. Their result suggests that there is scope for policies that change attitudes over children's life courses.

We use the questions related to the attitudes toward mathematics included in INVALSI data for year 5 (fifth year of primary school) and for year 10 (second year of secondary school). Year 5 and year 10 are the only years in which students are asked to report their attitudes toward mathematics in the INVALSI survey. These questions relate both to beliefs and emotions, but not behaviors. Therefore, with respect to the different definitions provided above, the Italian National Test utilizes a bidimensional definition of attitudes.

In these selected years, INVALSI data includes information about attitudes toward mathematics, including six questions asking students how much they like mathematics, as well as more specific questions about their learning, confidence, and understanding of the subject. In particular, for year 5 the following six items are included in the survey:

(a) I am usually good at mathematics,
(b) I learn mathematics easily,
(c) Mathematics is harder for me than for most of my classmates,
(d) I learn lots of things in mathematics,
(e) I like studying mathematics,
(f) Mathematics is boring.

The first four items relate to the dimension of beliefs, while the last two items to the dimension of emotions. Students reply to each statement using a Likert scale from 1 to 4, where 1 indicates "strongly disagree" and 4 "strongly agree."

For year 10, the six items related to attitudes toward mathematics are the following:

(a) I learn mathematics quickly;
(b) I learn lots of things in mathematics;
(c) I have always thought mathematics is one of my strongest subjects;
(d) During mathematics class I understand the hardest topic;
(e) I like studying mathematics;
(f) Mathematics is boring.

Similarly to the previous set of questions, the first four items belong to the dimension of beliefs, while the last two refer to the dimension of emotions.

INSTITUTIONAL CONTEXT AND DATA

Education begins in Italy at age 6. Primary school lasts for five years (until age 11) and is followed by three years of middle school and five years of secondary school. Compulsory education terminates at 16 years old. Students choose among different types of high school at age 13. There are three main types of secondary schools, with substantial differences in the curricula: the Lyceum, the Technical High School, and the Vocational High School. Lyceums offer a higher level of academic education with strong focus on the humanities, sciences, languages, or arts. Technical high schools provide a general education and a qualified technical specialization in a particular field. Vocational institutes have the objective of preparing students for entering the labor force.

We use data from INVALSI, which has been administered to all Italian children in grades 2, 5, 8, and 10 since 2010 and covers the whole population of Italian students (around 400,000 observations in each cohort). However, we use data from a subsample, which includes students who took the test under the supervision of an external inspector (between around 25,000 and 35,000 observations in each cohort). INVALSI data include two measures of mathematics test scores. The first one is the raw test score (calculated as number of correct answers), and the second one is the normalized test score, which ranges from zero to 100. We use normalized test scores provided by INVALSI, and we standardized them in order to interpret the results in terms of standard deviations.

The estimation sample includes only native children because migrants are more likely to repeat and/or to be enrolled in lower grades with respect to their ages due to their lack of proficiency in Italian (Contini, Di Tommaso, and Mendolia 2017). In this study, we use data from year 5 and year 10 for the years 2014 and 2015, which are the only datasets that include information on attitudes toward mathematics.[2] The final estimation sample includes almost 95,000 observations.

Table 1 presents descriptive statistics for attitudes toward mathematics in the estimation sample and shows that there is a gender gap in all items and girls are generally less likely to like mathematics and have less confidence in their ability to learn the subject effectively. These gaps are significantly different from zero. Further, the proportion of students who think that mathematics is harder for them than for their peers is substantially higher for girls than for boys, and girls are less likely to believe that mathematics is one of their strongest subjects.[3]

In order to analyze the relationship between gender and attitudes toward mathematics, we construct a single indicator of attitudes using Polychoric Principal Component Analysis and the students' answers to these six questions regarding their emotions and beliefs around mathematics.[4] Principal Component Analysis is a statistical multivariate technique that

Table 1 Descriptive statistics of attitudes toward mathematics (single questions)

	Year 5		*Year 10*	
	% Girls	*% Boys*	*% Girls*	*% Boys*
I like studying mathematics				
Strongly disagree	15.74	11.20	29.45	22.66
Disagree	18.43	12.57	26.40	27.34
Agree	31.05	26.45	30.24	34.53
Strongly agree	34.77	49.78	13.92	15.48
p Value t-test Difference mean (Girls–Boys) = 0	0.000		0.000	
I learn lots of things in mathematics				
Strongly disagree	3.92	4.12	24.28	17.79
Disagree	10.35	8.98	27.20	26.01
Agree	36.50	32.23	35.87	39.33
Strongly agree	49.23	54.67	12.65	16.21
p Value t-test Difference mean (Girls–Boys) = 0	0.000		0.000	
Mathematics is boring				
Strongly disagree	51.35	59.37	25.00	24.88
Disagree	25.22	20.59	29.86	31.69
Agree	12.00	9.73	22.68	22.55
Strongly agree	11.43	10.31	22.46	20.88
p Value t-test Difference mean (Girls–Boys) = 0	0.000		0.000	
I am usually good at mathematics				
Strongly disagree	6.66	4.16	NA	NA
Disagree	17.50	10.77		
Agree	45.56	42.13		
Strongly agree	26.28	42.94		
p Value t-test Difference mean (Girls–Boys) = 0	0.000			
I learn mathematics easily				
Strongly disagree	9.59	6.32	NA	NA
Disagree	20.38	13.85		
Agree	39.84	35.76		
Strongly agree	30.20	44.07		
p Value t-test Difference mean (Girls–Boys) = 0	0.000			
Mathematics is harder for me than for most of my classmates				
Strongly disagree	42.42	52.50	NA	NA
Disagree	28.56	24.76		
Agree	18.34	14.53		
Strongly agree	10.68	8.21		
p Value t-test Difference mean (Girls–Boys) = 0	0.000			
I learn mathematics quickly				
Strongly disagree	NA	NA	24.49	18.25

(*Continued*).

Table 1 Continued.

Disagree			30.04	27.48
Agree			33.66	36.79
Strongly agree			11.81	17.48
p Value t-test Difference mean (Girls–Boys) = 0			0.000	
I have always thought mathematics was one of my strongest subjects				
Strongly disagree	NA	NA	43.64	28.87
Disagree			24.75	27.21
Agree			19.85	25.84
Strongly agree			11.75	18.08
p Value t-test Difference mean (Girls–Boys) = 0			0.000	
During mathematics classes, I understand the hardest topics				
Strongly disagree	NA	NA	35.18	23.83
Disagree			29.57	30.53
Agree			26.65	31.85
Strongly agree			8.60	13.79
p Value t-test Difference mean (Girls–Boys) = 0			0.000	
N	20,031	20,446	27,079	27,337

aims at aggregating information collected in several numeric measures in one proxy variable. Principal Component Analysis, like Factor Analysis, is best used with continuous data, as discussed in Kolenikov and Angeles (2009).

We therefore specifically use Polychoric Principal Component Analysis, which allows incorporating discrete and categorical variables in Principal Component Analysis (Di Tommaso, Raiser, and Weeks 2007; Kolenikov and Angeles 2009; Van Phan and O'Brien 2019).[5]

Our methodology is consistent with several recent studies in economics, which use Factor Analysis and Principal Component Analysis to create a proxy variable/index to summarize several categorical and discrete variables capturing individual traits, personality, and attitudes (Cobb-Clark and Schurer 2013; Cobb-Clark, Kassenboehmer, and Schurer 2014; Mendolia and Walker 2014).

In both year 5 and year 10 data, results from Principal Component Analysis show that there is only one underlying factor for all the attitudes questions (one factor with eigenvalue greater than 1), and therefore we are able to define one attitudes index based on the six relevant questions (see Table A1 in Online Appendix A for the eigenvalues in the Principal Component Analysis). The attitudes index is standardized to have mean equal 0 and standard deviation equal 1. The raw gender gap in attitudes is generally higher than the gender gap in test scores (see first row of Tables 2 and 3).[6]

INVALSI data also include parental characteristics and family background, collected from a students' survey and from school board records. In selected years, INVALSI provides a synthetic indicator of economic and sociocultural status (ESCS) similar to the one available in PISA. The ESCS index is calculated by taking into consideration parental educational background, employment and occupation, and home possessions. The complete set of descriptive statistics for the variables used in the estimation is provided in Table A2 in Online Appendix A.

MODELING STRATEGIES

Linear cross section model and school fixed effects

Test scores are not measured on the same scale at different school years, and therefore the gender gap on the attitudes toward mathematics is not comparable across grades. For this reason, we use standardized test scores and the index of attitudes toward mathematics is also standardized (has mean equal to zero and variance equal to one), and therefore the results show the difference in standard deviations between girls and boys.

We begin our analysis by focusing on the total effect of gender on average mathematics achievement and attitudes toward mathematics. We estimate OLS models in order to capture the average effect of gender and a set of control variables, including maternal and paternal education, socioeconomic status of the family, and geographical area, on test scores and attitudes. We use both the single items and the synthetic index for attitudes presented earlier in the paper.

Further, it is important to consider the role of school characteristics in affecting children's learning. The effect of gender might operate both indirectly via school choices and directly net of school characteristics. Students attending the same school are exposed to similar teaching practices, learning targets, and peer characteristics (including socio-economic status, gender, and abilities). All these factors may have a separate effect on students' achievements and attitudes, and may affect the gender gap in test scores and attitudes in a specific way (Contini, Di Tommaso, and Mendolia 2017). For this reason, we estimate the direct effects of gender on mathematics achievement and attitudes including school fixed effects, which exploit within-school variability, and deliver valid estimates of the gender gap given individual controls and (observed and unobserved) school characteristics. Therefore, the impact of gender on test scores and on mathematics attitudes is estimated as follows:

$$y_{ijt} = \alpha + \beta g_i + \gamma' x_{it} + u_j + \varepsilon_{it} \quad (1)$$

where y_{ijt} represents the outcome of interest (mathematics test scores or attitudes toward mathematics) for individual i attending school j at time t, β is the coefficient of interest (capturing the impact of students' gender on the outcome), x_{it} is a vector of individual and family characteristics, u_j is a school fixed effect (capturing all time invariants school characteristics, which may have an impact on students' learning and attitudes) and ϵ_{it} is an individual specific error term.

Modeling strategy for mathematical capability

The existence of multiple, interrelated indicators to measure mathematical capability raises the question of how to combine them in empirical research. The Multiple Indicators Multiple Causes (MIMIC) model developed in this paper represents one possible approach to solve this problem.[7] One basic strategy could be to choose a single indicator we believe is the closest (replies to the question "I like mathematics," for example) to the unobserved construct (mathematical capability), and to ignore both measurement error and information on the remaining indicators.

Alternatively, we could use the information in all indicators by creating a synthetic variable, such as a simple mean indicator. The resulting Ordinary Least Squares model represents perhaps the most restrictive model given the neglect of measurement error and the reduction of many indicators to a single one.

Instead, in this approach, we assume that each indicator is a component of mathematical capability; and mathematics capability is an unobserved variable that is linked to the observable indicators. The principal advantage of this approach is that it does not rely on exact measurement of attitudes. Each indicator represents a noisy signal of attitudes toward mathematics. This modeling strategy has been extensively used in psychometrics (Edwards and Bagozzi 2000) and is founded upon the specification of a system of equations which specify the relationship between an unobservable latent variable (mathematics capability), a set of observable endogenous indicators, and a set of observable exogenous variables. A similar approach has been used in other studies measuring capabilities (Addabbo, Di Tommaso, and Maccagnan 2014; Hui 2017).

In particular, these indicators are called "reflective" indicators, as they are considered a manifestation of the underlying latent construct (Edwards and Bagozzi 2000). A construct, such as mathematics capability, can be measured in the measurement part of a structural equation model through a set of indicators. Each indicator can be described as the sum of a function of the latent construct and a measurement error, which is assumed to be uncorrelated with the latent construct. The measurement errors of the different indicators are also assumed to be uncorrelated with each other. The latent construct therefore represents the variance that the set of indicators have in common. Not taking this into account, and – for instance – running a regression model on an average score of the indicators can lead to biased estimates of the structural parameters due to the biasing effect of measurement errors (Jarvis, Mackenzie, and Podsakoff 2003).

This approach builds upon the early work of Karl J. Jöreskog and Arthur S. Goldberger (1975) and Miriam Zellner (1970). The Multiple Indicators and Multiple Causes (MIMIC) approach allows us to think of this model as comprising two parts: a structural equation for mathematical capability and a measurement equation that takes into account that there is no single variable called mathematics capability. For each of the indicators, a weight (a factor loading) will be estimated. This weight represents how much that specific indicator counts in explaining the capability respect to other indicators.

The structure of the model is as follows:

$$Y = \Lambda^{Y} y^{*} + \varepsilon, \quad j = 1, \ldots, m \tag{2}$$

where $Y = (Y_1, Y_2, Y_3, \ldots Y_m)'$ is a $m \times 1$ vector with each element representing an indicator of mathematics capability, denoted Y^{*}. $\Lambda^{Y} = \{\Lambda_1^{Y}, \Lambda_2^{Y}, \Lambda_3^{Y} \ldots \Lambda_j^{Y}\}'$ denotes a $m \times 1$ parameter vector of factor loadings, with each element representing the expected change in the respective indicator following a one unit change in the latent variable. ε is a $m \times 1$ vector of measurement errors, with dote the covariance matrix.

In addition we posit that mathematics capability is linearly determined by a vector of observable exogeneous variables $x = (x_1, x_2, \ldots x_s)'$ and a stochastic error ς giving,

$$Y^{*} = x'\gamma + \varsigma \tag{3}$$

where $\gamma$is a $s \times 1$ vector of parameters.

Examining (2) and (3) we may think of our model as comprised of two parts: (3) is the structural equation and (2) is the measurement equation reflecting that the observed measurements are imperfect indicators. The structural equation specifies the relationship between the observed exogeneous causes and the latent construct attitudes toward mathematics. Since Y^{*} is unobserved, it is not possible to recover direct estimates of the structural parameters γ. Combining (2) and (3) the reduced form representation is written as

$$y = \pi x + v \tag{4}$$

where $\pi = \Lambda^{Y}\gamma'$ is the $m \times s$ reduced form coefficient matrix and $v = \Lambda^{Y}\varsigma + \varepsilon$ is the reduced form disturbance.

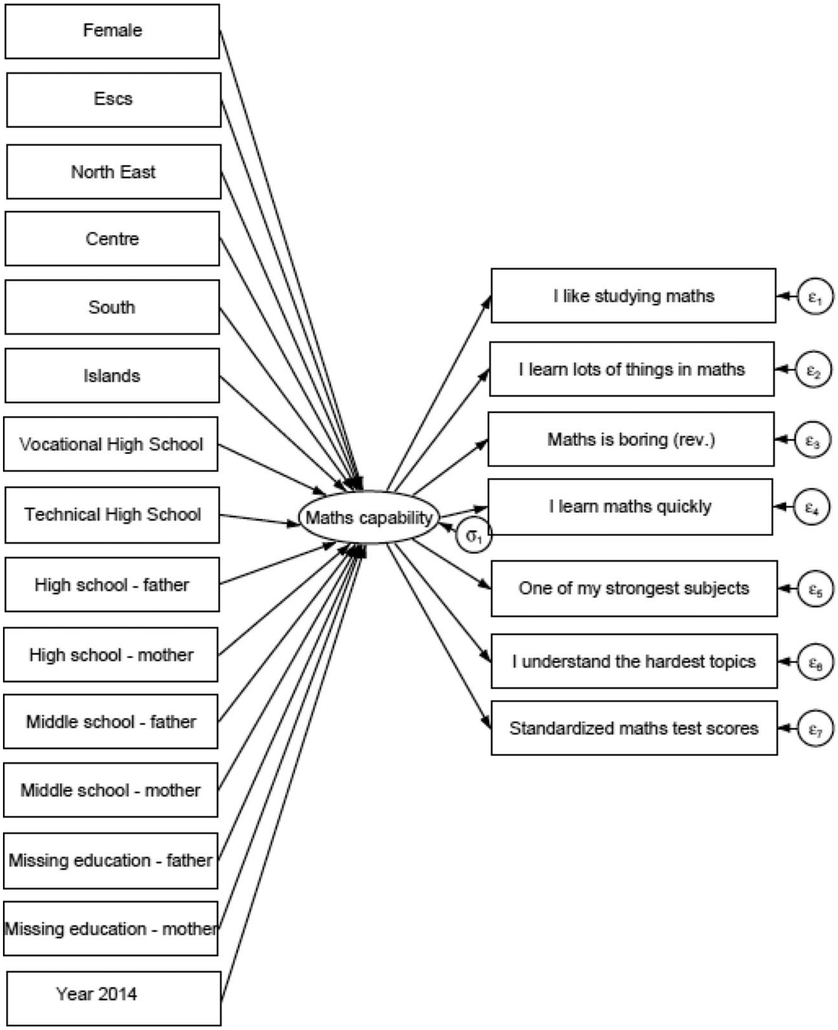

Figure 1 Path diagram for mathematical capability – example for year 10

In our case the indicators are the six items for attitudes and test scores (described above). The exogenous variables are gender, an indicator of the socioeconomic status of the parents, geographical area, father's and mother's education, and type of high school for year 10 (descriptive statistics for the exogenous variables are presented in Table A2).[8] The path diagram in Figure 1 graphically represents our model for mathematics capability.

RESULTS

Results from cross-sectional linear models and school fixed effects

We begin by exploring the gender gap in attitudes toward mathematics and present estimates of the effect of gender on the different items included in the mathematics attitudes indicator. We present results estimated using OLS, and OLS with school fixed effects.[9] Table A3 in Online Appendix A presents results for each item included in the index of attitudes toward mathematics. Overall, the gender gap is higher in the questions capturing mathematics self-confidence, such as "I am usually good at mathematics"; "I learn mathematics easily" (in year 5); "I have always thought mathematics is one of my strongest subjects"; and "During mathematics classes I understand the hardest topics" (in year 10). The impact of gender on these variables is around 30 percent of a standard deviation in year 5, and around 20 percent of a standard deviation in year 10. The gender gap is also high for the question "I like studying mathematics" for students in year 5 (around 30 percent of the standard deviation). On the other hand, the gender gap is much smaller in the questions capturing attitudes toward the learning process ("mathematics is boring" or "I learn lots of things in mathematics," where the gap is the lowest across all four cohorts), where the impact is usually around 10 percent of a standard deviation.

This is a particularly interesting point, as it shows that girls tend to lack self-confidence in their ability to perform well in mathematics (both in years 5 and 10) and tend to display more negative emotions (I like studying math in year 5), but do not necessarily show a gap in their attitude to the learning process. This finding is consistent with previous studies, showing that low confidence is one of the main factors explaining girls' reluctance to choose STEM subjects in their final high school exams (Cassidy et al. 2018). Further, recent evidence from PISA data shows that girls are less likely than boys to enjoy competition, and are more likely to experience self-doubt and fear of failure (OECD 2019).

This gap in self-confidence is also consistent with previous literature showing the importance of women's expectations and self-beliefs in their ability to succeed (see, for example, Ballard and Johnson 2005); and the gap could be worsened by traditional stereotypes promoted by families, teachers, and general society (OECD 2015, 2019).

Tables 2 and 3 show estimates of the gender gaps in mathematics achievements and attitudes calculated using OLS, and OLS with school fixed effects. Gender has a significant and sizable effect on test scores and attitudes toward in mathematics both in year 5 and in year 10. Results for year 5 are very stable when we control for school fixed effects, implying that there is no substantial indirect effect of gender via school characteristics.

Table 2 The gender gap (G-B) in mathematics attitudes (index): results with OLS and school fixed effects

	Year 5	*Year 10*
Raw gap	– 0.305***	– 0.220***
OLS	– 0.319***	– 0.268***
	(0.009)	(0.009)
School FE	– 0.305***	– 0.124***
	(0.009)	(0.009)
N	40,477	54,416

Notes: Standard errors are in brackets. ***, **, * denote statistical significance at the 0.1, 1, and 5 percent levels, respectively. All models include area of residence, maternal and paternal educations, and ESCS index (socioeconomic indicator). Models for year 10 also include the type of high school (Lyceum, Professional, or Vocational).

Table 3 The gender gap (G-B) in mathematics test scores: results with OLS and school fixed effects

	Year 5	*Year 10*
Raw gap	– 0.161***	– 0.240***
OLS	– 0.167***	– 0.404***
	(0.009)	(0.007)
School FE	– 0.166***	– 0.231***
	(0.008)	(0.0071)
N	42,507	54,938

Notes: Standard errors are in brackets. ***, **, * denote statistical significance at the 0.1, 1, and 5 percent levels, respectively. All models include area of residence, maternal and paternal education, and ESCS index (socioeconomic indicator). Models for year 10 also include the type of high school (Lyceum, Professional, or Vocational).

Results for year 10 substantially change when we include school fixed effects. In particular, the gender gap decreases by almost a half. This is because pupils' tracking in Italy happens in year 9, when students move from middle to high school, and high schools differ markedly in the subjects offered and the breadth of their academic curriculum. At this point, girls and boys are likely to self-select into different types of high schools, including a different level of focus on mathematics (and girls in Italy are more likely to be overrepresented in schools with a strong focus on the humanities – the so-called "Classic Lyceums," as noted in Anelli and Peri [2015]). This factor could partially explain why the gender gap in attitudes (and test scores) decreases in year 10, when we control for school fixed effects: when girls are surrounded by like-minded peers, they are less likely to feel uncertain of their ability to perform in mathematics. Previous literature has actually shown that girls' achievements and confidence in mathematics increase in single-sex schools (Eisenkopf et al. 2015). In addition, the choice between different types of high school is strongly related to individual and family characteristics. Therefore, it is more important to take into account school fixed effects in year 10 than in year 5.

Overall, Table 2 shows that the gender gap in mathematics attitudes ranges between 12 and 30 percent of a standard deviation of the index (the index for mathematics attitudes is standardized to have mean 0 and variance equal to 1). To put this in context, this is around at least three times the impact of a standard deviation increase in socioeconomic disadvantage (captured by the ESCS index; see Table A4 in Online Appendix A).

The gender gap in test scores ranges between 16 and 40 percent of a standard deviation, and increases in year 10 (see Table 3). Interestingly, the effect of gender on mathematics test scores persists in year 10, even after we control for school type. Therefore, our results show the existence of a substantial gender gap that carries on even after we take into account the fact that boys and girls could self-select into different high schools (see Contini, Di Tommaso, and Mendolia [2017] for an in-depth discussion of the gender gap in test scores).

We have tested the stability of our main results constructing the indicator of attitudes toward mathematics in three additional ways; using factor analysis; using an indicator ranging 1–6 based on dichotomized attitudes variables; and using a factor derived from the estimation of a measurement model using STATA package gsem. Results are presented in the Online Appendix (Table A5) and confirm the main findings.

We have estimated a model where all socioeconomic variables (including parental education, ESCS index, and region of residence) are interacted with gender, in order to understand the role of society and family stereotypes in creating the gender gap. Results are reported in the Online Appendix (Table A6) and do not show any consistent pattern for the interaction variables. Therefore, it seems that socioeconomic factors do not substantially affect the gender gap in attitudes toward mathematics.

Estimates of the MIMIC

In the following, we report the results of the estimation of the MIMIC model presented above. In the estimation results, we show both the standardized and unstandardized solutions. Both are meaningful. The unstandardized solution is achieved by setting a lambda parameter equal to 1, and it also reports the standard errors and significance level of the coefficients. The disadvantage of unstandardized solutions is that they are not easily interpretable, as they refer to changes in variables that have no clear and homogeneous measurement unit. Therefore, we also report

Table 4 The gender gap (G-B) in mathematical capability: gender coefficient in SEM models

SEM	*Year 5*	*Year 10*
Unstandardized	− 0.300***	− 0.265***
	(0.012)	(0.012)
Standardized	− 0.330***	− 0.301***
N	40,477	54,366

Notes: Standard errors are in brackets. ***, **, * denote statistical significance at the 0.1, 1, and 5 percent levels, respectively. All models include area of residence, maternal and paternal educations, and ESCS index (socioeconomic indicator). Models for year 10 also include the type of high school (Lyceum, Professional, or Vocational).

the standardized solution. Standardized coefficients can be read as the standard deviation change in the dependent variables (the latent capability variable and the indicators of the measurement model) that follows a unit change in the independent variable.[10]

Table 4 reports the gender gap in mathematical capability as a result of the estimation of the SEM model. Online Appendix B shows the estimation of the full SEM model. The gender gap in mathematical capability suggests that being female is associated with a lower mathematical capability, equal to 33 percent of a standard deviation in year 5 and 30 percent of a standard deviation in year 10.

As for year 5, this result is rather similar to the gender gap in attitudes (32 percent of a standard deviation in the OLS model). This is not surprising, as the results for the measurement model reported in Table B1 and B2 in Online Appendix B show that the latent construct mathematical capability is mainly reflected in the indicators of attitudes toward mathematics, especially for year 5. Liking studying mathematics has the highest factor loading for year 5: a standard deviation change in the latent capability leads to an increase of over 80 percent of a standard deviation in this indicator, while the standardized coefficients of the other attitudes indicators range from 54 percent to over 70 percent of a standard deviation. On the other hand, the factor loading for test scores is as low as 29 percent of a standard deviation.

Results for the year 10 sample show that the gender gap in mathematical capability (30 percent) is only slightly higher than the gender gap in attitudes (27 percent of a standard deviation in the OLS model), but lower than the gender gap in mathematics test score (40 percent of a standard deviation in the OLS model). Again, this is driven by the fact that, as shown in Tables B1 and B2 in Online Appendix B, the latent construct mathematical capability is mainly reflected in the indicators of attitudes toward mathematics, although to a lesser extent than for the year 5 sample.

Indeed, for year 10, the standardized coefficients of the attitude indicators range from 73 to 86 percent. However, the standardized coefficient for mathematics test scores is higher than in year 5, and equal to 41 percent of a standard deviation. This, together with the higher gender gap in test scores in year 10 than in year 5, helps explain the relatively higher gap in the capability with respect to the gap in the attitudes. The higher gender gap in test scores in year 10 (with respect to year 5) is consistent with previous findings (Contini, Di Tommaso, and Mendolia 2017) and could be related to the fact that boys and girls self-select into different types of high schools (and in particular into different types of Lyceums, which provide differing foci on mathematics). Unfortunately, INVALSI data do not include complete information on the type of high school attended (and in particular the type of Lyceum) and therefore we cannot control for this information in the MIMIC analysis.[11]

Overall, the main results from the measurement equation show that the factor loadings for attitudes are higher in absolute value than the factor loadings on test scores, suggesting that tackling differences in attitudes could be more effective than tackling test scores alone.

The results of the structural model presented in Tables B3 and B4 in Online Appendix B also suggest that the influence of gender on mathematical capability is the highest among all sociodemographic explanatory variables. Similarly to what has been found for the OLS and OLS fixed-effect models, the effect of gender is, for example, at least three times as high as the effect of ESCS.

In the SEM model, gender does not directly affect the single item for attitudes toward mathematics and test scores, as the relationship between these variables is modeled to be mediated by the latent capability. Nevertheless, the indirect effects of being female on the single indicators of mathematical capability can be computed. These effects are presented in Table B5 in Online Appendix B both in unstandardized and standardized form. These can be read as the gender gap (G-B) in the single indicators of the SEM model, confirming the higher impact of gender on attitudes than test scores.

CONCLUSIONS

This paper contributes to the existing literature on the gender gap in mathematics by adding an analysis of the attitudes toward mathematics in a gender perspective. Attitudes toward mathematics are strongly correlated with test scores and there is not a very clear one-direction causal link (Ganley and Lubienski 2016). Therefore, it is very important to understand if and how the gender gap changes when considering both elements.

We use a structural equation model, where we estimate a single indicator of mathematical capability including both test scores and attitudes, and we show that the gender gap in mathematical capability is different from the gap in test scores alone. There is a substantial gender gap in attitudes toward and confidence in doing mathematics, and girls are systematically less likely to express preferences for mathematics and confidence in their ability to perform at higher levels in this subject.

Our main results show that policies that tackle the gender gap in mathematics should address not only test scores but also attitudes. In particular, our estimates for the measurement equation of the model show that the factor loadings for attitudes are higher in absolute value than the factor loadings on test scores. This is an important contribution to the feminist economics field and a result that suggests that, indirectly, being female is associated with higher gaps in performance perception, rather than in actual performance, in line with previous literature findings (for example, Lubienski et al. 2013). Therefore, the gender gap in STEM education and, consequently, STEM occupation has its roots more in the belief dimension than in the performance dimension. This result is also consistent with previous findings in feminist scholarship, showing that young women have pessimistic expectations about their performance in mathematical subjects, even before they have any actual experience in the relevant areas (Ballard and Johnson 2005), and therefore it is essential to address the negative role of these expectations, which to some degree may become self-fulfilling. Programs focusing on motivation and encouragement may be very useful in this context. Given that girls' perception of their mathematical abilities is also the result of gender social norms, tackling gender stereotypes could be more effective than tackling test scores alone. This includes stereotyped gender models that are reproduced in school settings, for example through teachers' implicit messages and the presentation of stereotyped images in textbooks (Aragonés-González, Rosser-Limiñana, and Gil-González 2020), as well as stereotyped messages developing in the family setting, related for example, to educational and occupational choices made by previous generations (Fessler and Schneebaum 2012).

Our results have important economic implications. As noted in previous studies in the feminist economics literature and in previous work by European policy agencies, gender equality brings substantial economic benefits and it is particularly important to close the gender gap in STEM occupations in order to foster economic growth (Mitra, Bang, and Biswas 2015; European Institute for Gender Equality 2017a). In particular, girls' lack of confidence in mathematics-related subjects is likely to have a negative effect on the number of women enrolling in STEM-oriented degrees, and in turn, on the number of women working in STEM occupations. A large number of countries have already experienced shortages of labor supply in many STEM fields and individuals working in STEM fields experience low unemployment rates and high average wages. Encouraging women to choose this type of career would have positive economic effects in reducing STEM labor market disequilibrium and improving women's labor market outcomes. Closing the gender gap in STEM education would contribute to create additional jobs and increase overall employment in the economy (European Institute for Gender Equality 2017a).

Further, reducing gender gaps in mathematics achievements and confidence could help increase overall employment and productivity for women, and reduce occupational segregation. Eventually, this would have a positive effect on economic growth, labor market productivity, and increased activity in the labor market. The European Institute for Gender Equality has estimated that closing the gender gap in STEM education would improve the world's GDP by almost 1 percent by 2030 (between 130 and 180 billion Euros) and by 2.2–3 percent by 2050 (between 610 and 820 billion Euros).

At a microeconomic level, the gender gap in mathematics may cause women to experience lower earnings and reduced opportunities in the labor market and therefore reduced financial and economic independence. This may in turn generate high unemployment rates for women, as well as difficulty in managing careers' progressions and reduced levels of life satisfaction and well-being. In several countries, gender disparities in occupational and fields of study choices are contributing substantially to the gender wage gap between men and women (see, for example, Blau and Kahn 2000; Justman and Méndez 2018, among many others).

Italian policymakers have adopted some policies to address these issues. In particular, the Department of Equal Opportunity of the Italian Government[12] has supported some policies to fight gender stereotypes, to increase the percentage of girls in STEM subjects, and to increase girls' interest in science, math, and computer sciences. However, the scope and the budget of the initiatives has been very limited.

A possible interesting development of this analysis could be trying to understand how to address the gap in attitudes and self-confidence, and in particular, how to promote higher self-confidence in mathematics ability among girls. Girls' expectations, families' preconceptions, and teachers' attitudes may all play separate roles in generating this gap. Further, previous literature has showed that many young women perceived careers in STEM as highly remunerated, but male dominated, and they are concerned about taking STEM subjects at university as they fear that few other women will do so (Cassidy et al. 2018).

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NOTES

[1] An extensive review of the literature can be found in Judy Larsen (2013) and in Pietro Di Martino and Rosetta Zan (2011).

2 The 2013 survey also includes some information about attitudes, but it uses different questions with respect to 2014 and 2015 and therefore it has not been considered in this analysis.

3 We have also performed a preliminary descriptive analysis of girls' attitudes toward Italian, and we found that girls report higher preferences than boys for this subject.

4 In Principal Component Analysis, we reverse values for questions "Mathematics is boring" and "Mathematics is harder for me than for most of my classmates," so that higher values indicate higher preferences for mathematics.

5 In order to test the stability of our main findings, we construct the index of attitudes in four different ways: Polychoric Principal Component Analysis; Factor Analysis; a standardized indicator ranging 1–6 based on dichotomised attitudes variables; and a factor derived from the estimation of a measurement model using STATA package gsem, which allows specifying that the attitudes indicators should be treated as ordinal variables. We present the results using all these indicators in the Online Appendix A (Table A4).

6 The cumulative density function of the indicator of attitudes toward math by gender is presented in Online Appendix A (Figures A1 and A2).

7 On the operationalization of the capability approach see, for example, Jaya Krishnakumar and Florian Chávez-Juárez (2016).

8 Unfortunately, no information is available in the data on whether the child lives with both parents.

9 We have also estimated an ordered probit given that the items for attitudes vary on a Likert scale 1–4. Results are very similar to the OLS and are available from the authors upon request.

10 It should be noted that the software STATA gives only unstandardized coefficients and completely standardized coefficients. Completely standardized coefficients can be read as the standard deviation change in the dependent variable that follows one standard deviation change in the explanatory variable. The relationship between standardized and completely standardized coefficient is the following: $b_{STD\_YX} = b_{UNSTD} * \left(\frac{SD(x)}{SD(y)}\right)$. Nevertheless, as suggested by Linda K. Muthén and Bengt O. Muthén (1998–2010), in the case of binary covariates, standard deviation changes in x are meaningless and coefficients should be standardized only with respect to *y*: $b_{STD\_Y} = b_{UNSTD} * \left(\frac{1}{SD(y)}\right)$. It is straightforward to see that $b_{STD\_Y} = b_{UNSTD} * \left(\frac{1}{SD(y)}\right) = b_{STD_{YX}} * \left(\frac{1}{SD(x)}\right)$. We have therefore computed b_{STD_Y} efficients and presented these results in Table 4 and Table B4. It should also be noted that the SEM standardized coefficients are numerically comparable with the results of the OLS.

11 This could be achieved by using a fixed effects model. However, adding school fixed effects in our MIMIC model has not been possible, as the STATA gsem package does not allow for correlations between exogenous variables and the residuals of the dependent variable.

12 Dipartimento delle pari opportunità della Presidenza del Consiglio dei Ministri. http://www.pariopportunita.gov.it/cultura-scientifica-e-stereotipi-di-genere/.

SUPPLEMENTAL DATA

Supplemental data for this article can be accessed at https://doi.org/10.1080/13545701.2021.1908574.

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